BOOK OF ABSTRACTS

14th International Conference

LCA FOOD 2024

HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

8 – 12 September, Barcelona, Spain

14th International Conference
HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET
LCA FOOD 2024

Cite this publication as: Núñez M 2024. Book of abstracts of the 14th International Conference on Life Cycle Assessment of Food (LCA Food 2024), 8 -12 September 2024, Barcelona, Spain.

Cite an abstract in this publication as: Author 1, Author 2, Author 3 et al 2024. Title, in Núñez M 2024 (ed) Book of abstracts of the 14th International Conference on Life Cycle Assessment of Food (LCA Food 2024), 8 -12 September 2024, Barcelona, Spain, p. X-Z.

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Welcome to the LCA Food 2024 conference in Barcelona, Spain!

On behalf of the Local Organising Committee and the Scientific Committee I very warmly welcome you to the 14th edition of the LCA Food international conference, held from 8 – 12 September 2024 in Barcelona, Spain.

The LCA Food conference series is pioneering discussions and exchange on sustainability in food systems since the mid 90's and takes place biennially, alternating between Europe and other continents. Over the three decades of its history, the conference has become the world's leading forum on the topic of sustainable food production and consumption. It unites hundreds of environmental professionals from all over the world representing multiple sectors including academia, business, public policy, and NGOs to share and advance the science and practice of assessing and improving the sustainability of food production and consumption using LCA and related tools.

Whether you are an expert or just beginning your journey into this field, as a participant you will find yourself surrounded by many colleagues who are also enthusiastic about measuring and improving the sustainability of food systems. The conference programme will provide a variety of formats and subjects to find inspiration, share and learn, maintain and expand your network, get to know the local host institution IRTA, and of course enjoy the many sights and experiences the beautiful city of Barcelona has to offer: modernist architecture, vibrant neighbourhoods, vivid culture, sea and beaches, and of course, a rich and renowned gastronomy.

With its 14th iteration, the LCA Food 2024 conference sets a new record, with more than 450 attendees from 36 countries worldwide. Yet another sign how LCA and its application to agri-food systems is thriving, undergoing constant methodological development, serving as the scientific foundation for public policies and business development strategies towards a fairer and more sustainable food supply and economy. It evidences that the LCA Food community is growing, in line with its social, political, and industrial relevance and impact. As in previous editions, the attendee profile is mostly scientific and from public organisations (50% of registrants), 30% are students, and the remaining 20% come from the private sector. 92% are from OECD countries, whereas only 8% are from non-OECD countries, a lower percentage than in the two editions before, which were held in a fully hybrid format in 2022 and fully virtual, due to the COVID pandemic, in 2020, where non-OECD countries represented 12% and 14 % of registrants, respectively.

This year, due to limited demand for remote participation, we opted for a purely physical meeting at the beautiful historic University of Barcelona, a symbol of science and education in the city. The conference is structured around three days of sessions (September 9 – 11), complemented by a pre-conference day of special sessions (September 8) and a post-conference day of visits to three IRTA research centres specializing in a diverse array of R&D activities, including aquaculture, regenerative farming practices to recover soil health and biodiversity, or developing a new, high-tech generation of circular dairy cattle farms using precision feeding and digitalisation (September 12).

Over the three-day conference, there will be 38 session blocks. These blocks are distributed across six plenary sessions and four parallel session tracks, dedicated to traditional conference topics, such as the presentation and discussion of methodological advances in LCIA for assessing food systems, and the LCA application to cropping and livestock systems. Emerging and rapidly growing topics include nutritional LCA, grading-based ecolabelling, the territorial perspective, or the environmental and social assessment of novel foods and alternative protein sources. Besides, two of the plenary sessions are key notes deliberately chosen from outside the LCA field but highly related to it. We want these sessions to inspire on subjects like soil health and net-positive tipping points towards global sustainability. Additionally, the conference will feature more than 200 posters displayed throughout the three days, with multiple poster sessions programmed to facilitate peer-to-peer communication, networking, and foster exchange and generation of new ideas.

Each edition of LCA Food is unique. This time, three aspects of the scientific programme stand out. First, we wanted to give a special focus to the business sector and address its main challenges and strategies. We thus included session blocks for companies in the programme to explain their uses of LCA and collaborations with academia that delivered change or acceleration in their transition towards sustainability. Second, two plenary sessions are roundtable discussions, one of them gathers the experience and future lookout from internationally renowned companies, the other explores the future of agriculture amid geopolitical tensions, climate challenges, and the need for innovation with a complex systems approach to achieve social and ecological outcomes. And third, there will be five topical discussion sessions designed to tackle critical, controversial, and timely topics, with everyone in the room invited to contribute.

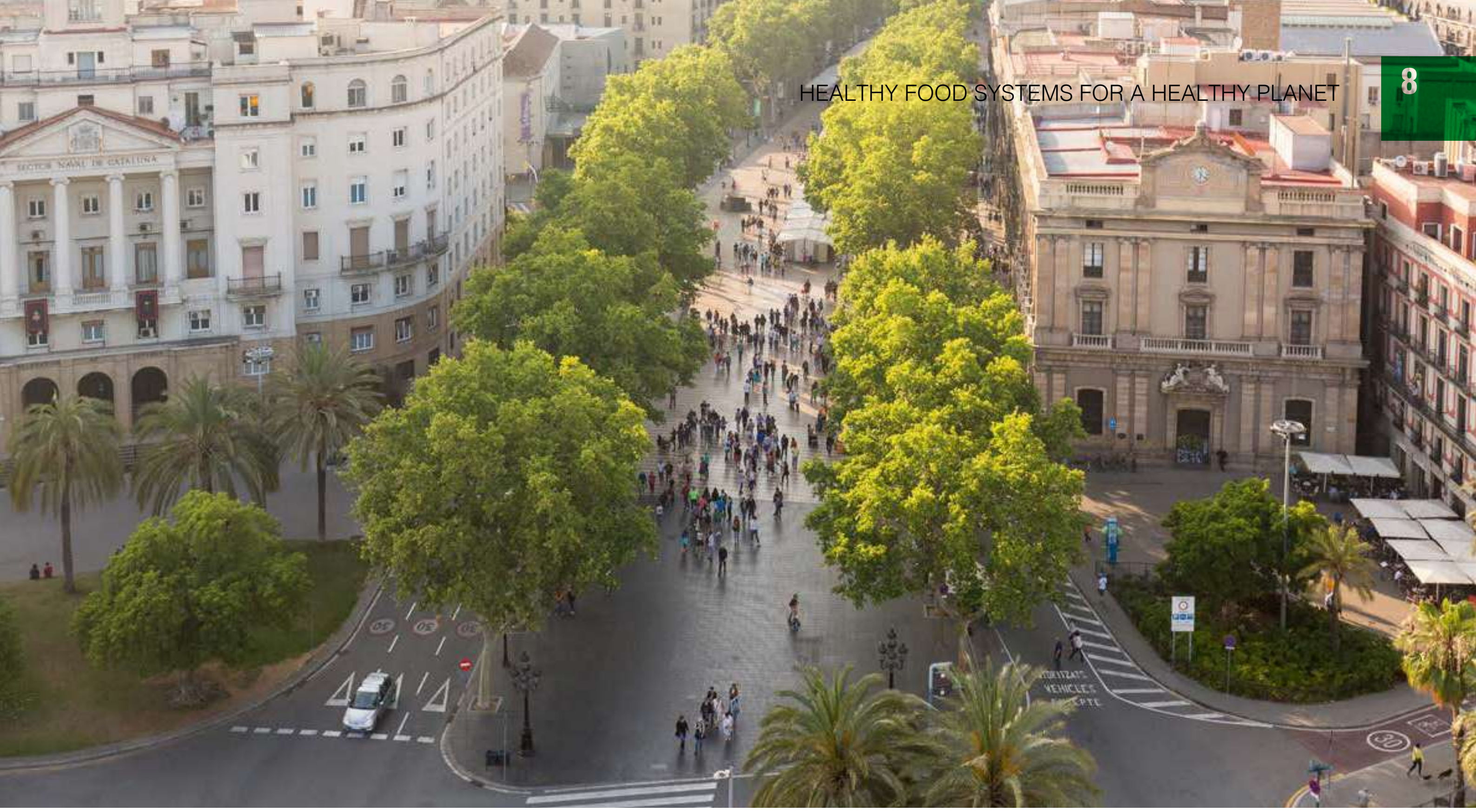
Additionally, to honour this year's conference motto, "Healthy food systems for a healthy planet", we are proud to offer attendees a healthy and rich Mediterranean gastronomic experience, both during the conference and the gala dinner, consisting mainly of non-animal and low-footprint foods, and local and organic fruits, all served with reusable dishes and cutlery. Please, make sure to bring the reusable coffee cup included in your conference package with you at all times for your drinks.

Taking advantage of Barcelona's rich historical, cultural, and gastronomical heritage, the social programme includes an exhibition of the iconic human tower (castells), and impressive and emotive symbol of collaboration and part of the UNESCO List of Intangible Cultural Heritage of Humanity; also, a tasting of different olive oils, an emblematic ingredient of Spanish cuisine, and many other surprises!

On behalf of the Local Organising Committee, I would like to sincerely thank all authors for their presentations, posters, and discussion sessions. I am very thankful to the 22 international Scientific Committee members and 8 Local Organising Committee members for their time reviewing abstracts, selecting oral presentations, moderating sessions during the conference, and helping to shape the entire LCA Food 2024 experience. Of course, we are also deeply grateful to our sponsors for partnering with us, helping to make the most of our conference in Barcelona. Finally, I want to extend my deepest gratitude to all my colleagues at IRTA who supported us with their essential contribution to the 14th LCA Food conference.

May your experience during the 14th LCA Food conference be inspiring and unforgettable!

Montse Núñez,
conference chair



¡Bienvenidos y bienvenidas al congreso LCA Food 2024 en Barcelona, España!

En nombre del Comité Local Organizador y del Comité Científico, te doy una calurosa bienvenida a la 14ª edición del congreso internacional LCA Food, que se celebrará del 8 al 12 de septiembre de 2024 en Barcelona, España.

La serie de congresos LCA Food es pionera en los debates e intercambios sobre la sostenibilidad de los sistemas alimentarios desde mediados de los noventa y tiene lugar cada dos años, alternando entre Europa y otros continentes. A lo largo de sus tres décadas de historia, el congreso se ha convertido en el foro líder mundial sobre la producción y el consumo de alimentos sostenibles. Reúne cientos de profesionales del medio ambiente de todo el mundo que representan múltiples sectores, incluyendo la academia, las empresas, las instituciones públicas y las ONG. El objetivo es compartir y avanzar en la ciencia y la práctica de evaluar y mejorar la sostenibilidad de la producción y el consumo de alimentos utilizando el ACV (Análisis de Ciclo de Vida, en inglés Life Cycle Assessment, LCA) y otras herramientas relacionadas.

Tanto si eres experto como si acabas de iniciar tu camino en este campo, como participante te encontrarás rodeado de numerosos colegas que también sienten pasión por medir y mejorar la sostenibilidad de los sistemas alimentarios. El programa del congreso ofrecerá variedad de formatos y temas para encontrar inspiración, compartir y aprender, mantener y ampliar tu red de contactos, conocer la institución anfitriona local, el IRTA y, por supuesto, disfrutar de los numerosos lugares de interés y experiencias que ofrece la hermosa ciudad de Barcelona: arquitectura modernista, barrios vibrantes, una cultura viva, el mar y las playas, y, por supuesto, una gastronomía rica y reconocida.

Con su 14ª edición, el congreso LCA Food 2024 establece un nuevo récord, con más de 450 asistentes procedentes de 36 países de todo el mundo. Esto es otro indicio de que el ACV aplicado a los sistemas agroalimentarios goza de muy buena salud, está en constante desarrollo metodológico, sirviendo de base científica para las políticas públicas y las estrategias de desarrollo empresarial orientadas hacia una producción de alimento y economía más justas y sostenibles. El gran número de inscritos evidencia que la comunidad ACV dedicada al estudio de los sistemas alimentarios está creciendo, en consonancia con su relevancia e impacto social, político e industrial. El perfil del asistente es, como en las ediciones anteriores, eminentemente científico y de organismos públicos (50% de los inscritos); un 30% son estudiantes, y el 20% restante procede del sector privado. En cuanto a su procedencia, un 92% de los participantes son de países de la OCDE y solo el 8% son de países no OCDE, un porcentaje inferior al de las dos ediciones anteriores, celebradas en formato híbrido en 2022 y completamente virtual, debido a la pandemia de COVID, en 2020, donde los países no pertenecientes a la OCDE representaron el 12% y 14% de los inscritos, respectivamente.

Este año, debido a la limitada demanda de participación remota, hemos optado por una reunión puramente presencial en una preciosa sede histórica, la Universidad de Barcelona, emblema de la ciencia y la educación de la ciudad. El congreso se estructura en torno a tres días de sesiones (9 – 11 de septiembre), complementados con un día previo de sesiones especiales, el 8 de septiembre. Además, el día 12 de septiembre se harán visitas a tres centros del IRTA especializados en actividades de I+D tan dispares como la acuicultura, las prácticas agrícolas regenerativas para recuperar la salud de suelo y la biodiversidad, o el desarrollo de una nueva generación de granjas de vacas lecheras circular y de alta tecnología que utilizan la alimentación de precisión y la digitalización.

Durante los tres días de congreso habrá 38 bloques de sesiones. Estos bloques están distribuidos en seis sesiones plenarias y cuatro pistas de sesiones paralelas destinadas a temas ya tradicionales en el congreso, como la presentación y discusión de avances metodológicos en ACV para evaluar sistemas agroalimentarios, y como la aplicación del ACV al estudio de sistemas ganaderos y agrícolas. Los temas emergentes y de rápido crecimiento incluyen el ACV nutricional, el eco-etiquetado basado en rangos, la perspectiva territorial o la evaluación de la sostenibilidad de nuevos alimentos y de fuentes alternativas a la proteína animal. Por su lado, dos de las sesiones plenarias son conferencias magistrales elegidas expresamente por ser externas al ACV pero altamente relacionadas con este campo de estudio. Queremos que estas sesiones inspiren con referencia a la salud del suelo y los llamados tipping points, puntos de inflexión positivos hacia la sostenibilidad global. Además, el congreso contará con más de 200 pósteres expuestos los tres días y con múltiples sesiones de pósteres para facilitar la comunicación entre expertos, ampliar la red de contactos y fomentar el intercambio y la generación de nuevas ideas.

Cada edición del LCA Food es única. Esta vez, destacan tres aspectos del programa científico. Primero, hemos querido dar un enfoque especial en el sector empresarial y abordar sus principales retos y estrategias. Por ello, el programa incluye bloques de sesiones para que las empresas expliquen sus usos del ACV y las colaboraciones científicas que les hayan aportado cambios o aceleración en su transición hacia la sostenibilidad. En segundo lugar, dos sesiones plenarias son mesas redondas de discusión, una de ellas recoge la experiencia y visión de futuro de empresas de referencia internacional, mientras que la otra explora el futuro de la agricultura en medio de tensiones geopolíticas, desafíos climáticos y la necesidad de innovar con un enfoque de sistemas complejos para lograr resultados sociales y ecológicos. Y tercero, habrá cinco sesiones de discusión destinadas a tratar temas críticos, controvertidos y de candente actualidad, en las que todos los presentes en la sala estarán invitados a contribuir.

Además, para honrar el lema del congreso de este año, “Sistemas alimentarios saludables para un planeta sano”, estamos orgullosos de ofrecer a los asistentes una rica y saludable experiencia gastronómica mediterránea, tanto durante el congreso como en la cena de gala. Principalmente incluirá alimentos de origen no animal, de baja huella ambiental, y frutas locales y ecológicas; todo ello servido con vajilla y cubiertos reutilizables. Por favor, asegúrate de llevar siempre contigo la taza de café reutilizable, incluida en tu paquete del congreso, para tomar tus bebidas.

Aprovechando el abundante patrimonio histórico, cultural y gastronómico de Barcelona, el programa social incluye una exhibición de la icónica torre humana (castells), un impresionante y emotivo símbolo de colaboración, considerado Patrimonio Cultural Inmaterial de la Humanidad por la UNESCO; también, una degustación de diferentes aceites de oliva, ingrediente emblemático de la cocina española, ¡y otras sorpresas más!

En nombre del Comité Local Organizador, quiero agradecer sinceramente a todos los autores y autoras por sus presentaciones, pósteres, y sesiones de discusión. Estoy muy agradecida a los 22 miembros del Comité Científico internacional y a los ocho miembros del Comité Local Organizador por el tiempo dedicado a revisar los resúmenes, seleccionar las presentaciones orales, moderar las sesiones durante la conferencia y por su ayuda en dar forma a la experiencia LCA Food 2024. Por supuesto, también estamos profundamente agradecidos a nuestros patrocinadores por asociarse con nosotros, ayudándonos a sacar el máximo provecho de nuestro congreso en Barcelona. Finalmente, quiero extender mi más sincero agradecimiento a todos mis colegas de IRTA por su contribución esencial a la 14ª edición de la conferencia LCA Food 2024.

¡Espero que tengáis una experiencia inspiradora e inolvidable durante la 14ª edición del LCA Food!

Montse Núñez,
presidenta del congreso

Benvingudes i benvinguts al congrés LCA Food 2024 a Barcelona, Espanya!

En nom del Comitè Local Organitzador i del Comitè Científic, us dono una càlida benvinguda a la 14a edició del congrés internacional LCA Food, que se celebrarà del 8 al 12 de setembre de 2024 a Barcelona, Espanya.

La sèrie de congressos LCA Food és pionera en els debats i intercanvis sobre la sostenibilitat dels sistemes alimentaris des de mitjans dels anys noranta i té lloc cada dos anys, alternant entre Europa i altres continents. Al llarg de les seves tres dècades d'història, el congrés s'ha convertit en el fòrum líder mundial sobre la producció i el consum d'aliments sostenibles. Reuneix centenars de professionals del medi ambient de tot el món que representen múltiples sectors, incloent-hi l'acadèmia, les empreses, les institucions públiques i les ONG. L'objectiu és compartir i avançar en la ciència i la pràctica d'avaluar i millorar la sostenibilitat de la producció i el consum d'aliments utilitzant l'ACV (Anàlisi de Cicle de Vida, en anglès Life Cycle Assessment, LCA) i altres eines relacionades.

Tant si sou expert com si acabeu d'iniciar el vostre camí en aquest camp, com a participant us trobareu envoltats de nombrosos col·legues que també senten passió per mesurar i millorar la sostenibilitat dels sistemes alimentaris. El programa del congrés oferirà varietat de formats i temes per trobar inspiració, compartir i aprendre, mantenir i ampliar la vostra xarxa de contactes, conèixer la institució amfitriona local, l'IRTA i, per descomptat, gaudir dels nombrosos llocs d'interès i experiències que ofereix la preciosa ciutat de Barcelona: arquitectura modernista, barris vibrants, una cultura viva, el mar i les platges, i, per descomptat, una gastronomia rica i reconeguda.

Amb la seva 14a edició, el congrés LCA Food 2024 estableix un nou rècord, amb més de 450 assistents procedents de 36 països de tot el món. Això és una altra indicació que l'ACV aplicat als sistemes agroalimentaris gaudeix de molt bona salut, està en constant desenvolupament metodològic, servint de base científica per a les polítiques públiques i les estratègies de desenvolupament empresarial orientades cap a una producció d'aliment i economia més justes i sostenibles. El gran nombre d'inscrits evidencia que la comunitat ACV dedicada a l'estudi dels sistemes alimentaris està creixent, en consonància amb la seva rellevància i impacte social, polític i industrial. El perfil de l'assistent és, com en les edicions anteriors, eminentment científic i d'organismes públics (50% dels inscrits); un 30% són estudiants, i el 20% restant procedeix del sector privat. Pel que fa a la seva procedència, un 92% dels participants són de països de l'OCDE i només el 8% són de països no OCDE, un percentatge inferior al de les dues edicions anteriors, celebrades en format híbrid el 2022 i completament virtual, a causa de la pandèmia de la COVID, el 2020, on els països no pertanyents a l'OCDE van representar el 12% i 14% dels inscrits, respectivament.

Aquest any, a causa de la limitada demanda de participació remota, hem optat per una reunió purament presencial en una bonica seu històrica, la Universitat de Barcelona, emblema de la ciència i l'educació a la ciutat. El congrés s'estructura al voltant de tres dies de sessions (9 – 11 de setembre), complementats amb un dia previ de sessions especials, el 8 de setembre. Així mateix, el dia 12 de setembre es faran visites a tres centres de l'IRTA especialitzats en activitats de R+D tan dispars com l'aqüicultura, les pràctiques agrícoles regeneratives per recuperar la salut del sòl i la biodiversitat, o el desenvolupament d'una nova generació de granges de vaques lleteres circulars i d'alta tecnologia que utilitzen l'alimentació de precisió i la digitalització.

Durant els tres dies de congrés hi haurà 38 blocs de sessions. Aquests blocs es distribuiran en sis sessions plenàries i quatre pistes de sessions paral·leles destinades a temes ja tradicionals al congrés, com la presentació i discussió d'avanços metodològics en ACV per avaluar sistemes agroalimentaris, i com l'aplicació de l'ACV a l'estudi de sistemes ramaders i agrícoles. Els temes emergents i de ràpid creixement inclouen l'ACV nutricional, l'eco-etiquetatge basat en rangs, la perspectiva territorial o l'avaluació de la sostenibilitat de nous aliments i de fonts alternatives a la proteïna animal. Per la seva banda, dues de les sessions plenàries, són conferències magistrals escollides expressament per ser externes a l'ACV però altament relacionades amb aquest camp d'estudi. Volem que aquestes sessions inspirin amb referència a la salut del sòl i els anomenats tipping points, punts d'inflexió positius cap a la sostenibilitat global. A més, el congrés comptarà amb més de 200 pòsters exposats tots tres dies i amb múltiples sessions de pòsters per facilitar la comunicació entre experts, ampliar la xarxa de contactes i fomentar l'intercanvi i la generació de noves idees.

Cada edició de l'LCA Food és única. Aquesta vegada, destaquen tres aspectes del programa científic. Primer, hem volgut donar un enfocament especial al sector empresarial i abordar els seus principals reptes i estratègies. Per això, el programa inclou blocs de sessions perquè les empreses expliquin els seus usos de l'ACV i les col·laboracions científiques que els han aportat canvis o acceleració en la seva transició cap a la sostenibilitat. En segon lloc, dues sessions plenàries són taules rodones de discussió, una de les quals recull l'experiència i visió de futur d'empreses de referència internacional, mentre que l'altra explora el futur de

l'agricultura enmig de tensions geopolítiques, reptes climàtics i la necessitat d'innovar amb un enfocament de sistemes complexos per assolir resultats socials i ecològics. I tercer, hi haurà cinc sessions de discussió destinades a tractar temes crítics, controvertits i de candent actualitat, en què tots els presents a la sala estaran convidats a contribuir.

A més, per honrar el lema del congrés d'aquest any, "Sistemes alimentaris saludables per a un planeta sa", estem orgullosos d'oferir als assistents una rica i saludable experiència gastronòmica mediterrània, tant durant el congrés com al sopar de gala. Principalment, inclourà aliments d'origen no animal, de baixa empremta ambiental, i fruites locals i ecològiques; tot plegat servit amb vaixella i coberts reutilitzables. Si us plau, assegureu-vos de portar sempre a sobre la tassa de cafè reutilitzable, inclosa en el vostre paquet del congrés, per prendre les vostres begudes.

Aprofitant l'abundant patrimoni històric, cultural i gastronòmic de Barcelona, el programa social inclou una exhibició dels icònics castells, un impressionant i emotiu símbol de col·laboració considerat Patrimoni Cultural Immaterial de la Humanitat per la UNESCO; també, una degustació de diferents olis d'oliva, ingredient emblemàtic de la cuina espanyola, i moltes altres sorpreses!

En nom del Comitè Local Organitzador, vull agrair sincerament a tots els autors i autores les seves presentacions, pòsters i sessions de discussió. Estic molt agraïda als 22 membres del Comitè Científic internacional i als vuit membres del Comitè Local Organitzador pel temps dedicat a revisar els resums, seleccionar les presentacions orals, moderar les sessions durant el congrés i per la seva ajuda a donar forma a l'experiència LCA Food 2024. Per descomptat, també estem profundament agraïts als nostres patrocinadors per associar-se amb nosaltres, ajudant-nos a treure el màxim profit del nostre congrés a Barcelona. Finalment, vull estendre el meu més sincer agraïment a tots els meus col·legues d'IRTA per la seva contribució essencial a la 14a edició de la conferència LCA Food 2024.

Desitjo que tingueu una experiència inspiradora i inoblidable durant la 14a edició de l'LCA Food!

Montse Núñez,
presidenta del congreso

Why host the LCA Food conference in Spain

Spain is, along with other nearby countries, the cradle of the Mediterranean diet, which is usually considered one of the best in the world. Based on fruit, vegetables, healthy fats, pulses, and lean meat and incorporating specific cooking methods, it has a positive impact on human health and the planet compared to prevailing Westernised diets. Spain is also Europe's orchard, being one of the largest producers of fruits and vegetables for export, which indicates the strategic importance of the agricultural sector for the economic, territorial, social, and environmental development of the country.

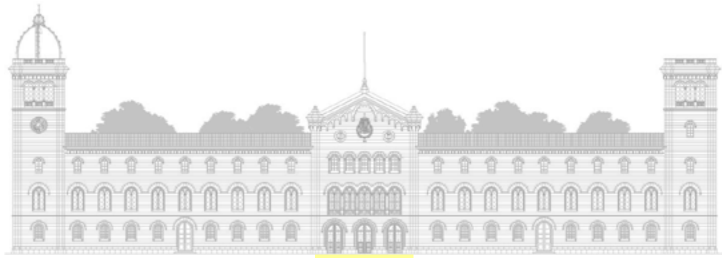
Nevertheless, current food consumption and production trends in Spain need improvement: many Spaniards have turned their back on the Mediterranean diet and eat more than they should. Moreover, intensive crop and livestock production has led to many unresolved environmental and social impacts that need to be addressed urgently.

The LCA food community in Spain is mature, large, and always growing. We use LCA to address the challenges of our food systems and contribute to improve the method to better represent critical aspects in the country, including but not limited to water scarcity, soil quality, and nutrient pollution.

So, we hope to see you in Spain to help us celebrate this 14th edition of the LCA Food conference.

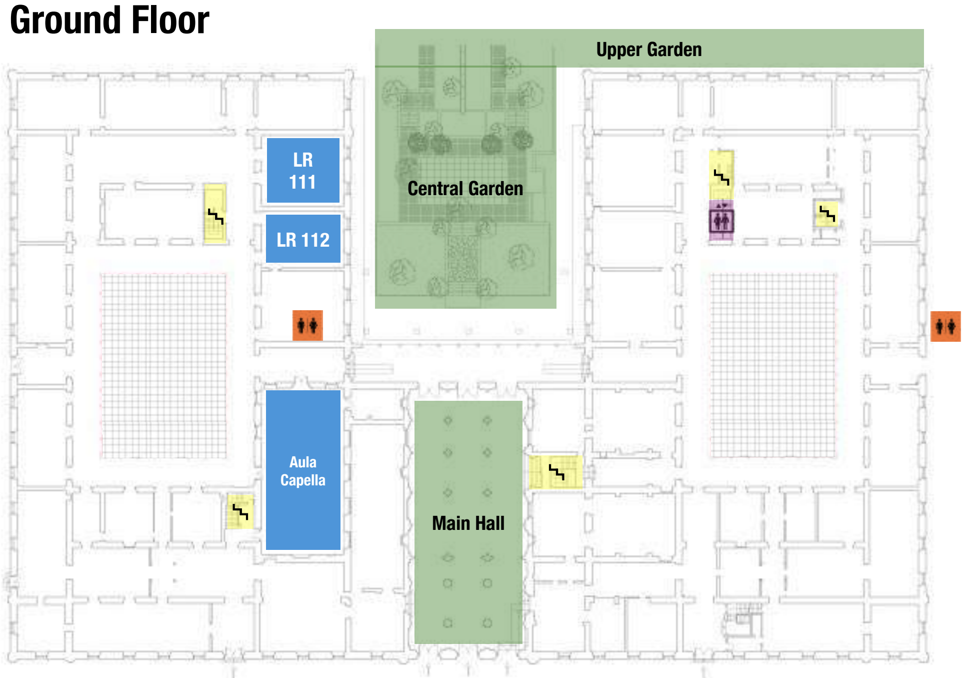
Venue and conference room plan

University of Barcelona



Gran Via de les Corts Catalanes, 585

Ground Floor

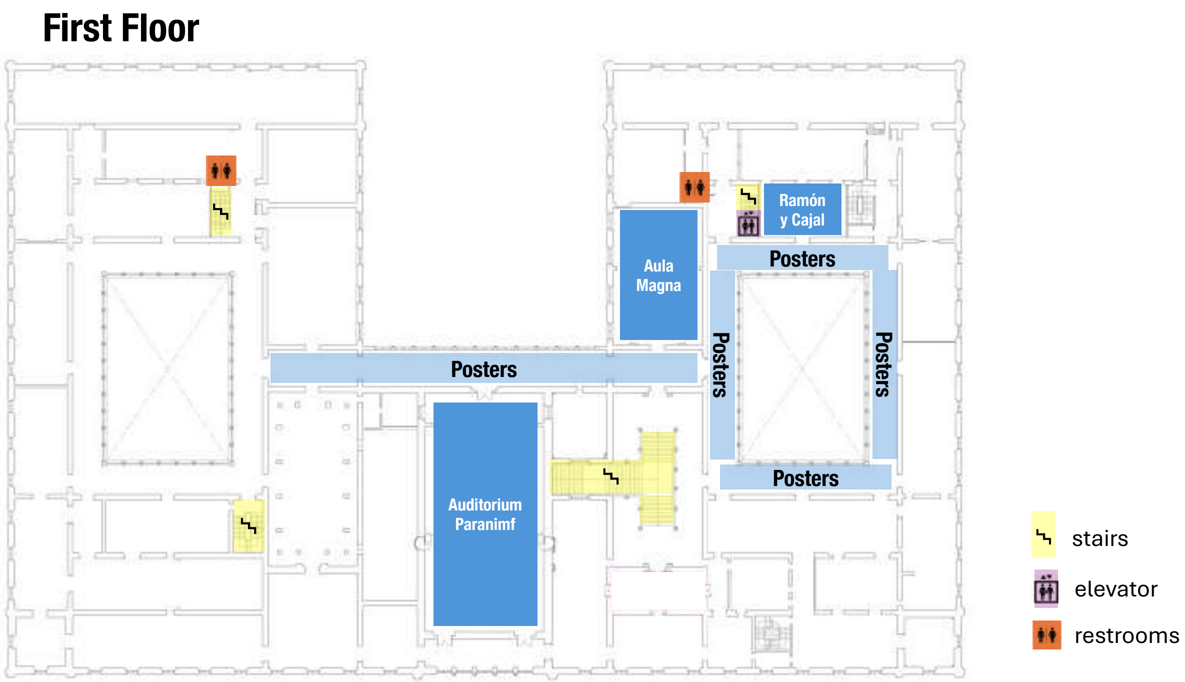


Main entrance

The University of Barcelona is a Spanish public university based in the city of Barcelona. Its faculties are currently distributed in Barcelona and the surrounding area.

The University of Barcelona Library, with 1,611,721 volumes, is the second largest university library in Spain after the Complutense University Library in Madrid.

It is the university with the largest higher education space in Catalonia, and is a leader in terms of student numbers, teaching, research and innovation.



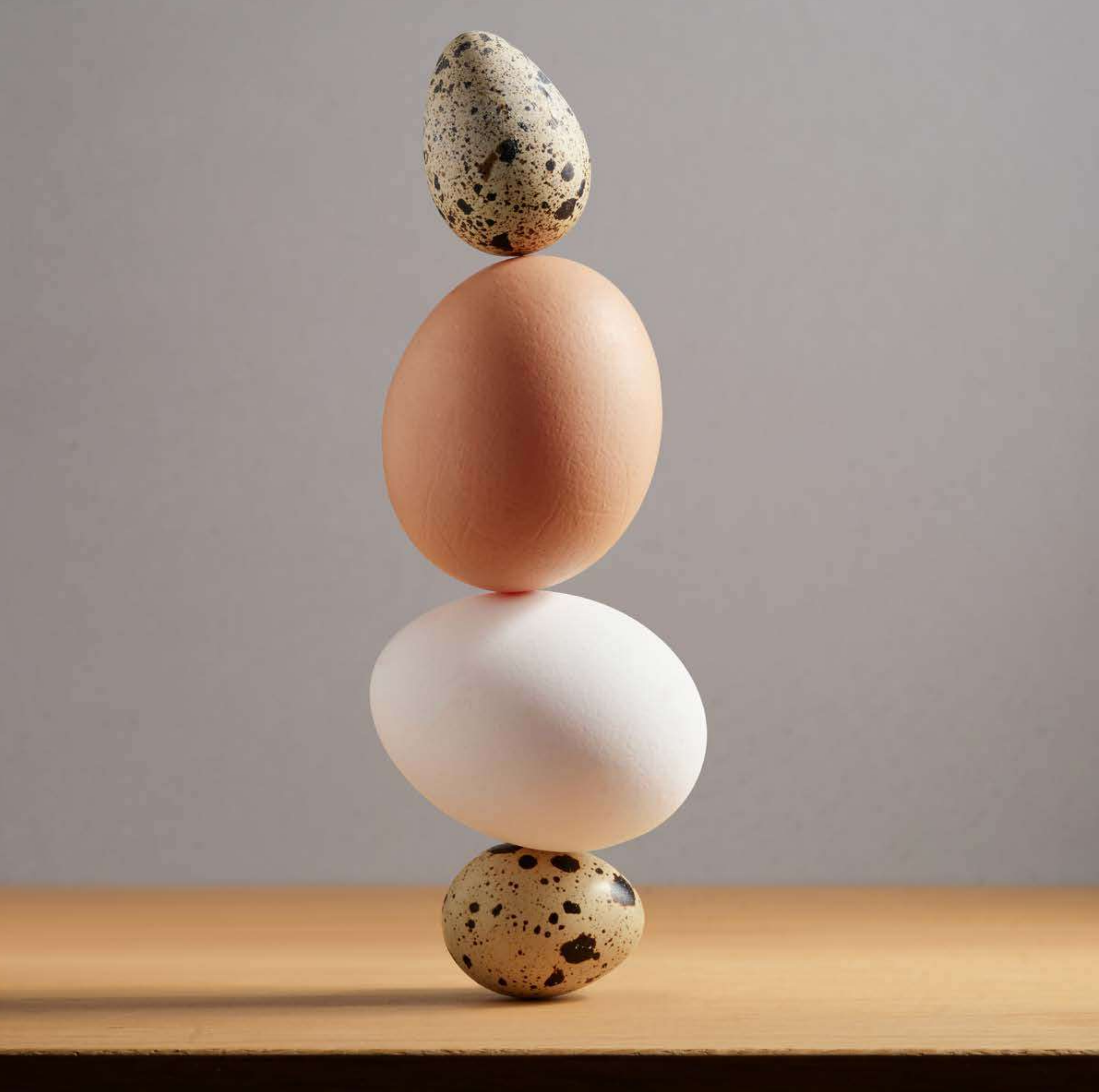
Historic Building of the University of Barcelona,

Address:

Gran Via de les Corts Catalanes 585, 08007 Barcelona.

The 14th LCA Food 2024 will be held in the historic building of the University of Barcelona, conveniently located in the heart of the city. It is well connected to both the Barcelona Sants international train station and to the Josep Tarradellas Barcelona airport by public transportation.

Diets are much more than food; they are culture, identity, and a lifestyle, to the point that "we are what we eat."



Healthy food systems for a healthy diet

Across the world, there has been a change away from traditional diets, characterised by high consumption of seasonal and local plant-based foods, grains, and fruits, towards a homogeneous, global diet made of processed foods high in calories, sugar, and animal fat, and sedentary lifestyles. This “nutrition transition” is highly relevant because modern diets have been related to negative effects on the health of people and the planet. Particularly, overconsumption of unhealthy food options has led to an increase in chronic, non-communicable diseases and obesity, even in children. Furthermore, overconsuming food requires producing more of it, resulting in significant environmental and social impacts as well as a large amount of food lost and wasted before it reaches consumers. Also, as the global diet Westernises, concern for the world’s food security and sovereignty is growing. In this context, it is essential to take action at all levels to further transform food systems to more sustainable and healthier systems, while simultaneously respecting local eating tradition and culture.

Life cycle sustainability assessment (LCSA = LCA + Life Cycle Costing + Social LCA) is an approach that applies systems thinking, identifying all processes along value chains that matter from environmental, social, and economic perspectives. It is a powerful tool to critically measure the sustainability of current food systems and help them improve their ability to build a healthy planet, in which food systems are a source of health for people and a guarantee of a future planet Earth for all.

Organizing Committee

Montse Núnez,
conference chair, IRTA

Researcher at IRTA's Sustainability in Biosystems Research Program and Ramon y Cajal fellow. Montse's research focuses on furthering quantitative environmental footprint methods and on applying life cycle-based approaches to evaluate and improve the sustainability of agri-food systems along their value chains.

Marta Ruiz-Colmenero,
IRTA

Researcher at IRTA's Sustainability in Biosystems Research Program since 2020. Marta is an expert in the application of LCA to food products and agrosystems.
She is interested in quantifying and improving the environmental impact of agricultural management practices.

Ralph K. Rosenbaum,
IRTA

Head of IRTA's Sustainability in Biosystems Research Program and researcher focusing on practical decision support via LCA and methodological improvement of quantitative methods for environmental sustainability assessment.

Alba Bala,
UNESCO Chair in Life Cycle and Climate Change ESCI-UPF

Executive Director of the UNESCO Chair in Life Cycle and Climate Change at ESCI-UPF and Academic Director and lecturer for the Master's Degree in Sustainability Management, a collaborative program between ESCI-UPF and BSM-UPF. Her expertise lies in Life Cycle Assessment, Eco-design, and Circular Economy. Alba is currently focusing on integrating various life cycle approach methodologies to conduct comprehensive Sustainability Assessments.

Almudena Hospido,
Universidad de Santiago de Compostela

Professor at the Department of Chemical Engineering of the Universidade de Santiago de Compostela. Member of the Environmental Biotechnology Group and the Centre for cross-Research in Environmental Technologies- CRETUS. More than 20 years of experience in the development and application of life cycle based tools for decision-making support in several productive sectors

Neus Sanjuan,
Institute of Food Engineering – FoodUPV. Universitat Politècnica de València

Professor of Food Technology. Neus is responsible for the research line "Assessment of environmental footprint and Sustainability of agri-food systems", where they delve into methodological aspects derived from the application of LCA to those systems, as well as multicriteria methodologies for sustainability assessment.

Saioa Ramos,
AZTI, Food Research, Basque Research and Technology Alliance (BRTA)

Saioa has experience in the application of the Environmental Footprint in the food sector to identify potential improvement stretagies and reduce environmental impacts. Her work is also focused on the development of ad-hoc multicriteria tools for the implementation, calculation, verification and effective communication of the environmental footprint of food products.

Mariluz Latorre
University of Barcelona

Associate professor in the Department of Nutrition, Food Science and Gastronomy. Food and Nutrition Torribera Campus. University of Barcelona.
She belongs to the consolidated research group "Food Bioactive Compounds." Her research mainly focuses on the study of bioactive amines in food. In recent years, she has also been dedicated to study new strategies to improve the safety and quality of fermented products through the revalorization of vegetable by-products of the food industry.

Carmen Vidal-Carou,
University of Barcelona

Prof. Dr. M. Carmen Vidal Carou leads the consolidated research group "Food Bioactive Compounds." She has an extensive experience in the study of bioactive compounds in food and its effects on health, food quality and food safety. Her current focus is the reuse of plant by-products from the agri-food industry for safer and more environmentally friendly foods. She develops methodologies to integrate nutritional parameters into the assessment of environmental impacts along food value chains and is actively engaged in social studies on food knowledge and perceptions.

Scientific Committee

Name	Affiliation	Country
Cécile Bessou	CIRAD	France
Clea Figueiredo	Embrapa	Brazil
Michael Corson	INRAE	France
Ulrike Eberle	corsus-corporate sustainability GmbH	Germany
Shabbir H. Gheewala	Joint Graduate School of Energy and Environment	Thailand
Kiotada Hayashi	EarthShift Global, Asia G.K.	Japan
Nicholas Holden	University College Dublin	Ireland
Niels Jungbluth	ESU-services Ltd	Switzerland
Sergiy Smetana	DIL	Germany
Sarah McLaren	Massey University	New Zealand
Corina van Middelaar	Wageningen University	Netherlands
Llorenç Milà i Canals	UNEP	
Rattanawan Tam Mungkong	Kasetsart University	Thailand
Thomas Nemecek	Agroscope	Switzerland
Bruno Notarnicola	University of Bari Aldo Moro	Italy
Montserrat Nuñez	IRTA	Spain
Brad Ridoutt	CSIRO	Australia
Laura Scherer	CML, Leiden University	Netherlands
Hanna Tuomisto	University of Helsinki	Finland
Greg Thoma	University of Arkansas	United States
Ian Vazquez Rowe	Pontifical Catholic University of Peru	Peru
Bo Weidema	2. -0 LCA Consultants	Denmark
Edmundo Muñoz	Andres Bello National University	Chile

Plenary speakers

Louise O. Fresco

Louise O. Fresco, as President of Wageningen University & Research (WUR) since 1 July 2014 till 1 July 2022, received the Norman E. Borlaug Medallion in June 2022 for outstanding contributions to life sciences research and global food security. Her leadership strengthened WUR's societal impact and public engagement. Recognized for sustainable development efforts, she earned honorary doctorates from the University of Liège and KU Leuven in 2017. Fresco was honored with the Comenius Prize in 2014 for promoting scientific awareness. In 2009, she spoke at the TED Conference, and in 2008, she received the Groeneveld Award for significant contributions to the nature and landscape debate.

Marta G. Rivera Ferre

Marta G. Rivera-Ferre is Research Professor at INGENIO (CSIC-UPV), with a broad academic background in Veterinary Science, Animal Production, Agricultural Economics and Sociology. Her experience spans institutions in the UK, the Netherlands and Spain, with a focus on agroecology and food systems. As Director of the Chair of Agroecology and Food Systems at the University of Vic-Central University of Catalonia, she explored the interaction between agriculture, food, society and environment, with a focus on climate change and food security. He has led UN panels, participated in IPCC and IPBES, and coordinated reports on sustainable food systems and the link between water, food, energy and ecosystems. She also contributed to the UNWomen CSW66 report on gender equality and climate change.

J. David Tàbara

Dr. J. David Tàbara is an independent social scientist with 30 years' experience in international interdisciplinary research on sustainable development. He is a member of the Earth Commission Working Group on Transformations of the Global Commons Alliance, and an Associated Researcher to the Global Climate Forum in Berlin (created by climate Nobel Prize Klaus Hasselmann) and to the Autonomous University of Barcelona. He has published extensively (over 100 scientific publications) on methods for social-environmental knowledge integration, social learning, and public participation for sustainability. He has been involved in many EU research projects on transformative science and solutions to support sustainable climate action. Recently, he was the Principal Investigator to the EU project TIPPING+ on "Enabling Positive Tipping Points towards clean-energy transitions in Coal and Carbon Intensive Regions" that involved over 20 cases studies in Europe and elsewhere. As a member of the Earth Commission, he is a co-author of paper in the Lancet- Planetary Health that will be published later this week on 'a Just World on a Safe Planet" led by Prof. Joyeeta Gupta of the University of Amsterdam.

Joan Romanyà

Joan Romanyà is Professor of soil science at the University of Barcelona. He has experience working on plant-soil relationships in natural and man-made ecosystems. Recently, he has specialized in the management of soil organic matter for crop production. His main research interests are i) optimizing the use of local resources (organic waste, microbes and plants) to design sustainable agroecosystems, ii) identifying agricultural practices that promote the reserve of soil organic matter and plant growth promoting organisms, iii) studying the relationships between soil organic matter, soil-plant microbes and nutrient availability, and iv) the relationships between soil quality and plant quality.

Sarah Sim

Sarah Sim is the Environmental Sustainability Programme Director in Unilever's Safety and Environmental Assurance Centre and Extraordinary Professor Corporate Environmental Sustainability at Radboud University, Netherlands. She holds an EngD in Environmental Technology: Sustainable Food Supply chains. She has worked at the corporate-academic interface for over 20 years, gaining a deep understanding of business needs and the pathway from research to application. She is responsible for the development and execution of Unilever's environmental sustainability science strategy and for application of this science to inform business decision-making across the company's Nutrition, Ice Cream, Beauty & Wellbeing, Personal Care and Home Care product portfolios. Her main research focus is on approaches to assess the environmental impacts of technologies, products and organizations. These include life cycle approaches, predictive and spatial modelling, biodiversity and ecosystem indicators.

Paz Fentes

Deputy Director General of Herbaceous and Industrial Crops and Olive Oil of the Ministry of Agriculture, Fisheries and Food. MSc in Agricultural Engineering from Universidad Politécnica de Madrid. She began her career in the Union of Agricultural Cooperatives of Madrid, in the olive grove sector. She has been an official of the Ministry of Agriculture, Fisheries and Food since 2006, where she has carried out tasks related to the monitoring, analysis and development of policies regarding to several sectors (cereals, oilseeds, legumes, rice, fodder, sugar beet, cotton, olive groves, etc.), as well as horizontal tasks related to the environment, renewable energies or the common agricultural policy and its successive reforms. Currently she holds the position of Deputy Director General for arable and industrial crops and olive oil.

Lisbeth Hernández

Lisbeth Hernández is a Sustainability Officer for OSI Group in all European markets. OSI Group is one of the world's largest privately held food manufacturers and supplies leading retail and foodservice brands. OSI's products include traditional proteins such as beef patties and chicken nuggets, to sauces, and plant-based proteins. Lisbeth is an Industrial Chemical Engineer with a master's in food technology from KU Leuven and UGent. Her experience includes development of strategies to reduce Scope 3 emissions in the supply chain of agricultural products, calculation of life cycle assessments, and implementation of measures to help farmers transition to a more sustainable production. This intersects with helping farmers improve animal welfare and achieving financially viable farms. But everything is connected to the overarching goal of measuring the emissions of all farmers in the supply chain and achieving a reduction of GHG emissions in different farming systems.

Joan Gòdia

Joan Gòdia Tresánchez is currently the General Director of Agri-Food Companies, Quality, and Gastronomy in the Department of Climate Action, Food, and Rural Agenda of the Government of Catalonia (Generalitat de Catalunya). He previously held several senior management and academic positions in various research institutes and universities in Catalonia, including a role as Deputy Director General of Industries and Agrifood Quality at the Department of Agriculture, Fisheries, and Food of the Government of Catalonia. Moreover, he is a member of the Governing Board of the Catalan Council of Integrated Production (CCPI) and the Catalan Council of Organic Production (CCPAE). In international presentation, he has been a member of the board of directors of the European Producers Association for Designations of Origin (AREPO) and is currently a member of the European Association of Fruit and Vegetable Producers (ARFLH). Additionally, he is a member of the Catalan Food Council and the Food Safety Steering Commission of Catalonia.

Leo Bejarano

Leonardo Bejarano Manjón holds a Degree in Environmental Sciences from the University of Girona, Spain. He has worked for more than 20 years for the Government of Catalonia (Generalitat de Catalunya), first as a technician in the Department of the Environment and the Department of Agriculture, Livestock, Fisheries, and Food and later in the General Directorate of Environmental Policies and the Natural Environment of the Department of Territory and Sustainability. Since March 2023, he has been the Head of the Catalan Office for Climate Change of the Department of Climate Action, Food, and Rural Agenda.

Isabelle Privat

Isabelle Privat is the Head of "Plant & Nutrition" Department in the newly created Nestlé Institute of Agricultural Science part of Nestlé R&D. She has been part of Nestlé R&D since 20 years with different roles – from research scientist covering functional genomics in coffee & cacao linked to sensory quality to department head leveraging plant diversity to improve nutrition & taste of our plant-based products. Isabelle holds a Ph.D. in Plant Molecular Biology and Genetics. She is deeply convinced that plant-based products can be improved right at the early stage of the value chain – in the field. Integrating sustainable production (including RegAgri), highly performing varieties with limited inputs, improved functionality and limited off taste could make a great difference for the quality of the end product that justifies investing significantly to understand how those different criteria can be quantified and integrated in the supply chain.

Conference topics

Sustainable livestock systems

Food loss and waste: environmental impacts and solutions

Sustainable cropping systems

Innovations in food production beyond the farm gate

Life cycle sustainability assessment of food systems

Greenhouse gas accounting and reporting

Combined nutritional and environmental assessment of foods and diets

Life cycle sustainability assessment of food systems

Integration of agroecology and soil health in LCA

Sustainability in fisheries and aquaculture systems

LCA and footprint studies explained by companies

Circular food systems

Cocoa and olive oil: sustainability assessments

Life cycle inventory: modelling, databases and tools

Ecolabelling

Communication of LCA results and integration of ESG criteria into business

Novel foods and protein diversification

Sustainable territories and economies

Sustainability of food systems in developing and emerging economies

Life cycle impact assessment: new developments

Topical discussion sessions

Bridging the environmental footprint data gap: enhancing collaboration between users and creators of background databases

Opportunities from land use change assessments frameworks to unlock supply chain interventions

Achieving alignment and transparency within the feed and food supply chain: embracing the complexity of new developments in impact assessment and modelling

Recommendations for sustainable nutrition in the political debate

Ecolabeling of food products is happening – the devil is in the details

Special sessions (1)

Harmonized methods for cultivated meat LCA

Organizers:
Hanna Tuomisto
(University of Helsinki and the Natural Resources Institute Finland, Luke)
and Nicole Tichenor Blackstone
(Tufts University)

Tufts University | Gerald J. and Dorothy R. Friedman School of Nutrition Science and Policy

Date and time: 12:00 - 17:00, 8th September
Location: University of Barcelona, meeting room "Ramón y Cajal"
Zoom option: available

By invitation only. If you have worked or are actively working on cultivated meat LCAs and are interested in attending, please emai: lhanna.tuomisto@helsinki.fi to introduce yourself and be added to the participant list.

On-site attendance requires being registered at the Conference.

Description:
Wide variability in LCA results for cultivated meat underscores the need for standardized guidance to estimate its environmental performance. Because of the nascency of the industry, practitioners face critical barriers in developing cultivated meat LCAs related to data availability, as well as data and system representativeness. Additionally, the choice of comparison products, byproduct handling, and boundaries of the analysis can significantly influence results, further underscoring the need for harmonized guidance. The objectives of this workshop are to develop consensus guidance for LCA practitioners on developing and implementing cultivated meat LCAs. This will become the core part of a short publication that interested participants will continue to co-author and submit in the months after the workshop. Participants will be expected to pre-read materials (i.e., an initial proposal of harmonized guidance) in advance of the workshop to make best use of the workshop time.

Preliminary agenda

- Introduction to the workshop and an introduction round of the participants
- An overview presentation of the published cultivated meat LCAs
- Discussion of the harmonization topics:
  - Should some standard be followed (e.g. PEF)
  - Methodological choices: system boundaries, FU, allocations, impact assessment methods, environmental impact categories, uncertainty assessments, comparisons with livestock meat/plant-based foods/other products
  - Data: medium ingredients, large-scale bioreactors, cell yields
  - Results: presentation of the results (grouping or life cycle stages)
  - Discussion: limitations
- Planning the journal paper writing process
- Discussion of other possible collaborations (e.g. creating a shared database, development of a tool for cultivated meat LCAs, other ideas)

Special sessions (2)

Harmonized methods for food loss and waste LCA

Organizers:
FOLOU & WASTELESS projects.
Joan Colón, Nancy Peña and Jorge Senan
(BETA Technological Center, University of Vic – Central University of Barcelona),
Ana Isabel Novo de Barros (University of Trás-os-Montes and Alto Douro) and
Sofia Reis (ISEKI-Food Association).

Date and time: 14:00 - 16:00, 8th September.
Location: University of Barcelona, room "Aula 112"
How to Attend: Limited physical attendance (90 people).
To register, please email folou@uvic.cat. This session is open to all registered conference attendees.

Description:
The mitigation of food waste (FW) and losses (FL) is crucial for sustainability (Sustainable Development Goal 12.3). Thus, assessing the FLW contribution to the overall environmental burdens associated to the agri-food value chain is essential, e.g., impacts associated with resource consumption, field operations, food left on the ground or discarded and FLW treatments (on-farm or external). Current commercial LCA databases often do not fully consider these impacts, especially for the FL at the primary sector.

FOLOU and WASTELESS project aims to fill the gap by developing harmonized methodologies to account and allocate the impacts related to FL and FW. During the session, the presentation of an initial proposal of harmonized guidance on quantification and assessment of FL will be presented (if you are interested in reading in advance the guidance please write an email at folou@uvic.cat) and discussed aiming at incorporating expert feedback from panelist and attendees.

Preliminary agenda

- Introduction to the workshop and an introduction round of the expert panelists.
- Overview presentation of the State of the Art
- Presentation of the "harmonized guidance on quantification and assessment of FL".
- Discussion of the harmonization topics:
  - How to align FL and FW impacts in the PEF/OEF standard
  - Methodological choices (system boundaries, FU, allocations, etc.)
  - Gaps identification
  - Discussion: limitations
- Discussion of other possible collaborations (e.g. joint publications, creation of a FLW working group, other ideas)

Special sessions (3)

Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) phase 3

Organizers:
Llorenç Milà i Canals (United Nations Environment Programme, Life Cycle Initiative)
and Laura Scherer (Leiden University, Institute of Environmental Sciences)

Date and time: 10th of September, 1:40 – 2:25 PM
Location: University of Barcelona, Auditorium Paranimf

How to Attend: Open session, registration not required

Description:
The Life Cycle Initiative started GLAM in 2013 in collaboration with the University of Michigan, the Norwegian University of Science and Technology (NTNU), and Denmark's Technical University (DTU) to enhance global consensus on environmental life cycle impact assessment indicators. The project aims to generate tangible and practical recommendations for different environmental indicators and characterization factors used in Life Cycle Impact Assessments (LCIA).
GLAM works with a balanced mix of international experts from three topical tracks: LCIA method developers, providers of life cycle thinking studies (primarily consultants and industry associations), and users of life cycle information, including governmental and intergovernmental organizations, government, industry, NGOs, and academics.
The objective of this workshop is to provide participants with a thorough understanding of the GLAM framework. We will begin by introducing the basics of GLAM, followed by a detailed presentation of the GLAM method and the GLAM Characterization Factors (CFs) with a focus on food-related impact categories. Additionally, the workshop will outline the process for consultation and stewardship within the GLAM framework.

Preliminary agenda:
1. Introduction to GLAM
2. Overall presentation of the GLAM method
3. GLAM CFs with a focus on food-related impact categories
    a. Dietary impacts
    b. Eutrophication
    c. Water use
    d. Climate change
4. Process for consultation and stewardship
5. Questions and comments

PROGRAMME

14th International Conference

LCA FOOD 2024

HEALTHY FOOD
SYSTEMS FOR
A HEALTHY PLANET

- WHERE?
- WHEN? WHAT?
- SPECIAL EVENT

8 Sep

8 Sep | Main hall

11:00-19:30 Arrival and registration

8 Sep | Meeting room "Ramón y Cajal"

12:00-17:00 Special session, by invitation only:

Harmonized methods for cultivated meat LCA.

Organizers: Hanna Tuomisto *(University of Helsinki and the Natural Resources Institute Finland, Luke)* and Nicole Tichenor Blackstone *(Tufts University)*

Sponsor:

Tufts University | Gerald J. and Dorothy R. Friedman School of Nutrition Science and Policy

Detailed information here.

8 Sep | Lecture room 112

14:00-16:00 Special OPEN session:

Harmonized methods for Food Loss and Waste LCA.

Organizers: FOLOU & WASTELESS projects. Joan Colón, Nancy Peña and Jorge Senan *(BETA Technological Center, University of Vic – Central University of Barcelona)*, Ana Isabel Novo de Barros *(University of Trás-os-Montes and Alto Douro) and Sofia Reis (ISEKI-Food Association).*

Detailed information here.

8 Sep | Central Garden

16:00-17:00 Visit to the historic building of the University of Barcelona. Groups 1 / 2 / 3

17:00-18:00 Visit to the historic building of the University of Barcelona. Groups 4/5 / 6

18:00-19:30 Welcome reception & Castells (Human towers) exhibition

9 Sep

9 Sep | Main hall

08:00-18:00 Arrival and registration

9 Sep | Auditorium Paranimf

08:30-09:00 | Opening session

UB Vice-Chancellor, Ms. Mercè Segarra

IRTA DG, Mr. Josep Usall

Conference Chair, Ms. Montse Núñez

09:00-10:00 | Plenary 1

Chair: Ms. Montse Núñez

Ms. Paz Fentes. *Deputy Director General of Herbaceous and Industrial Crops and Olive Oil of the Ministry of Agriculture, Fisheries and Food*

Mr. Joan Gòdia Tresanchez. *Director General of Agri-Food Companies, Quality, and Gastronomy, Government of Catalonia.*

Mr. Leo Bejarano i Manjón. *Head of the Catalan Office for Climate Change, Government of Catalonia.*

Public policies for sustainable food systems in Spain and Catalonia

10:30-11:30 | Plenary 2

Chair: Ms. Anna Pallí Güell

Mr. Joan David Tàbara. *Global Climate Forum, Berlin, and Autonomous University of Barcelona*

From less negative impact cycles to regenerative spirals. How can we build the conditions for the emergence of net-positive tipping points in global systems?

WHERE?
WHEN? WHAT?
SPECIAL EVENT

9 Sep | Lecture room 112

11:30-13:00 | Sustainable livestock systems (I)

Chair: Ms. Corina van Middelaar

11:30-11:45 The contribution of dam evaporation to Brazilian cattle water use. Michael Lathuillière. *Stockholm Environment Institute*

11:45-12:00 Absolute Environmental Sustainability of Milk Production in Brazil with a focus on climate change mitigation. Daiane Vitória Dai. *Federal University of São Carlos.*

12:00-12:15 Climate Impact and Ecosystem Services in Cattle Production: Including Non-Provisioning Ecosystem Services in Life Cycle Assessments. Karin von Greyerz. *Swedish University of Agricultural Sciences.*

12:15-12:30 Assessing the Carbon Footprint of Small-Scale Dairy Cattle Systems in Kenya, Africa: An Application of Life Cycle Assessment Methodology. Ricardo Gonzalez Quintero. *International Center for Tropical Agriculture.*

12:30-12:45 Farm efficiency and environmental impact of dairy sheep. Irene Sodi. *University of Pisa.*

12:45-13:00 LCA unveils positive contribution from traditional sheep-farming. Koesling Matthias. *NIBIO – Norwegian Institute of Bioeconomy Research.*

14:30-16:00 | Sustainable livestock systems (II)

Chair: Ms. Corina van Middelaar

14:30- 14:45 Can milk and beef footprint reductions deliver national climate targets? Daniel Henn. *University of Limerick.*

14:45- 15:00 Integrating ecosystem services into LCA of livestock farming: a comparative analysis of beef production systems in Galicia (NW Spain). Alberto Fraile De Benito. *Universidade de Santiago de Compostela.*

15:00- 15:15 Assessing the Overall Sustainability Performance of the Meat Processing Industry Before and After Wastewater Valorization Interventions. Angeliki Petridi. *DIGNITY PRIVATE COMPANY.*

15:15- 15:30 Hunting for meat with low greenhouse gas emissions- a case study of wild boar in Sweden. Danira Behaderovic. *RISE Research Institutes of Sweden.*

15:30- 15:45 Evaluation of the ecoefficiency of post-weaned swine production. Clandio Ruviaro. *Universidade Federal da Grande Dourados.*

15:45- 16:00 Developing a climate scan for pig farms without overlooking the regional policies on nitrogen emissions. Freya Michiels. *ILVO.*

16:30-18:00 | Sustainable livestock systems (III)

Chair: Ms. Hanna Tuomisto

16:30-16:45 Cropland and carbon footprints of global crop demand for animal feed. Neus Escobar. *Basque Centre for Climate Change (BC3).*

16:45- 17:00 Spent Coffee Grounds as a sustainable livestock feed ingredient. Maite Cidad. *AZTI.*

17:00- 17:15 Multi-objective optimization of Canadian laying hen feed formulation for least-carbon footprint and -economic costs. Ian Turner. *University of British Columbia.*

17:15- 17:30 Investigation of lay cycle extension as an environmental sustainability improvement strategy for the Canadian egg industry using LCA and predictive modelling. Ian Turner. *University of British Columbia.*

17:30- 17:45 Ecosystem services and life cycle assessment frameworks provide opposite assessments of animal-production systems. Jean-Charles Joly Frédéric. *INRAE.*

9 Sep | Lecture room 111

11:30- 13:00 | Food loss and waste: environmental impacts and solutions

Chair: Ms. Ulrike Eberle

11:30-11:45 Sensor-based solution in retail food waste reduction: an LCA perspective on uncertainties and impacts. Junzhang Wu. *University of Padova.*

11:45- 12:00 Consequential Life Cycle Assessment of a Novel Resource Recovery Solution for Food Waste Management. Haodong Lin. *University College London.*

12:00-12:15 Evaluate environmental impacts of uneaten food in the food chain. Yanne Goossens. *Thuenen Institute of Market Analysis.*

12:15-12:30 Environmental impact of food losses and food waste of the milk sector in Catalonia, Spain. Ariadna Bàllega Calvo. *IRTA.*

12:30- 12:45 Direct valorization of grocery food waste for poultry feed: opportunities to improve sustainable egg production. Shaiyan Siddique. *The University of British Columbia Okanagan.*

12:45- 13:00 Food waste reduction strategies in independent restaurants from the eco-efficiency perspective. Sergey Mikhaylin. *Université Laval*

14:30- 16:00 | Sustainable cropping systems (I)

Chair: Mr. Bo Weidema

14:30- 14:45 Urbanization of food production: Can indoor vertical farming reduce the environmental footprint of kitchen herbs? Wanner Silvan. *Zurich University of Applied Sciences.*

14:45-15:00 LCA comparison of vertical and rooftop farming with conventional agricultura. Joan Muñoz Liesa. *KTH.*

15:00- 15:15 LCA to inform detailed agricultural practice ecodesign at farm scale, example of viticulture. Renaud Gentié Christel. *ESA.*

15:15-15:30 Life Cycle Assessment (LCA) of Frost Protection Methods in Viticulture: A Conceptual Framework to Assess and Compare Different Technologies. Vincent Baillet. *Ecole Supérieur des Agricultures (ESA)*

15:30- 15:45 Winery 4.0: technology innovations to improve grape production sustainability. Michele Zoli. *Department of Environmental Science and Policy - University of Milan.*

15:45- 16:00 Assessing the environmental performance of valorisation opportunities for sunflower hulls. Villi Ieremia. *KU Leuven.*

16:30- 18:00 | Sustainable cropping systems (II) and Innovations in food production beyond the farm gate

Chair: Ms. Neus Sanjuan

16:30 - 16:45 Improving rice production sustainability through variable rate fertilization and alternative water management. Michele Zoli. *Department of Environmental Science and Policy - University of Milan.*

16:45-17:00 Towards climate-neutral agriculture: exploring scenarios for arable and dairy farms. Emily Miranda Oliveira. *INRAE.*

17:00-17:15 Assessing Organic Waste Products in LCA: Insights from Agribalyse. Melissa Cornelus. *INRAE.*

17:15-17:30 Comparison between a delivery service of ready-to-cook ingredients and a meal prepared by a home helper for the elderly. Gremy-Gros Cécile. *Université d Angers.*

17:30-17:45 Analyzing the impacts of the production of vegetable oil: understanding the role of packaging impacts. Diana Ita Nagy. *PELCAN-Pontificia Universidad Católica del Perú.*

17:45- 18:00 Interlaboratory collaborative life cycle assessment study in the food and packaging sector. Andrea Casson. *Università degli studi di Milano.*

9 Sep | Lecture room Aula Magna

11:30-13:00 | Combined nutritional and environmental assessment of foods and diets (I)

Chair: Ms. Sarah McLaren

11:30- 11:45 REFRESH: a Validated Public Health Screener for Healthy Diets with Low Environmental Impact. Ujué Fresán. *ISGlobal*

11:45- 12:00 The Planet Health Conformity-Index: bridging the gap between nutritional and environmental sustainability in nLCAs. Toni Meier. *INL Institute for Sustainable Agriculture and Food Economics.*

12:00- 12:15 Do Swiss food trends lead to healthier, more nutritious and environmentally friendly diets? Alba Reguant-Closa. *Agroscope.*

12:15- 12:30 Environmental and nutritional performance of meal trays served in public collective catering. Caroline Penicaud. *INRAE.*

12:30-12:45 Nutrition-related health and environmental impacts of shifting to recommended diets in the US. Brooke M. Bell. *Friedman School of Nutrition Science and Policy, Tufts University.*

12:45- 13:00 Environmental and Health Impact Assessment of 6,000 Menu Items. Genta Sugiyama. *Waseda University.*

14:30-16:00 | Combined nutritional and environmental assessment of foods and diets (II

Chair: Ms. Alba Bala

14:30- 14:45 Changes in dietary-related greenhouse gas emissions through time in Peruvian cities. Joan Sanchez Matos. *Pontificia Universidad Católica del Perú.*

14:45- 15:00 Climate change impacts of dietary patterns of young adults in Canada. Sadaf Mollaei. *George Brown College.*

15:00- 15:15 Environmental Impacts and Nutrition of Dietary Patterns: A Case Study of Canadian Provinces. Goretty Días. *University of Waterloo.*

15:15- 15:30 Nutritional life cycle assessment of Canadian grains, oilseeds and pulses. Nicole *Bamber. University of British Columbia, Okanagan campus.*

15:30- 15:45 Combined nutritional and environmental assessment of the Portuguese Dietary Pattern. Joana Bôto. *Faculty of Nutrition and Food Sciences, University of Porto.*

15:45- 16:00 Towards a combined environmental and nutritional Life Cycle Assessment of the four most caught fish by Belgian fisheries. Matthys Sarah. *KU Leuven.*

16:30-18:00 | Combined nutritional and environmental assessment of foods and diets (III)

Chair: Mr. Brad Ridoutt

16:30- 16:45 Calculating thresholds for differentiating different levels of climate friendliness for meals. Miguel Brandao. *KTH - Royal Institute of Technology.*

16:45- 17:00 Methodological considerations for quantifying the effect of nutritional compositions and product formulation in environmental life cycle assessments of food items. *Ashley Green. ETH Zurich.*

17:00- 17:15 Multi-criteria decision analysis (MCDA) as a context-adaptable weighting method for Life Cycle Assessment impact categories in sustainable nutrition science. Elise de Boer. *University Medical Center Groningen.*

17:15- 17:30Mitigating environmental impacts through more sustainable diets: consequential life cycle assessment of various regional diet shift scenarios. Guillaume Aurore. *KU Leuven & UCT Prague.*

17:30- 17:45 Life cycle environmental consequences of a more cycling-oriented mobility including additional calorie intakes and regional diet evolutions. Anne de Bortoli. *CIRAIG, PolyMTL.*

17:45- 18.00 A Protein Quality Adjusted nutritional-LCA of Soy-Based Meat and Dairy Alternatives: Understanding the Environmental and Nutritional Implications of Food Processing. Eric Mehner. *Agroscope.*

9 Sep | Lecture room Aula Capella

11:30-13:00 | Greenhouse gas accounting and reporting

Chair: Ms. Cécile Bessou

11:30- 11.45 Integrating land use and land-use change greenhouse house gas emissions into the French life cycle inventory database Agribalyse. Xavier Boton. *Arvalis institut du végétal.*

11:45-12:00 Methodological development to include the effect of land management changes in GWP of field crops. Noora Anniina Lehtilä. *Natural Resources Institute Finland (Luke)*

12:00- 12:15 Quantifying land conversion carbon emissions in the absence of traceability. Jürgen Reinhard. *AdAstra Sustainability.*

12:15-12:30 Radiative forcing footprints for the Australian red meat industry. Brad Ridoutt. *CSIRO.*

12:30-12:45 Application of environmentally extended input-output data to estimate greenhouse gas emissions attributable to packaged foods and beverages in Australia. Maria Shahid. *The George Institute for Global Health.*

12:45- 13:00 Carbon footprint of low-input livestock systems: accounting for natural baseline emissions within the ecosphere. Guillermo Pardo Nieva. *Basque Centre for Climate Change - BC3.*

14.30- 16:00 | Topical discussion session 1

Carolina Carrillo Diaz. *Mérieux NutriSciences | Blonk*

Bridging the Environmental Footprint Data Gap: Enhancing Collaboration between Users and Creators of Background Databases.

16:30-18:00 | Topical discussion session 2

Jürgen Reinhard and Lisanne de Weert. *AdAstra Sustainability*

Renan Novaes. *Embrapa*

Iana Salim. *Mérieux NutriSciences | Blonk*

Opportunities from land use change assessments frameworks to unlock supply chain interventions.

9 Sep | Conference dinner

20:00 L'Estació Espai Gastronòmic

Address: Estació de França (France Railway Station), Avinguda del Marquès de l'Argentera 6, Barcelona

WHERE?
WHEN? WHAT?
SPECIAL EVENT

10 Sep

10 Sep | Main hall

08:00-18:00 Arrival and registration

10 Sep | Auditorium Paranimf

10:30-11:30 | Plenary 3

Chairs: Ms. Carmen Vidal and Ms. Mariluz Latorre

Mr. Joan Romanyà. *University of Barcelona*

Healthy soils for a healthy life.

13:40 – 14:25 | Special OPEN session:

Global Guidance for Life Cycle Impact Assessment Indicators and Methods (GLAM) phase 3

Organizers: Llorenç Milà i Canals (United Nations Environment Programme, Life Cycle Initiative) and Laura Scherer (Leiden University, Institute of Environmental Sciences)

Detailed information here.

16:30-17:30 | Plenary 4

Chairs: Ms. Alba Bala and Mr. Llorenç Milà i Canals

Roundtable with Ms. Louise Fresco *(Wageningen University & Research -WUR)* and Ms. Marta Rivera-Ferre *(INGENIO -CSIC-UPV-)*

Sustainable food systems: what, why, how?

10 Sep | Lecture room 112

08:30-10:00 | Life cycle sustainability assessment of food systems

Chair: Mr. Sergiy Smetana

8:30- 8:45 Integrated sustainability assessment of insect-fed chicken: Integrated Sustainability Index. Dusan Ristic. *German Institute of Food Technologies (DIL e. V.).*

8:45-9:00 Sustainability performance of innovative ruminant systems in Europe. Pietro Goglio. *Department of Agricultural, Food and Environmental Science, University of Perugia.*

9:00-9:15 DEXi a framework to integrate LCA in sustainability assessment. Application to animal production system. Aurélie Wilfart. *INRAE.*

9:15-9:30 LCA to feed multi-criteria sustainability assessment of intermediate food value chains. Mehran Naseri Rad. *RISE - Research Institutes of Sweden.*

9:30- 9:45 A practitioner-driven methodological framework to assess the environmental, social and economic sustainability of regional food products. Barbara Mejía. *Agroscope, LCA Group.*

9:45-10:00 Environmental and Social Life Cycle Assessment of drinking water. Marianna Garfí. *Technical University of Catalonia (UPC).*

11:30-13:00 | Integration of agroecology and soil health in LCA

Chair: Ms. Neus Sanjuan

11:30- 11:45 Enhancing Life Cycle Assessment Methods for Agroecological Systems: Insights from a UK Case Study. Sally Westaway. *University of Reading.*

11:45-12:00 Mapping a Path to Climate Neutrality for Nebraska Agriculture: Approach and Findings. Martin Heller. *Blonk Consultants.*

12:00- 12:15 Organic farming expansion: identifying areas optimal for achieving EU organic agriculture goals using spatial-explicit LCA modelling. Anna Muntwyler. *Institute of Environmental Engineering, ETH Zurich.*

12:15- 12:30 Combining LCA results and soil indicators for long-term decision making: a case study with Californian cotton. Ellie Williams. *PRé Sustainability.*

12:30- 12:45 Evaluation of different fertilization scenarios in a vineyard, integrating the LCA methodology and the RothC model to analyze carbon dynamics in soil. Ana Cavallo. *University of Bologna.*

12:45- 13.00 Climate change impacts of organic crops in Canada. Shenali Madhanaroopan. *Riverside Natural Foods Ltd.*

14:30-16:00 | Sustainability in fisheries and aquaculture systems

Chair: Ms. Saioa Ramos

14:30- 14:45 How do illegal, unreported, and unregulated (IUU) fishing activities influence Life Cycle Assessment results? Ian Vázquez Rowe. *Pontifical Catholic University of Peru.*

14:45- 15:00 Building Life Cycle Inventories of IUU fishing activities in the Peruvian EEZ using remote sensing techniques. Eizo Muñoz. *PELCAN Pontificia Universidad Católica del Perú.*

15:00- 15:15 BASES: a biophysical assessment framework for valuating ecosystem services. Aurélie Wilfart. *INRAE*

15:15- 15:30 A Novel Approach to including Ecosystem-Scale Biodiversity Impacts of Wild Capture Fisheries in Life Cycle Impact Assessment. Arnaud Helias. Elsa - *INRAE*

15:30- 15:45 Operational Accounting of two Major Drivers of Marine Biodiversity Loss in LCA of Seafood Products. Aurore Wermeille. *Sayari*

15:45- 16.00 Expanding Life Cycle Impact Assessment to account for marine plastic emissions: a case study for the fishing industry. Cecilia Askham. *NORSUS AS.*

10 Sep | Lecture room 111

08:30-10:00 | LCA and footprint studies explained by companies

Chair: Ms. Clea Figueiredo

8:30-8:45 Assessing Oatly's Handprint. Vasiliki Takou. *Oatly AB.*

8:45-9:00 Using environmental footprint in dairy and plant-based dairy alternative sectors. Saioa Ramos. *AZTI.*

9:00-9:15 Creating Novel Value in the Pork Chain Through LCA-Quantified Carbon Reductions Enabled by Genetic Innovation. Lindsay Case. *PIC.*

9:15-9:30 Carbon footprint and decarbonization of a territorial agrifood research institute. Núria Martínez Soler. *IRTA*

9:30-9:45 A Comparative Life Cycle Assessment of RSPO certified and non-certified palm oil in Malaysia, Indonesia, Thailand, Colombia, and Nigeria, with inclusion of regionalisation, time Series, and diverse FFB Suppliers. Iris Helena Weidema. *2.-0 LCA consultants.*

11:30-13:00 | Circular food systems

Chair: Ms. Ulrike Eberle

11:30-11:45 Circular integration of insect bio-converting food waste into protein: A Life Cycle Assessment perspective on black soldier fly. Vikunu Khieya. *German institute for Food Technology e. V. (DIL)*

11:45- 12:00 Potential of insects for the nutrient circularity in food systems through the framework of Life Cycle Assessment. Sergiy Smetana. *DIL.*

12:00- 12:15 Framework to assess the potential of circular food system technologies. Clark Halpern. *Wageningen University.*

12:15- 12:30 Leveraging circular nutrients to improve the sustainability of urban agricultura. Maria Angelica Mendoza Beltran. *2.-0 LCA consultants.*

12:30- 12:45 An Ecodesign Framework for Sustainable Food Product Development. Beatriz Ines Queiroz Lopes da Silva. *DIL Deutsches Institut für Lebensmitteltechnik e.V.*

12:45- 13:00 Life Cycle Assessment for the eco-design of an innovative strategy for the valorization of whey in a bioeconomy approach. Lauranne Collet. *AgroParisTech - UMR SayFood*

14:30-16:00 | Cocoa and olive oil: sustainability assessments

Chair: Mr. Shabbir H. Gheewala

14:30-14:45 Land use change emissions linked to Ivorian cocoa exports. Carina Miriam Mueller. *Stockholm Environment Institute.*

14:45-15:00 A Landscape-scale Biodiversity Impacts Analysis of Côte d'Ivoire's Cocoa Cultivation Along Export Supply Chains. Shuntian Wan. *ETH Zürich.*

15:00-15:15 Social LCA to Support Decision-Making in the Cocoa Supply Chain. Naeem Adibi. *WeLOOP.*

15:15-15:30 Plastic biopolymers: a second life to olive oil. Almudena Hospido. *Universidade de Santiago de Compostela.*

15:30- 15:45 Environmental Assessment of the daily intake of polyphenols derived from Extra Virgin Olive Oil in the Mediterranean Population. Maria Vittoria Di Loreto. *Università Campus Bio-Medico di Roma.*

10 Sep | Lecture room Aula Magna

08:30-10:00| Life cycle inventory: modelling, databases and tools (I)

Chair: Mr. Bruno Notarnicola

8:30-8:45 A food biodiversity database has been born! Karin Morell. *RISE Research Institutes of Sweden.*

8:45- 9:00 The Biodiversity Value Increment method in the GaBi database. Jan Paul Lindner. *University of Augsburg.*

9:00- 9:15 Agro-SCAN: A new Multi-Regional Input-Output database for estimating cropland and calorie footprints of agri-food consumption. Neus Escobar. *Basque Centre for Climate Change (BC3).*

9:15- 9:30 Incorporating environmental impact data in existing agri-food software using API: a case study on Haifa NutriNet. Eline Willems. *Pre sustainability.*

9:30- 9:45 Promoting harmonization of life cycle inventory and food composition databases through semi-automatic standardization. Thomas Nemecek. *Agroscope.*

9:45- 10:00 Batch generation of agricultural LCIs: comparison of strategies. Patrik Henriksson. *Stockholm University.*

11:30-13:00 | Life cycle inventory: modelling, databases and tools (II)

Chair: Mr. Niels Jungbluth

11:30- 11:45 The big Climate Database - 500 food products. Jannick Schmidt. *2.-0 LCA consultants.*

11:45-12:00 Trase/Orbae: spatially-explicit supply chain mapping of forest risk commodities for scope 3 GhG emissions. Michael Lathuillière. *Stockholm Environment Institute.*

12:00-12:15 An open-source toolset to assess deforestation impact embodied in trade of bio commodities. Selene Eliana Patani. *ARCADIA SIT*

12:15-12:30 Development of the Crop System Efficiency Index. Iana Camara Salim. *Mérieux NutriSciences | Blonk.*

12:30- 12:45 Exploring HESTIA – a platform storing standardised data on agricultural production systems. Lucy Walker. *University of Oxford.*

12:45- 13:00 Development of an Italian Life Cycle Inventory Database of Agri-Food Products (ILCIDAF). Bruno Notarnicola. *Università degli Studi di Bari Aldo Moro.*

14:30-16:00 | Life cycle inventory: modelling, databases and tools (III)

Chair: Mr. Sergiy Smetana

14:30-14:45 The GRINS Project for the development of Life Cycle Inventory databases of beef cattle raised in Italy: preliminary results of the statistical dataset. Umile Gianfranco Spizzirri. *Università degli Studi di Bari Aldo Moro.*

14:45-15:00 Environmental assessment of swine and beef cattle sectors in Catalonia. Marta Ruiz. *IRTA.*

15:00-15:15 Cause-effect-based approach to inventory and model pig products in slaughterhouses. Annika Erjavec. *2.-0 LCA Consultants.*

15:15-15:30 The water footprint of global crop production – Country level and gridded LCI data for 175 crops from 1990 to 2019. Markus Berger. *University of Twente.*

15:30-15:45 Can we account for all agri-food chemicals in the impact assessment? Nyberg Carl Oskar Peter. *Stockholm Resilience Centre.*

15:45-16:00 Global pesticide application data for use in LCA. Yuyue Zhang. *QSA, DTU (Technical University of Denmark)*

18:00-19:00 | LCA Food Scientific committee meeting

(by invitation only)

10 Sep | Lecture room Aula Capella

08:30-10:00 | Ecolabelling

Chair: Mr. Ralph Rosenbaum

8:30- 8:45 A Comparison of Databases to assess the climate impact of labeled foods. Katrin Geburt. *Thünen Institute of Market Analysis.*

8:45-9:00 How to develop robust Sustainability labels for food? Learnings from the Environmental Footprint. Laura Garcia Herrero. *EC-JRC.*

9:00-9:15 Reducing complexity for a single score for food products. Felix Lücking. C*orsus corporate sustainability GmbH.*

9:15-9:30Product Environmental Footprints of organic food – status quo and improvement potentials. Antony Florian. *Öko-Institut e.V. Institute for Applied Ecology.*

9:30- 9:45 The environmental footprint of packaged food and beverage products in Australian supermarkets. Pankti Shah. *Deakin University.*

9:45-10.00 Ecolabeling, time for action; the French case. Vincent Colomb. *ADEME.*

11:30-13:00 | Communication of LCA results and integration of ESG criteria into business

Chair: Mr. Thomas Nemecek

11:30-11:45 From gut feeling to data driven decisions in Michelin starred restaurants. Ellie Williams. *PRé Sustainability.*

11:45-12:00 From LCA to on-the-ground impact- a case study with Californian cotton. Danai Mangana. *PRé Sustainability.*

12:00-12:15 Accounting for Overfishing in Environment Labelling – Comparing LCA and Fishery Science Methods. *Gregoire Gaillet. Sayari.*

12:15-12.30 Scaling LCA capabilities within companies. Peter-Jan Roose. *BrightWolves.*

12:30-12:45 Assessing impacts on biodiversity on an Aquaculture porfolio. Anne Asselin. *SAYARI.*

12:45-13.00 Biodiversity footprint for food products: a research agenda. Laura Garcia Herrero. *EC-JRC.*

14:30-16:00 |Topical discussion session 3

Delanie Kellon. *Global Feed LCA Institute (GFLI).*

Achieving alignment and transparency within the feed and food supply chain: embracing the complexity of new developments in impact assessment and modelling.

10 Sep | Paranimf Gallery and Cloister

17:30-18:00 | Poster session

10 Sep | Central Garden

18:00-19:00 Olive oil tasting

10 Sep | External location

20:00 | Scientific committee side event

WHERE?
WHEN? WHAT?
SPECIAL EVENT

11 Sep

11 Sep | Main hall

08:00-10:30 | Arrival and registration

11 Sep | Auditorium Paranimf

10:30-11:30 | Plenary 5

Chairs: Ms. Almudena Hospido and Mr. Ralph Rosenbaum

Business roundtable, with Ms. Sarah Sim (*Unilever*), Ms. Lisbeth Sofia Hernández (*OSI*) and Ms. Isabelle Privat *(Nestlé Institute of Agricultural Science)*

On the Road of Green Business Transition for Sustainable Food Systems

14:00-15:00 | Closing ceremony

Chair: Ms. Montse Núñez

11 Sep | Lecture room 112

08:30-10:00 | Novel foods and protein diversification (I)

Chair: Ms. Marta Ruiz

8:30-8:45 Greenhouse gas emissions of farmed Ulva and three conservation methods. Anna Frida Maria Axelsson. *RISE Research Institutes of Sweden.*

8:45-9:00 Life Cycle Assessment of microalgae production for food and feed: from light to dark. Abbigel Sadhu. *Deutsch Institute für lebensmittle (DIL).*

9:00-9:15Life Cycle Assessment of Oatly products compared to dairy equivalents for Oatly's key global markets. Elisabeth Keijzer. *Blonk Consultants*

9:15-9:30 Life cycle assessment of Beefy-9 and Beefy-R serum-free culture media for cell-cultivated beef production. Nicole Blackstone. *Friedman School of Nutrition Science and Policy, Tufts University.*
9:30-9:45 Life Cycle Assessment of Growth Factor Production for Cultivated Meat Through Molecular Farming. Taiwo Omotosho. *University of Helsinki.*

9:45- 10:00 Looking forward a sustainable insect meal value-chain: a LCA study on yellow mealworm meal production. Matteo Cordara. *CNR-STIIMA.*

11:30-13:00 | Novel foods and protein diversification (II)

Chair: Ms. Marta Ruiz

11:30-11:45 The nutritional and environmental consequences of replacing meat and dairy products with market-ready alternatives in recommended and average Swiss diets. Eric Mehner. *Agroscope.*

11:45-12:00 The sustainability and nutritional profile of alternative protein sources - Avoiding fallacy by including protein quality and nutrient density in LCIA of novel foods. Julian Quandt. *Augsburg University.*

12:00- 12:15A novel nutrient quality index for life cycle assessment of protein-rich foods. Ana Fernández Ríos. *University of Cantabria.*

12:15-12.30 Global environmental impact of replacing livestock with cell-cultured and microbial proteins. Mohammad El Wali. *University of Helsinki.*

12:30-12:45 Comparative Life Cycle Assessment of Innovative Plant-Based and Conventional Meat Products. Joel Bonales Revuelta. *EarthShift Global.*

12:45-13.00 Comparative assessment of alternative protein sources for meat substitution. Sergiy Smetana. *DIL.*

11 Sep | Lecture room 111

08:30-10:00 | Sustainable territories and economies

Chair: Ms. Almudena Hospido

8:30-8:45 LCA of territorial food supply scenarios: a spatialized and prospective approach. Lazare Deteix. *INRAE.*

8:45-9:00 Advancing the sustainability transformation of agriculture under the European Green Deal: An Agent-Based LCA for policymaking support. Raül López i Losada. *Centre for Environmental and Climate Science - Lund University.*

9:00-9:15 Comparative assessment of the land footprint and regulating ecosystem services embodied in the EU-27 consumption of vegetable oils: an environmental trade-off analysis among substitutes godos. Giovanni Bausano. *University of Padova.*

9:15-9:30 Mapping Deforestation Embodied in EU Bio-based Imports. Teresa Armada Bras. *European Commission, Joint Research Centre (EC-JRC).*

9:30-9:45 Carbon and Biodiversity Footprints of the Swiss food consumption. Wanner Silvan. *Zurich University of Applied Sciences.*
9:45-10.00 "Land-related biodiversity impacts in global agri-food supply chains a spatially-resolved assessment from 1995 to 2022". Schlosser Veronika. *Technical University of Munich.*

11:30-13:00 | Sustainability of food systems in developing and emerging economies

Chair: Mr. Llorenç Milà i Canals

11:30-11:45 Environmental and socio-economic analysis of the Ivorian market vegetables suburban systems. Moussa Dosso. *CIRAD UPR Recyclage et risque*

11:45- 12:00 Life Cycle Assessment of major Myanmar crop products using HESTIA. Valentina Caldart. *University of Oxford.*

12:00-12:15 LCA of the Ivorian cashew value chain as a key component of a corporate sustainability framework. Angel Avadí. *Cirad UPR Recyclage et risque.*

12:15-12:30 LCA of Robusta coffee production in Vietnam:How grafting and cycle lengths influence the impacts?. Sandra Payen. *Cirad.*

12:30- 12:45 LCA and carbon sequestration evaluation: cupuacu jam from agroforestry in the Amazon rainforest. Valeria Arosio. *Demetra.*

12:45- 13:00 Social Life Cycle Assessment of low -tech digesters in small-scale farms. Kurt Eduardo Ziegler Rodriguez. *Universitat Politécnica de Catalunya.*

11 Sep | Lecture room Aula Magna

08:30-10:00 | Life cycle impact assessment: new developments (I)

Chair: Mr. Ian Vazquez Rowe

8:30-8:45 Development of a regionalized dynamic weighting method for the environmental impact of alternative protein sources. Aditya Francis. *German Institute for Food Technology e. V.*

8:45-9:00 Ecotoxicity assessment of pesticide use based on Japanese PRTR data. Marika Muramoto. *Waseda University.*

9:00-9:15 Framework for evaluating animal welfare in life cycle assessments of diets. Sebastian Richter. *Research Institute of Organic Agriculture (FiBL)*

9:15-9:30 Biodiversity impacts of major crops – Spatially explicit characterization factors for 152 major crops. Julian Quandt. *Augsburg University.*

9:30- 9:45 Assessing the impact of vegetables on biodiversity in life cycle assessment. Pépin Antonin. *INRAE*

9:45-10:00 Characterization factors for land use impacts on terrestrial ecosystem quality considering intensities and fragmentation. Laura Scherer. *CML, Leiden University.*

11:30-13:00 | Life cycle impact assessment: new developments (II)

Chair: Ms. Laura Scherer

11:30- 11:45 The effect of El Niño events and climate change in the water scarcity characterization factors based on AWARE. Joan Sanchez Matos. *Pontificia Universidad Católica del Perú.*

11:45- 12.00 Drivers of trends and uncertainty in prospective water scarcity impact assessment with AWARE2.0. Georg Seitfudem. *CIRAIG, Chemical Engineering Department, Polytechnique Montreal.*
12:00-12:15 Resource criticality in LCIA: regionalised characterisation factors for water and land. Lazare Deteix. *INRAE.*

12:15-12:30 Regional characterization of the albedo impacts of agricultural land use at the global scale. Kathryn Loog. *CIRAIG, Polytechnique Montreal.*

12:30-12:45 Assessment of Agricultural Microplastic Emissions Impacts via Novel Comprehensive Multimedia Characterization Factors. Juliette Louvet. *CIRAIG, Polytechnique Montréal*

11 Sep | Lecture room Aula Capella

08:30-10:00 |Topical discussion session 4

Niels Jungbluth. *ESU-services Ltd.*

Ujué Fresán. *ISGlobal*

Recommendations for sustainable nutrition in the political debate.

11:30-13:00 |Topical discussion session 5

Roline Broekema. *Wageningen University and Research.*

Ecolabeling of food products is happening the devil is in the details.

12 Sep |Visit to IRTA's facilities

8:30- 18:00 IRTA La Ràpita

8:30- 18:00 IRTA Mas Badia and IRTA Monells

9:00- 16:00 IRTA Torre Marimon

(+ details here)

LIST OF POSTERS

14th International Conference

LCA FOOD 2024

HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

Lists of posters

	Sustainable livestock systems		
01	Reduction of greenhouse gas emissions from pig and poultry production in Japan by climate change mitigation measures	Akifumi Ogino	National Agriculture and Food Research Organization
02	Evaluation of Eco-efficiency in a Swine Production System in Post-weaning Phase: A Sustainability Approach	Clandio Ruviaro	Universidade Federal da Grande Dourados
03	Mitigation actions to reduce the carbon footprint of dairy sheep farming systems. Net benefits assessment from an Italian case study	Enrico Vagnoni	AGRIS
04	Environmental Sustainability Evaluation of PIC Genetics vs. Industry Average: North America	Greg Thoma	Resilience Services, PLLC
05	Life cycle assessment of alternative heating ventilation and air conditioning (HVAC) systems for poultry housing in Canada.	Leandra Vanbaelinghem	University of British Columbia - Okanagan
06	Life cycle environmental sustainability assessment of feed supplementation strategies to reduce enteric methane emissions in dairy cattle production	Lisbeth Mogensen	AArhus University
07	Life Cycle Assessment (LCA) of intensive sheep milk production system	Maria Ravani	Hellenic Agricultural Organization DIMITRA
08	Insect meal from rice by-product as low-impact feed in aquaculture: life cycle assessment of different insect diets	Michele Zoli	University of Milan
09	Best practices on scientific computing applied to dairy LCA models	Miguel Fernández Astudillo	2.-0 LCA consultants
10	Optimization of resource use and reduction of Environmental impact in different pig genetics	Miquel Andón Mañero	IRTA
11	Assessing the environmental impacts of beef production chains integrating grazing and landless systems	Raisa Margarita Tinitana Bayas	Universitat Politècnica de València
12	Strategies for mitigating the carbon footprint of milk production in the South and Southeast of Brazil	Vanessa Romário de Paula	Brazilian Agricultural Research Corporation
13	An environmental cost-benefit analysis of organic and non-organic sheep farming in Iceland	Vincent Merida	University of Iceland
14	Development of the National Environmental Sustainability and TechnologyTool (NESTT) for Canadian egg farmers	Vivek Arulnathan	University of British Columbia - Okanagan
15	Effects of early season drought on carbon footprint of milk in northern latitudes	Yajie Gao	University of Helsinki
16	Improving the sustainability of livestock system by using low carbon trace mineral sources	Yron Manaig	ANIMINE
17	Carbon footprint of Basque dairy farms under different production systems	Haritz Arriaga	NEIKER
	Food loss and waste: environmental impacts and solutions		
18	Circling the sandwich: A characterisation of food waste and its drivers in UK commercially-prepared sandwiches	Alexander Moores	Brunel University London
19	Exploring sustainable approaches to mitigate food waste and reduce environmental impact at the Ortomercato wholesale fruits and vegetables market in Milan	Andrea Casson	Università degli studi di Milano
20	Comparative Life Cycle Assessment of surplus food waste prevention through reuse and upcycling	Asimina Bairaktari	University of Copenhagen
21	Sustainability of the food supply chain: Impacts assessment of food losses at primary production stages of plant-based food products	Imane Uald Lamkaddam	UVic UCC - BETA TC
22	Farm level dominates losses in Swedish beef supply chain	Ingrid Strid	Swedish University of Agricultural Sciences

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22	Farm level dominates losses in Swedish beef supply chain	Ingrid Strid	Swedish University of Agricultural Sciences
	Sustainable cropping systems		
23	Assessing Land Use of an Indoor Vertical Farm, Microgreens production through Life Cycle Assessment	Ana Cavallo	University of Bologna
24	Improving environmental impacts of apple	Ariane Grisey	CTIFL

25	Ex-ante LCA of Rooftop Greenhouse Vegetable Production in Barcelona	Diego Macall	ICTA-UAB
26	Controlled Environment Agriculture in the City of Barcelona	Diego Macall	ICTA-UAB
27	Life cycle assessment of a building-integrated rooftop aquaponics farm	Elisabet Henriksson	IVL Swedish Environmental Research Institute
28	Life cycle assessment of mycorrhizae production	Emma Cecilia Girón Rojas	Universitat Politècnica de Catalunya
29	Transitioning from Conventional to Zero Chemical Nitrogen Grass Production: Promoting Healthier Food Systems in the Republic of Ireland	Everton Vogel	Universidade Federal da Grande Dourados
30	What is the climate and environmental impact of organic food? A meta-analysis of food LCA studies	Fatemeh Hashemi	Aarhus University-Department of Agroecology
31	Life cycle assessment of peat substitutes: sustainability of Danish growing media	Fatemeh Hashemi	Aarhus University-Department of Agroecology
32	Life Cycle Assessment on Semi-closed Lettuce Greenhouses	Fatima Marashi	Van der Hoeven Horticultural Projects B.V.
33	Life Cycle Assessment (LCA) of seed-to-fruit tomato to promote renewable energy sources and sustainable agricultural production	Georgios Ntinas	Hellenic Agricultural Organisation-Dimitra
34	Life Cycle Assessment of a Container Farm in Toronto, Canada	Goretty Dias	University of Waterloo
35	Growing Green: Environmental Assessment of Struvite Fertilization in Hydroponic Tomato Cultivation	Guido Evangelista	Universitat Autònoma de Barcelona
36	Applicability of LCA to analysing the biodiversity impacts of different coffee production systems	Jasmine Savallampi	LUT University
37	Displacing imports and impacts with peri-urban agriculture: An integrated assessment of local produce in the Metropolitan Area of Barcelona	Juan David Arosemena	Universitat Autònoma de Barcelona (UAB)
38	The use of biochar to offset the lifecycle greenhouse gas emissions of sugarcane produced in Brazil	Lucas Pereira	Embrapa Environment
39	Impact of installing a cashew orchard in an area with native vegetation in Brazil	Maria Cléa Brito de Figueirêdo	Embrapa Tropical Agroindustry
40	Addressing climate change, blue water scarcity and toxicity-related impacts of citrus tree nurseries	María Inés Cabot Lujambio	Unión de Productores y Exportadores de Frutas de Uruguay
41	Identifying environmental hotspots in malting barley production: an Italian case study	Maria Vittoria Di Loreto	Università Campus Bio-Medico di Roma
42	Environmental impact scenarios for the introduction of True Potato Seed-based starting material in ware potato cultivation practice	Roel Helmes	Wageningen Economic Research
43	Data science integration with LCA modelling: a review with a focus on spatial-temporal variability in agriculture	Sofia Bahmutsky	University of British Columbia
44	Environmental evaluation of digital and connectivity solution for agricultural application with LCA	Valtteri Manninen	Seinäjoki University of Applied Sciences
45	Carbon and water footprints of an oat-based drink	Victor Rancaño Garcia	IRTA
	Innovations in food production beyond the farm gate		
46	Emerging technologies in agriculture – an Environmental and Social LCA assessment	Annabel Oosterwijk	Wageningen Economic Research
47	Optimising Downscaled Food Chains for Sustainable Resource Use: A Comprehensive Case Study on Tomato Juice	Beatriz Ines Queiroz Lopes da SIlva	DIL Deutsches Institut für Lebensmitteltechnik e.V.
48	Simplified parametrized LCA user-friendly tool to eco-design returnable bottles scenarios	Caroline Penicaud	INRAE
49	Optimizing Food Transportation Boxes	Catarina Basto-Silva	PIEP
50	Life Cycle Assessment comparing Conventional and Active Packaging for Fresh-cut salads	Diana Alexandra Murcia Velasco	Universidad de Valladolid

51	Integrated Assessment of E-LCA and S-LCA based on a techno economic assessment of side stream valorization in the brewery industry	Dimitri Chryssolouris	ZHAW Zurich University of Applied Sciences
52	Technical and Environmental Assessment of Mushroom Production and its Inputs	Éamonn Walsh	Teagasc
53	Life cycle assessment of processed peas, lentils, and beans products in Canada	Jannatul Ferdous	University of British Columbia
54	Carbon Footprint of Pasteurized Foods: A Case Study on Salmorejo Production	Javier Rocher Morant	Universitat Politècnica de Valencia
55	Promoting Food Safety and Sustainability through the revalorization of a winery by-products in fermented Sausages	Mariluz Latorre	Universitat de Barcelona
56	Environmental assessment of multilayer flexible coffee packaging: italian case study	Matteo Cigada	Politecnico di Milano
57	Design of a sustainable product in gastronomy: integrating LCA and consumer-centered design	Paula Toran Pereg	BCC Innovation
	Combined nutritional and environmental assessment of foods and diets		
58	LCA as a tool to unravel the challenges of algae biomass production	Lais G. Speranza	GreenCoLab
59	Are quinoa-based snacks a healthier and more ecofriendly alternative to their traditional counterparts? A comparative study based on nutritional life cycle assessment	Ana Fernández Ríos	University of Cantabria
60	Not presented		
61	Perceptions of food and food sustainability among college students in the field of food science	Carmen Vidal	Universitat de Barcelona
62	Knowledge and perceptions of food sustainability in a Spanish university population	Carmen Vidal	Universitat de Barcelona
63	Sustainability on the plate- Footprint Reduction and Nutritional Improvement through Meal Optimization in University Canteens	Dimitri Chryssolouris	ZHAW Zurich University of Applied Sciences
64	Not presented		
65	Eating habits and sustainability:environmental impacts of the consumption of fruit and vegetables	Ilenia Bravo	University of Cassino and Southern Lazio
66	Assessing the climate impacts of different protein sources: an nLCA approach based on system expansion	Ilkka Leinonen	Natural Resources Institute Finland
67	Climate and nutrition benefits of diets compatible with 1.5°C lifestyles	Laura Scherer	Leiden University
68	Assessing the Nutritional Attributes of Plant-Based Meat Analogues and conventional Meat Products: A Comparative Study	Mariluz Latorre	Universitat de Barcelona
69	Increasing healthier and more sustainable food consumption at daycare centers	Marita Kettunen	Natural Resources Institute Finland (Luke)
70	Product grouping and nutrient selection for nutritional functional units in the product-group specific approach to nutritional Life Cycle Assessment	Merja Saarinen	Natural Resources Institute Finland
71	Prediction of oil losses with a filter (winter) cake during the sunflower oil winterization	Ranko Romanic	Faculty of Technology Novi Sad, University of Novi Sad
72	Investigation of wax content in sunflower winter cake	Tanja Luzaic	University of Novi Sad, Faculty of Technology Novi Sad
73	Novel Sustainable Food Profiling Model to evaluate the absolute environmental sustainability of foods while considering nutritional quality	Venla Kyttä	Natural Resources Institute Finland (Luke)
74	Eating Within Planetary Limits- Life Cycle Assessment of Food Waste Prevention and Dietary Shifts in Danish Universities	Xun Zhou	University of Copenhagen

75	The Potential of National Dietary Guidelines to Meet Planetary Boundaries: A Life Cycle Assessment of Canada's Food Guide	Xuyang Guo	University of Waterloo
76	Life Cycle Assessment of Plant-Forward Meals at Canadian University Campuses	Xuyang Guo	University of Waterloo
	Greenhouse gas accounting and reporting		
77	Potential Climate Change impact associated with the milk production chain. Is it possible to make a complete assessment?	Anna Mourad	Independent scientific researcher
78	Radiative forcing climate footprints in China's agri-food systems	Huang Jing	Southwest University of Science and Technology
79	Determination of N2O emission factor in hydroponic cultivation with alternative nitrogen fertilization sources: the case of Struvite and human urine	Jonatan Manosalva	ICTA
80	Carbon footprints for food systems: A readiness assessment	Koen Deconinck	OECD
81	Footprint Pro Carbono: A RobustTool for Carbon Accounting of Agricultural Products	Marilia Ieda da Silveira Folegatti	Embrapa Environment
82	Evaluating methods to estimate carbon sequestered in biomass and its climate change effects	Muhammad Ahmed Waqas	Aarhus University
83	An analysis of the mathematical logic on IPCCTier 1 andTier 2 methods in soil organic carbon storage estimation	Teng Hu	University of Helsinki
	Life cycle sustainability assessment of food systems		
84	A study of environmental, social and economic sustainability in vegetable and fruit production in Norway	Erik Svanes	NORSUS- Norwegian Institute for Sustainability Research
85	Environmental, economic and social impact of contemporary dairy industry	Dimitra - Nektaria Fragkouli	National Technical University of Athens (NTUA)
86	Life cycle sustainability assessment (LCSA) of goat meat in Western Nepal	Ira Bhattarai	Natural Resources Institute Finland (Luke)
87	Environmental, technological, and economic evaluation of precision agriculture farming: A review of the life cycle assessment and costing literature	Sofia Bahmutsky	University of British Columbia
	Integration of agroecology and soil health in LCA		
88	Assessing Sustainability of Land Use:The SHARInG-MeD project	Carlo Russo	Dipartimento di Scienze Veterinarie - Università di Pisa
89	Charting a research agenda for modelling agroecological practices in Life Cycle Assessment: insights from an interdisciplinary collaboration	Cecilia Casonato	ALMA MATER STUDIORUM - Università di Bologna
90	NOT PRESENTED		
91	Environmental trade-offs of Bio-Based Fertilizers application: Adaptability of non-LCA impacts and methods into LCA	Jorge Senan Salinas	UVIC-BETA
92	Species richness of vascular plant species within regenerative farms in the Netherlands as a basis for updated land-stress based biodiversity impacts with life cycle assessment.	Natasha Järviö	LUT university
93	Modelling the environmental impacts of Swiss mixed agroforestry systems	Philipp Oggiano	Research Institute of Organic Agriculture FIBL Switzerland
94	Using participatory approaches for the development of LCA methodology aiming at assessing crop-livestock interaction and legume-based cropping systems	Pietro Goglio	Department of Agricultural, Food and Environmental Science, University of Perugia
95	Estimating SOC change rates from agricultural management. A systematic review and meta-analysis of long-term experiments.	Raül López i Losada	Centre for Environmental and Climate Science, Lund University

	Sustainability in fisheries and aquaculture systems		
96	Identifying current trends in the environmental impacts linked to fishmeal and fish oil production in Peru	Alejandro Deville	Pontificia Universidad Católica del Perú
97	LCA of artisanal fishing in the Union of the Comoros	Angel Avadí	Cirad UPR Recyclage et risque
98	Navigating the environmental impacts of Manila clam seed production in hatcheries: combining innovation with resources' recovery	Arianna Martini	CREA
99	Can the transition from mono- to polyculture reduce aquaculture environmental footprint? An LCA approach proposed within the BLUEBOOST project	Arianna Martini	CREA
100	Not presented		
101	Hidden water scarcity footprint of salmon aquaculture feed in Iceland	Clara Maria Vasquez Mejia	University of Iceland
102	Sustainability Assessment of Octopus industry in Portugal: An Environmental Life Cycle Perspective from Two Key Regions	David Alonso Baptista de Sousa	ANFACO-CECOPESCA
103	Environmental performance of oyster farming technologies in Maine, USA	Friederike Ziegler	RISE Research Institutes of Sweden
104	Constraints in supply of marine capture fish: empirical evidence and substitution effects	Giovanni Codotto	Aalborg University
105	LCA of fish oil production: inclusion of biotic resource depletion in impact assessment	Gregoire Gaillet	Sayari
106	Evaluating the Environmental Performance of Salmon Aquaculture with Microbiome Application	Hafiz Usman Ghani	Natural Resources Institute Finland (Luke)
107	Assessing Environmental Impacts: Mussel Imports at La Spezia Farms	Letizia Caroscio	University of Bologna
108	Comparative analysis of aquaponic and hydroponic production: a Life Cycle Assessment (LCA) study	Maria Ravani	Hellenic Agricultural Organization DIMITRA
109	Evaluating the environmental impacts of seaweed cultivation and derived products	Muhammad Ahmed Waqas	Aarhus University
110	Assessing cumulative fishing impacts on marine ecosystem quality	Nico Mumm	Corsus - corporate sustainability GmbH
111	Assessing the environmental impacts of conventional and organic scenarios of rainbow trout farming in France	Pouil Simon	INRAE
112	Sustainability of luxury food: LCA of sturgeon caviar and meat	Riccardo Napolitano	CREA

	LCA and footprint studies explained by companies		
113	A tailored carbon footprinting solution to enable farmer engagement and portfolio assessment: A pilot study for Nomad Foods	Eline Willems	Pre sustainability
114	Application and value of life cycle sustainability assessment for food ingredients portfolio	Eleni Moutousidi	Corbion
115	Environmental food impact: semi-specific LCA approach for food sector industrials and their supply chain	Jaune Vaitkeviciute	FoodPilot
116	Establishing a harmonized environmental footprint approach in the European Fresh Produce industry	Jeroen Weststrate	Wageningen University and Research
117	SMEs experience in assessing the Environmental Footprint using an easy-to-use life cycle-based tool	Maite Cidad	AZTI
118	Returnable glass bottles vs single-use alternatives: the case of "Le Fourgon" company	Naeem ADIBI	WeLOOP
119	Can Chained Life Cycle Analysis be economically viable?	Sampsa Nisonen	Luke Natural Resources Institute Finland

	Circular food systems		
120	Circular Economy for Food and Environmental Sustainability: Integrating Plastic Recycling and Banana Waste Valorization in the Canary Islands (Spain) through LCA	Alba Bala	ESCI-UPF
121	Circularity and sustainability metrics for Italian agri-food systems: the CIRCULAGRIS project	Alberto Simboli	University “G.d’Annunzio” of Chieti-Pescara
122	An assessment framework to incorporate circularity, sustainability, and systems thinking in transformative food systems innovation	Alexander Moores	Brunel University London
123	Analyzing the uses of biomass and land at the Agro-Food-Waste System level to assess the environmental benefits of livestock-based circularity	Alvanitakis Manon	CIRAD
124	Assessing the role of livestock within circular food systems	Clark Halpern	Wageningen University
125	Methodological framework to evaluate circularity in livestock systems	Guillermo Pardo Nieva	Basque Centre for Climate Change - BC3
126	Nature-positive harvest and processing of green tide sea lettuce into feed and food-grade proteins	Irsa Anwar	University of Copenhagen
127	Fertilisers from fish processing and aquaculture production waste: An ecofriendly alternative for crop production?	Landert Jan	Research Institute of Organic Agriculture FiBL
128	Modelling and assessment of circular scenarios in local sheep supply chains: the MAX-SHEEP project	Raffaella Taddeo	Department of Economic Studies - University "G. d
129	Environmental Perspectives on Wine Packaging: A Comparative Study of Single-Use and Reusable Options	Sahar Azarkamand	UNESCO Chair in Life Cycle and Climate change ESCI-UPF
130	LCA of hazelnut by-products valorization through animal feed application	Urko Goya Piñeiro	University of Zaragoza
	Cocoa and olive oil: sustainability assessments		
131	Olive pit:Transform a waste product into a valuable resource	Catarina Faria	PIEP
132	Life Cycle Assessment of organic chocolate products in Peru	Ian Vázquez Rowe	Pontificia Universidad Católica del Perú
	Life cycle inventory: modelling, databases, and tools		
133	Input-output based life cycle inventory for staple foods in Indonesia	Adisa Ramadhan Wiloso	University of Helsinki
134	Improved Life Cycle Inventory Data for Food Packaging in a Public Database for Eco-design and Food labelling	Audoye Pauline	CTCPA
135	Not presented		
136	Making a consistent environmental footprint database for the agri-food sector: Agri-footprint	Carolina Carrillo Diaz	Blonk Sustainability
137	Improving data availability for agricultural life cycle inventories through a common data standard	Christian Schader	FiBL
138	Towards streamlined and transparent tools in the agri-food sector: a user-friendly benchmarking protocol to align tools with LCA standards	Eline Willems	Pre sustainability
139	NewTools- social categories as a part of a food scoring system	Hanne Møller	NORSUS
140	Harvesting Precision: Developing an Uncertainty Strategy for an Agricultural Carbon Footprint Calculator	José Paulo Pereira das Dores Savioli	Embrapa
141	FarmLCA: a LCA tool for capturing the complexity of agro-ecological farm systems	Laura de Baan	FiBL
142	Recommendations for ISO-compliant allocation in agri-food scenarios	Nicole Bamber	University of British Columbia, Okanagan campus
143	An overall system perspective on food (processing) residues in life cycle inventories	Niels Jungbluth	ESU-services Ltd.
144	Completeness issues in LCA data results in underestimated results	Patrik Henriksson	Stockholm University
145	Novel Emissions Database for Enhanced SBTi FLAG and Land-Related Emissions Accounting at Scale	Piers Cooper	Altruistiq (EXPANDING CIRCLE LTD)

146	AGRIBALYSE, the French LCI database: a reference tool for the transition of food systems	Audrey Rimbaud	ADEME
147	Enhancing Accessibility and Reliability of LCA-Based Tools: A Case Study of a Climate Scan for Dairy Farms in Flanders	Sacré Anne-Sophie	EV ILVO- Technology and Food
148	Flexible, efficient and consistent agricultural inventory modelling with SALCA	Thomas Nemecek	Agroscope
149	Revealing persistent trends in LCA: a study of vineyard supply chain dynamics	Valentina Niccolucci	Univesity of Siena
150	Climate impact dataset to promote sustainability of food service operators in Finland – learnings from dataset creation	Venla Kyttä	Natural Resources Institute Finland (Luke)
151	Optimizing agroecosystem biodiversity: a review and framework for food system modelling	Wendy Jenkins	Wageningen University and Research
	Ecolabelling		
152	Reliable and meaningful environmental footprint communication to consumers – harmonization in Finland	Hannele Heusala	Natural Resources Institute Finland Luke
153	The status of ecolabels considering climate change for food products in Europe	Huayang Zhen	Aarhus University
154	Identification of most important environmental impacts of food	Ulrike Eberle	corsus - corporate sustainability GmbH
	Communication of LCA results		
155	The carbon footprint of Irish seafood	Benen Dallaghan	bord iascaigh mhara
156	A practitioner's role against eco-amplification- a case study with California cotton	Danai Mangana	PRé Sustainability
157	Calculating pre-crop effects from legume production in Norway by using system expansion	Erik Svanes	NORSUS
158	Navigating the Path of Climate Transparency:Oatly's Product Climate Footprint Declarations	Estefania Herrera Osorio	Oatly
159	Advancing and Automating LCA for Sustainable Agrifood Production with OpteinicsTM	Irene Rosique Conesa	Chemovator GmbH
160	Towards more harmonized PEF wise food LCAs in Finnish context	Juha-Matti Katajajuuri	Natural Resources Institute Finland
161	13. Ecolabelling of food products – exploring interactions between methodological challenges and stakeholder interests	Marius Rödder	corsus - corporate sustainability GmbH
162	LCA: value for businesses, beyond compliance	Peter-Jan Roose	BrightWolves
163	Defining benchmarks for the downstream supply chain stages for LCA-based voluntary sustainability standards: case study of the NZ avocado sector	Sarah McLaren	Massey University
	Integration of Environmental, Social, and Governance criteria (ESG) into business strategies		
164	Combining environmental and social LCA in brewing industry	Eugène Fremond	SicencesPo Rennes
165	How can an LCA support investors' and companies' decisions to align impact and financial return?	Laure Peronnin	Astanor Ventures
	Novel foods and protein diversification		
166	Mass-based & Nutritional Life Cycle Assessment (nLCA) of Crickets as Human Food	Aditya Francis	German Institute for Food Technology e. V.
167	Environmental impacts of Acheta domesticus flour production with different rearing management	Alejandro Corona Mariscal	Universitat Politecnica de Valencia
168	Social Life Cycle Analysis for vegan burger production compared to meat burger	Angeliki Petridi	DIGNITY
169	The relevance of methodological choices and nutritional value in sustainability analyses of waste-to-protein pathways	Ashley Green	ETH Zurich
170	Microbial Protein from Agro-Industrial Waste: A Century of Progress	Cresha Gracy Nadar	University of Queensland
171	Sustainability trade-offs in designing three protein production lines for alternative proteins production and processing	Edoardo Desiderio	RISE Research Institutes of Sweden

172	Methodological framework for consequential life cycle assessment of pea fractionation in Canada for increasing production of pea protein	Jannatul Ferdous	University of British Columbia
173	The environmental impact of mycoprotein-based meat alternatives compared to plant-based meat alternatives: a systematic review of life cycle assessments	Maria Shahid	The George Institute for Global Health
174	Assessing the Environmental Costs of different Protein sources	Sahar Azarkamand	UNESCO Chair in Life Cycle and Climate change ESCI-UPF
175	Are Novel Foods sustainable for the planet and human health? A Literature Synthesis of Life Cycle Assessments.	Silvia Zingale	University of Catania
176	Protein supply with controlled environmental agriculture system: a life cycle assessment	Zhengxuan Wu	Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT
	Sustainable territories and economies		
177	Modelling resilience of European Agriculture utilizing synergism of Life Cycle Assessment, macro-economic model (MAGNET) and dynamic crop and livestock models	Annabel Oosterwijk	Wageningen Economic Research
178	Assessing food consumption patterns in Spain towards LCA of diets: pathways for a just transition	Chiara De Tomassi	Basque Centre for Climate Change (BC3)
179	Brazilian biodiesel mandate: challenges and limitations in future scenarios	Diego Ribeiro do Amaral	Embrapa
180	Environmental Rebound Effects of Embracing Sustainable Diets- A Macroscopic Exploration of Consumption Patterns in Belgium	Edgar Towa	Université libre de Bruxelles
181	LCA of local food chains: the compromise of environmental sustainability	Gerard-Simonin Hélène	Institut Agro Dijon
182	Food system transformation potential of house gardening across Europe – quantifying potential environmental benefits with hybrid Life Cycle Assessment	Jan Matuštík	University of Chemistry and Technology, Prague
183	Land use, crop rotation and emissions consequences of a European transition from meat towards legume-based foods	Sophie Saget	Trinity College Dublin
184	Exploring willingness to pay for healthier and more sustainable diets in Iceland: A four-part contingent valuation study	Vincent Merida	University of Iceland
185	Environmental assessment of intermediate processes in fresh vegetable supply chain: a case study of tomatoes in Japan	Yuki Sano	Institute for Future Initiatives, the University of Tokyo
	Sustainability of food systems in developing and emerging economies		
186	Some environments aspects of Brazilian typical meal preparation in restaurants	Anna Mourad	Independent scientific researcher
187	Environmental assessment of an artisanal production system of minipigs in Brazil	Ariadna Bàllega Calvo	Institute of Agrifood Research and Technology
188	Chosing the most promising technological route for extracting collagen from tilapia skin, considering environmental and economic criteria	Ednaldo Benicio de Sá Filho	Universidade Federal Do Ceará
189	Integration of industrial process modeling with environmental assessment applied to a Mango Biorefinery layout	Ednaldo Benicio de Sá Filho	Universidade Federal Do Ceará
190	Life Cycle Assessment applied to biochar from green coconut husk	Ednaldo Benicio de Sá Filho	Universidade Federal Do Ceará
191	Comparison of life cycle environmental impacts of a traditional roof and a green roof using non-conventional food plant	Florence Rezende Leite	São Paulo State University (UNESP)
192	Socially-oriented approach for LCI construction: accounting Environmental Footprints in Peruvian Agroforestry Systems	Lucía Rucoba	PUCP - PELCAN
193	Compiling a Life Cycle Inventory for avocado production in Ecuador: challenges and future steps	Margarita Baquero	KU Leuven
194	Ex-ante environmental impact assessment of extracting natural colorant from dragon fruit	Maria Cléa Brito de Figueirêdo	Embrapa Tropical Agroindustry

195	Ex-ante Life Cycle Assessment of the dry methanization process of organic waste from horticultural wholesalers	Maria Cléa Brito de Figueirêdo	Embrapa Tropical Agroindustry
196	Greening Growth: Expanding Data Perspectives from Social Life Cycle Assessment Databases for Agricultural Innovation in Ghana	Monika Cera	Institute of Sustainability in Civil Engineering, RWTH Aachen University
197	Environmental performance of intensive and alternative soybean production systems in Minas Gerais and Paraná states, Brazil	Reussite Malembaka	ETH Zurich
	Life cycle impact assessment: new developments		
198	Challenges in creating Product Category Rules for biobased fertilizers aligned with Product Environmental Footprint method	Hannele Heusala	Natural Resources Institute Finland Luke
199	Taxa and reference state in LCA methods for biodiversity impact assessment	Huayang Zhen	Aarhus University
200	Biodiversity efficiency vs. effectiveness at the product level	Jan Paul Lindner	University of Augsburg
201	Phylogenetic diversity as an indicator for biodiversity loss	Jannick Schmidt	2.-0 LCA consultants
202	Applying existing four biodiversity assessment methods to Agribalyse : similarities and differences among methods ?	Melissa Cornelus	INRAE
203	Regional characterisation factor to assess biodiversity loss in high diversity areas	Nelson Sinisterra Solís	Universitat Politècnica De València
204	Foundation Earth Methodology	Nicola Organ	Foundation Earth
	Last minute		
205	Urban symbiosis of a Vertical Hydroponic Farm and a Mushroom Farm: an environmental assessment	Loris Mazzaferro	

ABSTRACTS

14th International Conference

LCA FOOD 2024

HEALTHY FOOD
SYSTEMS FOR
A HEALTHY PLANET

Plenary Sessions

9 Sep

Auditorium Paranimf

09:00-10:00 | Plenary 1

Chair: Ms. Montse Núñez

Ms. Paz Fentes. *Deputy Director General of Herbaceous and Industrial Crops and Olive Oil of the Ministry of Agriculture, Fisheries and Food*

Mr. Joan Gòdia Tresanchez. *Director General of Agri-Food Companies, Quality, and Gastronomy, Government of Catalonia.*

Mr. Leo Bejarano i Manjón. *Head of the Catalan Office for Climate Change, Government of Catalonia.*

Public policies for sustainable food systems in Spain and Catalonia

10:30-11:30 | Plenary 2

Chair: Ms. Anna Pallí Güell

Mr. Joan David Tàbara. *Global Climate Forum, Berlin, and Autonomous University of Barcelona*

From less negative impact cycles to regenerative spirals. How can we build the conditions for the emergence of net-positive tipping points in global systems?

10 Sep

Auditorium Paranimf

10:30-11:30 | Plenary 3

Chairs: Ms. Carmen Vidal and Ms. Mariluz Latorre

Mr. Joan Romanyà. *University of Barcelona*

Healthy soils for a healthy life.

10 Sep

Auditorium Paranimf

16:30-17:30 | Plenary 4

Chairs: Ms. Alba Bala and Mr. Llorenç Milà i Canals

Roundtable with Ms. Louise Fresco *(Wageningen University & Research -WUR)* and Ms. Marta Rivera-Ferre *(INGENIO -CSIC-UPV-)*

Sustainable food systems: what, why, how?

11 Sep

Auditorium Paranimf

10:30-11:30 | Plenary 5

Chairs: Ms. Almudena Hospido and Mr. Ralph Rosenbaum

Business roundtable, with Ms. Sarah Sim (*Unilever*), Ms. Lisbeth Sofia Hernández (*OSI*) and Ms. Isabelle Privat *(Nestlé Institute of Agricultural Science)*

On the Road of Green Business Transition for Sustainable Food Systems

Plenary 1

Ms. Paz Fentes

Deputy Director for Arable Crops and Industrial Crops and Olive Oil, Ministry of Agriculture, Fisheries and Food of the Government of Spain

Mr. Joan Gòdia

Director General of Agri-Food Companies, Quality, and Gastronomy, Government of Catalonia

Mr. Leo Bejarano

Head of the Catalan Office for Climate Change, Government of Catalonia

Public policies for sustainable food systems in Spain and Catalonia

The three public policy speakers will discuss, within their respective competences in Spain and Catalonia, environmental policies and strategies for mitigating and adapting to climate change. They will address public initiatives aimed at reducing the primary sector's environmental footprint and fostering more sustainable agrifood systems through the entire value chain, from production to consumption. Additionally, they will cover measures to protect biodiversity, soil health, and air, continental and marine water quality. The speakers will also explain current policies facilitating the communication and disclosure of environmental information, including primary sector inventory data and carbon farming sequestration schemes.

Plenary 2

Keynote speaker

Joan DavidTàbara, Autonomous University of Barcelona

From less negative impact cycles to regenerative spirals. How can we build the conditions for the emergence of net-positive tipping points in global systems?

How can we accelerate deep social-ecological transformations to not only avoid the catastrophic effects of negative global environmental change but mostly to regenerate the life-support systems that secure the safe and just development of human societies in the long term? What particular strategic, and apparently small additional actions, can we implement to yield greater net-positive systemic effects on global sustainability? In this talk, I will address these broad questions by focusing on the notion of net-positive tipping points and also, by briefly exploring some of the implications that the rising narrative on regenerative sustainability could have for those working on LCA. Net-positive tipping points can be defined as those thresholds of development in which additional, deliberate actions taken by individuals, organisations or societies not only manage to reduce the socioenvironmental harm inflicted from their daily activities (with regenerative effect <0), or achieve neutral outcomes (=0), but above all, manage to fast regenerate and enhance the conditions that make life in all its diversity flourish on Earth in the long term. To achieve such regenerative thresholds, I will argue that positive synergies and self-propelling virtuous feedbacks between improvements in social systems conditions (e.g., social equity, inclusion and access) and improvements in biophysical ones (e.g., environmental quality and functional integrity) need to be continuously institutionalised. Based on my recent interdisciplinary research, I will share some insights on how this could be achieved and how I understand the role transformative science and knowledge plays in this critical endeavour.

Plenary 3

Keynote speaker

Joan Romanyà, University of Barcelona

Healthy soils for a healthy life

Soils provide the basis for human food supply and are key to the environment, with implications for biodiversity conservation and air and water quality. While well-preserved forest and grassland soils can be considered natural soils, intensively used agricultural soils are generally vulnerable to degradation due to reduced organic matter content, exposure of their surface mineral layer to the atmosphere and to climate change. The amount of land used for agriculture is currently increasing and accounts for 12.9 % of the habitable land. This practice increases greenhouse gas emissions and threatens biodiversity conservation and the environmental services provided by forest and grassland soils. Therefore, in the context of climate change, it is important to conserve grassland and forest soils and to achieve good agronomic productivity while adapting agricultural soils to climate change. Our aim is to define land management strategies and scalable agricultural practices that promote resource circularity and enhance the services of plant soil biota in the agroecosystem to grow healthy crops in a healthy environment. Soil biota is generally sustained by soil organic matter (SOM), but since the Green Revolution SOM levels in agricultural soils have continued to decline, mainly due to the intensification of tillage practices, monocultures and reduced use of organic fertilizer. While in many cases the reduction of SOM in agricultural soils may be reversible, soils become vulnerable to degradation when SOM levels approach the degradation threshold. In the Mediterranean context we have seen that this occurs in dry areas especially in carbonate rich soils. While the organic matter levels have been used as a single stand-alone indicator of soil quality, the complexity of the soil microbiome and associated processes requires the development of advanced indicators of soil quality that include SOM quality and soil biome composition. Soil microbiota contribute to soil aggregation, which in turn, protects organic matter from decomposition. In forests and grasslands, the soil biome lives on carbon- rich plant residues coming from roots or litter, which contribute to the microbial mobilisation of nutrients held in organic matter within soil aggregates. In contrast to this biological functioning, nutrient mobilisation in most agricultural soils is based on mechanical breaking of soil aggregates and the use of nutrient-rich fertilizers, such as mineral or organic nutrient-rich materials, to which the natural soil biota is not well adapted. In fact, most composts, manures and slurries are richer in nitrogen than any plant residue. Yet the dung of grazing animals is a nitrogen rich source occurring in grassland soils. Our challenge is to find scalable, circular ways to maintain or increase yields while regenerating soils. To do this, we need to develop no-till or reduced tillage practices in the different farming systems and promote the use of plant residues, polycrops and green manures combined with the moderate use of composts and manures.

Plenary 4


Roundtable with

Louise Fresco (Wageningen University)

and **Marta Guadalupe Rivera Ferre** (CSIC-UPV)

Sustainable food systems: what, why, how?

A truly interactive roundtable on "Sustainable Food Systems: What, Why, and How" features Louise Fresco and Marta G. Rivera. Louise Fresco will discuss the future of agriculture amid geopolitical tensions, climate challenges, and the need for innovation. Marta G. Rivera will highlight how food systems contribute to unsustainability and inequality, emphasizing the need for a complex systems approach to achieve social and ecological outcomes. She will also explore current scientific trends and research questions aimed at addressing these challenges through transdisciplinary methods. Questions from the audience will be woven into the interactive debate.

Plenary 5



Roundtable with

Sarah Sim (Unilever),

Lisbeth Sofia Hernández (OSI),

and **Isabelle Privat** (Nestlé)

On the Road of Green BusinessTransition for Sustainable Food Systems

A roundtable focusing on the food industry perspective "On the Road of Green Business Transition for Sustainable Food Systems" provided by Sarah Sim (Environmental Sustainability Programme Director in Unilever's Safety and Environmental Assurance Centre), Lisbeth Hernandez (Sustainability Officer for OSI Group in all European markets), and Isabelle Privat (Head of Plant & Nutrition Department at the Nestlé R&D Center). Three experts from three large, multinational companies, leading in different areas within the global food system, will share their company's angle on the sustainable transition of food systems, and their role and concrete actions in this process. The audience will be invited to interact, ask questions and discuss, for example, which obstacles and bottlenecks their companies are facing on their path, what roles science and particularly LCA play in their strategic decisions, or how they envision a sustainable food system.

ORAL PRESENTATIONS

Sustainable livestock systems (I)

The contribution of dam evaporation to Brazilian cattle water use

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1. INTRODUCTION

Brazil has the largest cattle herd on the planet, yet little is known about the amount of water consumed by the sector. Cattle are typically raised in extensive pasture systems containing natural and human-made small farm dams that serve as the main drinking water source. Mapping these dams and quantifying their evaporation across Brazil is a major challenge, but new developments in remote sensing now allow for better estimates of the location and area of these water sources. The goal of this study was to (1) investigate the importance of dam evaporation in Brazilian cattle water footprint inventories and (2) offer a method that could allow for annual data updates to improve Brazilian beef LCAs.

2. METHODS

We focus on blue water consumption as the sum of animal consumption and dam evaporation allocated to the living cattle herd (*Bos taurus*) in 2017 with a functional unit of one tonne of cattle liveweight (LW) per municipality that produces beef (5538 in total). Animal water consumptive uses as per Ridoutt *et al* (2012) comprise: water in feed (W_{feed}), metabolic water (W_{met}), and cattle drinking (W_{drink}) adapted for Brazil (Zanetti *et al* 2019) (Table 1). Dam evaporation was estimated using mean municipality reference evapotranspiration (Xavier *et al* 2022) over dams of 0.5-50 ha in the Mapbiomas Água (2023) dataset of anthropic dams, selected based on vicinity to pasture (> 10%) and removing irrigation and mining activities. Cattle LW was calculated for each municipality using the make-up of the cattle herd following age, development stage and sex (MCTI 2020).

3. RESULTS AND DISCUSSION

Total water consumed by the living cattle herd in 2017 was 10 km^3 with 69-88% due to dam evaporation (Table 2). Cattle water footprint inventories ranged from 66 m^3 (tonne LW)$^{-1}$ (Paraná, Southeast) to 1010 m^3 (tonne LW)$^{-1}$ (Rio Grande do Norte, Northeast), while the main producing states (> 6 Mtonnes LW y^{-1}) showed values of 82-141

m^3 $(\text{tonne LW})^{-1}$ (Figure 1). These results highlight the importance of dam evaporation for the beef sector and the need to continue to refine remote sensing products to allow for the more systematic mapping and monitoring of these reservoirs, particularly in the Northeastern region where our estimates were often more than double than what was found in the rest of the country. Most farm dams are not licensed by environmental agencies and therefore constitute an important blind spot in LCAs with potential impacts to small stream networks (e.g., eutrophication).

The geographic variability in water footprint inventories reflects the water needs of farmers in more water scarce regions, such as the Northeast (126,000 ha of dam area for 8.2 Mtonnes LW, or 65 tonnes LW $(\text{ha water})^{-1}$) compared to the more seasonally dry Central Western region with the most productive states (114,000 ha for 23.2 Mtonnes of LW, or 204 tonnes LW $(\text{ha water})^{-1}$). Dam evaporation is a water consumption activity that reduces water availability for other users downstream (e.g. energy, aquatic ecosystems) and, therefore, relevant to downstream water scarcity in Brazil.

4. CONCLUSIONS

We provided a spatially explicit water footprint inventory for Brazilian cattle following a method that can be updated annually, alongside other life cycle inventory data that use similar variables (e.g. as in enteric methane emissions, see MCTI (2020)).

5. ACKNOWLEDGEMENTS

This research was supported by Formas – a Swedish Research Council for Sustainable Development for the project “Water use and impacts in Brazilian agricultural production and consumption: from global supply chains to regional rainfall” [2020-00688].

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Xavier A.C. *et al* 2022 New improved Brazilian daily weather gridded data (1961-2020) *Int J Climatol* 42(16): 8390-8404, doi: 10.1002/joc.7731

Zanetti D. *et al* 2019 Prediction of water intake to Bos indicus beef cattle raised under tropical conditions *J Anim Sci* 97(3): 1364-1374, doi: 10.1093/jas/skz003

Table 1. Equations used to derive the animal blue water consumptive uses, where *DMI* (kg head^{-1} d^{-1}) is the dry matter intake, *MC* (%) is the feed moisture content, $Milk_c$ (L head^{-1} d^{-1}) is the calf milk consumption, *DE* (%) is the animal digestibility coefficient, *LW* (kg head^{-1}) is the animal liveweight, T_{max} (°C) and *RH* (%) are the maximum temperature and relative humidity obtained as a state average for the 2010-2019 period (Xavier *et al* 2022).

Animal blue water consumptive use (L head^{-1} d^{-1})	**Equation**	**Reference**
Water in feed (W_{feed})	$\frac{DMI\ MC}{100 - MC} + Milk_c$	Ridoutt *et al* (2012)
Metabolic water (W_{met})	$0.6DMI\frac{DE}{100}$	Ridoutt *et al* (2012)
Cattle drinking (W_{drink})	$9.499 + 0.190LW^{0.75} + 0.271T_{max} - 0.259RH + 0.489DMI$	Zanetti *et al* (2019)

Table 2. Contributions of blue water consumptive uses to the water footprint inventory of Brazilian live cattle in 2017 across the country's regions.

Water consumption	**South**	**Southeast**	**Central West**	**Northeast**	**North**
Animal	19%	25%	31%	12%	26%
Dam evaporation	81%	75%	69%	88%	74%

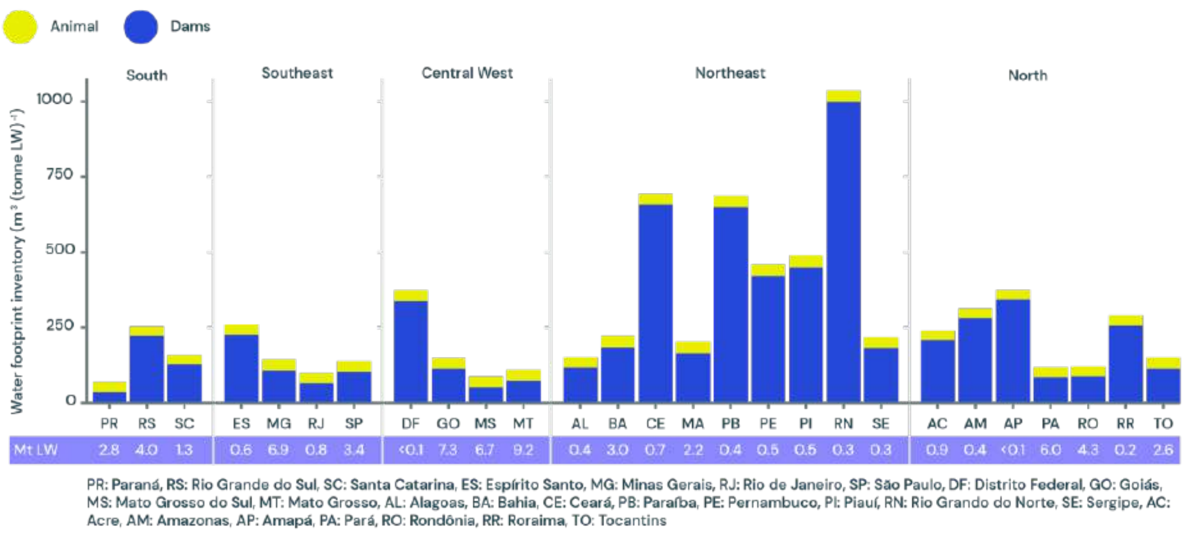

Figure 1. Mean water footprint inventory for live cattle in 2017 across Brazilian states in five regions. Values provided are weighted by cattle liveweight (LW) in each of the states' municipalities. Numbers represent the total LW in each state (Mtonnes).

Absolute Environmental Sustainability of Milk Production in Brazil with a focus on climate change mitigation

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1. INTRODUCTION

Brazil is the fourth largest producer of bovine milk in worldwide (35 million tons in 2022) (FAOSTAT, 2023). Given the importance of the dairy sector, there is growing concern not only regarding the associated impact per unit of delivered product, but also with respect to the impacts in absolute terms (Hjalsted et al. 2021). This study aimed to assess the Absolute Environmental Sustainability Assessment (AESA) of climate change (CC) impacts for different dairy production systems in Brazil.

2. METHODS

An assessment was carried out in 2021 on 314 dairy farms in Brazil, encompassing: compost-bedded pack barns, free-stall, grazing, organic, and semi-confinement. All systems were approached from cradle-to-farm perspective, with the functional unit of 1kg of fat and protein correction milk (FPCM). Biological allocation was applied to address system multifunctionality using the OpenLCA v.1.11.3 software tool with background data extracted from the ecoinvent v. 3.9 cut-off database. Greenhouse gas emissions were estimated and calculated according to IPCC (2019) impact factors. The CC impact per kg FPCM of each production system was multiplied by the total annual production of kg FPCM milk for the respective farms. This allowed for the determination of the total annual impact of each milk production system. AESA approach (Hjalsted et al., 2021) was performed in two steps: 1) downscaling: share of Safe Operating Space (SOS) was reduced to the individual level (SoSOSi) through the principle of equal sharing per capita. Thus, the SoSOSi was the value of 0.52ton CO_2 eq/cap/year (Bjorn; Hauschild, 2015); and 2) upscaling: expansion of the SoSOSi value to the dairy farms. This calculation accounted for the share of the Brazilian dairy sector (SoSOSs) by employing the Gross Domestic Product (GDP) of national milk production as a proxy relative to the country's overall GDP. Thus, it was possible to calculate the SOS of the farms (SoSOSf) using the percentage representation of the production of the analyzed farms into the share of national milk production. Finally, Absolute Sustainability Ratio (ASR) was calculated by dividing the total current impact by the farms' share of SoSOSf.

3. RESULTS AND DISCUSSION

The Absolute Environmental Sustainability (ASE) was not achieved for any dairy production system (Table 1). This implies that the current impacts of the farms surpassed the SoSOSs threshold quota. Among the evaluated systems, the compost-bedded pack showed barn the lowest index (36.30), while the grazing (55.99) and organic (59.84) system registered the highest, representing 22% of difference. Organic systems have specific characteristics and can include both semi-confinement and grazing. A production system can only be deemed the ASE if the ASR is less than or equal to 1, ensuring that the total impact of the farms falls within the assigned SoSOS quota for farms. Hjalsted et al. (2021) also revealed a quota exceedance for the Indian and Danish dairy sector, when applied ASR with the principle of equal per capita. In addition, given that enteric fermentation is one of the main contributors to the impacts of CC, implementing actions to reduce the associated emissions can assist in their reduction and bring the evaluated systems closer to the SoSOSs quota. Thus, for the systems to achieve AS, the average CC impact across all production systems must be less than 0.022 kg CO_2 eq/kg FPCM emitted.

4. CONCLUSIONS

In this assessment, we specifically focused on the ASR for CC, considering the different types of production systems. The findings revealed that all evaluated systems surpass the SoSOSf share allocated for the farms. Therefore, it is crucial to underscore those methodological choices, such as selecting sharing principles, can affect in the results interpretation. Consequently, to mitigate uncertainties and enhance the robustness of future studies, it is recommended to broaden the scope of analyses, including exploring alternative sharing methods and incorporating more pertinent impact categories to the dairy sector.

5. ACKNOWLEDGEMENTS

The authors are grateful to Brazilian Agricultural Research Corporation – Embrapa, the Nestlé Brazil Ltda, the “Fundação de Amparo à Pesquisa do Estado de São Paulo” (FAPESP, grant numbers 2019/16996-4) and the “Conselho Nacional de Desenvolvimento Científico e Tecnológico” (CNPq, grant number 303343/2022-2).

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Table 1. Description of the results: climate change (CC) impact, total production of fat and protein corrected milk (FPCM) and absolute Sustainability Ratio (ASR)

Production System	Mean (kg CO_2 eq/kg FPCM)	Total Production (kg FPCM/year)	Total farm (kg CO_2 eq /kg FPCM/year)	ASR
Compost-bedded pack barns (n = 61)	$9.80x10^{-1}$	71028366.77	$5.43x10^{7}$	38.30
Free-stall (n = 10)	$1.09x10^{0}$	12221048.05	$1.05x10^{7}$	38.09
Organic (n = 20)	$1.70x10^{0}$	5534280.32	$7.44x10^{6}$	59.84
Grazing (n =58)	$1.80x10^{0}$	24299231.23	$3.06x10^{7}$	55.99
Semi-confinement (n = 165)	$1.33x10^{0}$	60443202.18	$7.07x10^{7}$	52.08

Table 2. Variable data used for calculating ASR.

Variable	value	Unit	Source
SOS/per capita (CC)	0.522	ton CO_2 eq/cap/year	Bjorn & Hauschild (2015)
Brazil's population	213317639.	people	FAOTAT (2023)
Brazil GDP 2021	9012141999300	R$	IBGE (2021) https://www.ibge.gov.br
Milk GDP (value production)	67987725000	R$	

Climate Impact and Ecosystem Services in Cattle Production: Including Non-Provisioning Ecosystem Services in Life Cycle Assessments

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1. INTRODUCTION

Domesticated ruminants provide nutrient-dense foods and have high environmental impacts, but many ruminant production systems also offer other ecosystem services (ES) in addition to foods (von Greyerz et al., 2023). Life cycle assessments (LCA) of these systems often focus only on provisioning ES (e.g., beef and milk) (de Vries et al., 2015), overlooking the non-provisioning ES. To address this issue, these can be included in the LCA and handled by economic allocation, using compensatory payments from agri-environmental schemes as a proxy for their economic value, reflecting society's economic valuation of certain ES (Ripoll-Bosch et al., 2013). However, the relationship between payments, ES, and livestock production is not straight forward, leading to challenges in determining which payments to include and resulting in varied results. Therefore, we have examined how including non-provisioning ES in LCA for the climate impact of beef and milk from Swedish systems is affected by different coupling of ES to livestock production through payment schemes (von Greyerz et al., 2023).

2. METHODS

The climate impact was quantification using LCA for ten Swedish beef and/or dairy farms representing various production systems. The impact was allocated across meat, milk and ES with economic allocation, using payments through agri-environmental schemes as a proxy for the value of non-provisioning ES, since the farmers by these payments are compensated for management practices that are beneficial for ES, e.g. maintenance of semi-natural pastures. The payments were divided into three groups to investigate how different coupling of the ES to animals through the payments affects the results. Group 1 included payments directly to the animals, group 2 also included payments tied to animals but also affected by agricultural land, i.e. payments for organic animal husbandry, and group 3 also included payments for the feed production (von Greyerz et al., 2023).

3. RESULTS AND DISCUSSION

Including the non-provisioning ES, <1–48% and 11–31% of the climate impact was attributed to the non-provisioning ES instead of the beef and milk, respectively (Figure 1 and 2). Suckler farms were the most affected. Overall, payments in group 1 affected the results the most, 0-36%, but there was then still a large difference in the climate impact between the farms. This difference became smaller when more payments in group 2 and 3 were also included, affecting the results an additional 0-18% and 0-8%, respectively (Figure 1 and 2) (von Greyerz et al., 2023).

4. CONCLUSIONS

The climate impact of beef and milk was substantially influenced by allocating emissions to the non-provisioning ES. Which payments that were included affected the results, where payments most directly associated with the animals have the greatest impact. The results using this method can be used for consumer communication and decision making to reduce the risk of overlooking the value of ES provided by the production systems (von Greyerz et al., 2023).

5. ACKNOWLEDGEMENTS

The primary funding of this work was provided by the Swedish University of Agricultural Sciences. Additional funding was provided by the Uniseco project (an EU founded research project, https://uniseco-project.eu/), Grant agreement number 773901, and Swedish Farmers' Foundation for Agricultural Research, Grants R-18-26-136 (von Greyerz et al., 2023).

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Climate impact for beef, kg CO_2e per kg CW	Excluding non-prov. ES	Including non-prov. ES		
		Group 1	Group 2	Group 3
Suckler A	39	35 (-11%)	28 (-29%)	27 (-31%)
Suckler B	36	31 (-13%)	31 (-27%)	26 (-28%)
Suckler C	35	22 (-36%)	18 (-47%)	18 (-48%)
Suckler D	33	29 (-13%)	24 (-26%)	23 (-30%)
Suckler and dairy calves A	31	25 (-18%)	22 (-28%)	21 (-31%)
Dairy calves A	22	22 (0%)	22 (0%)	22 (-3%)
Dairy calves B	22	22 (0%)	22 (0%)	22 (-1%)
Dairy and dairy calves A	21	18 (-13%)	16 (-23%)	15 (-31%)
Dairy A	16	16 (-3%)	15 (-8%)	15 (-11%)
Dairy B	16	15 (-4%)	14 (-10%)	13 (-18%)

Larger change

Smaller change

Figure 1. Climate impact from beef per kg carcass weight (CW) from the different farms using the different grouping of payments for allocation. The values in parentheses shows the percentage changes in the climate impacts for beef from different farms, using the different groups for allocation compared to when the non-provisioning ES were excluded from the allocation.

Climate impact for milk, kg CO_2e per kg FPCM	Excluding non-prov. ES	Group 1	Group 2	Group 3
Dairy and dairy calves A	1.2	1.1 (-13%)	0.94 (-23%)	0.85 (-31%)
Dairy A	0.65	0.63 (-3%)	0.60 (-8%)	0.58 (-11%)
Dairy B	0.96	0.93 (-4%)	0.87 (-10%)	0.79 (-18%)

Larger change

Smaller change

Figure 2. Climate impact from milk per fat and protein corrected milk (FPCM) from the different farms using the different grouping of payments for allocation. The values in parentheses shows the percentage changes in the climate impacts for milk from different farms, using the different groups for allocation compared to when the non-provisioning ES were excluded from the allocation.

Assessing the Carbon Footprint of Small-Scale Dairy Cattle Systems in Kenya, Africa: An Application of Life Cycle Assessment Methodology

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1. INTRODUCTION

Kenya is the top milk producer in Africa, with 5.1 million dairy cattle and an annual yield of 4.1 billion liters (Kenya National Bureau of Statistics, 2020). Dairy cattle farming is a major source of greenhouse gas emissions (GHGE) in Kenya. The present study aims to (1) estimate the carbon footprint (CF) of dairy cattle farms in Kenya using a farm gate Life Cycle Assessment (LCA) approach, based on data gathered directly from producers; and (2) identify the hotspots of GHGE, and the ways of improving productivity with better environmental performance.

2. METHODS

Using LCA, we assessed the CF of small-scale dairy systems in Kenya. We applied a 100-year global warming potential with the following values: 27.2 for methane (CH_4), 273 for nitrous oxide (N_2O), and 1 for carbon dioxide (CO_2) (IPCC, 2014). The system boundary was defined by the GHGE related to dairy farms in a "cradle to farm-gate" perspective (Figure 1). The biophysical allocation approach delineated in the International Dairy Federation (IDF) Global Carbon Footprint Standard for the Dairy Sector (IDF, 2022) was employed. Data were collected from 96 farms in Nandi and Uasin Gishu Counties. The analysis used IPCC guidelines (Gavrilova et al., 2019), and local emission factors, with a functional unit of 1 kg fat and protein-corrected milk (FPCM). A principal component analysis (PCA) was conducted to identify patterns among variables by applying the PCA procedure from the FactoMineR package (Husson et al., 2015) included in the R program (R Core Team, 2018).

3. RESULTS AND DISCUSSION

The primary sources of GHGE were enteric fermentation (CH_4) and manure deposited (CH_4) on pastures contributing 70% and 80% of total GHGE in Nandi and Uasin Gishu, respectively. Feed production (CO_2) and burning of fossil fuels (CO_2) ranked second reaching 25.5 and 15% of total GHGE in Nandi and Uasin Gishu respectively. The milk CF ranged between 1.1 and 7.4 CO_2eq kgFPCM^{-1} in Nandi, and between 1.2 and 6.3 CO_2eq kgFPCM^{-1} in Uasin Gishu (Table 1). In both regions, farms with milk CF lower than 3.0 CO_2eq kg FPCM^{-1} showed higher milk productivity (3317 kg FPCM cow^{-1} year^{-1}) than the rest of the farms (2539 kg FPCM cow^{-1} year^{-1}). This negative correlation was also confirmed by the PCA analysis. The above was driven by the higher nutritional quality of the animal diet, specifically characterized by higher levels of crude protein and Neutral Detergent Fiber (NDF) This emphasizes that the reduction of GHGE intensities can be achieved by narrowing the productivity gap through the adoption of improved feed.

4. CONCLUSIONS

As a prevailing pattern, the primary hotspots of GHGE in small-scale dairy farms in Kenya stem from the animals, primarily attributed to enteric fermentation. Improving feed quality significantly boosts productivity and reduces the milk CF. Thus, high-quality feed is essential for enhancing productivity and environmental performance.

5. ACKNOWLEDGEMENTS

Supported by the One CGIAR Livestock and Climate Initiative (https://www.cgiar.org/funders) and the Bezos Earth Fund. Thanks to the dairy farmers, local leaders, and CIAT staff in Rift Valley for their assistance.

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Table 1. Average values for the herd structure, cow productivity, external feed consumption rates, and milk carbon footprint for 96 Dairy Farms in Nandi and Uasin Gishu Counties, Kenya.

	Nandi County			Uasin Gishu County		
	Average	min	max	Average	min	max
Farm Area, ha	8.1	0.4	40.5	4.1	0.2	22.3
Herd structure, n (% of herd)						
Cows	9 (52)	1	37	6 (54)	1	18
Female calves (0–1 year)	2 (12)	0	8	2 (14)	0	5
Male calves (0–1 year)	1 (6)	0	3	1 (8)	0	4
Female calves (1–2 years)	2 (12)	0	10	1 (8)	0	7
Male calves (1–2 years)	1 (6)	0	7	1 (8)	0	5
Heifers (2–3 years)	2 (12)	0	9	1 (8)	0	4
Steers (2–3 years)	0	0	3	0	0	2
Bulls	0	0	2	0	0	2
Milk production, kg FPCM[a] cow^{-1} $year^{-1}$	2999.6	1050.0	5840.0	3052.1	1200.0	6000.0
Concentrate consumption, kg DM AU^{b-1} $year^{-1}$	14.3	0.0	86.4	11.3	0.0	26.7
Cut and carry forages consumption, kg DM AU^{-1} $year^{-1}$	3.3	0.8	7.9	4.4	1.6	9.0
Silage consumption, kg DM AU^{-1} $year^{-1}$	10.5	0.0	37.1	20.4	0.0	115.3
Milk carbon footprint, kg CO_2-eq $kgFPCM^{-1}$	2.9	1.1	7.4	2.5	1.2	6.3

[a]FPCM: Fat and Protein Corrected Milk
[b]AU: Animal Unit (1 AU being either 1 cow, or 3.3 female and male calves less than 1 year, or 1.7 female and male calves 1—2 yr, or 1.3 heifers 2–3 yr, or 1.3 steers 1- 2 yr, or 0.8 bulls)

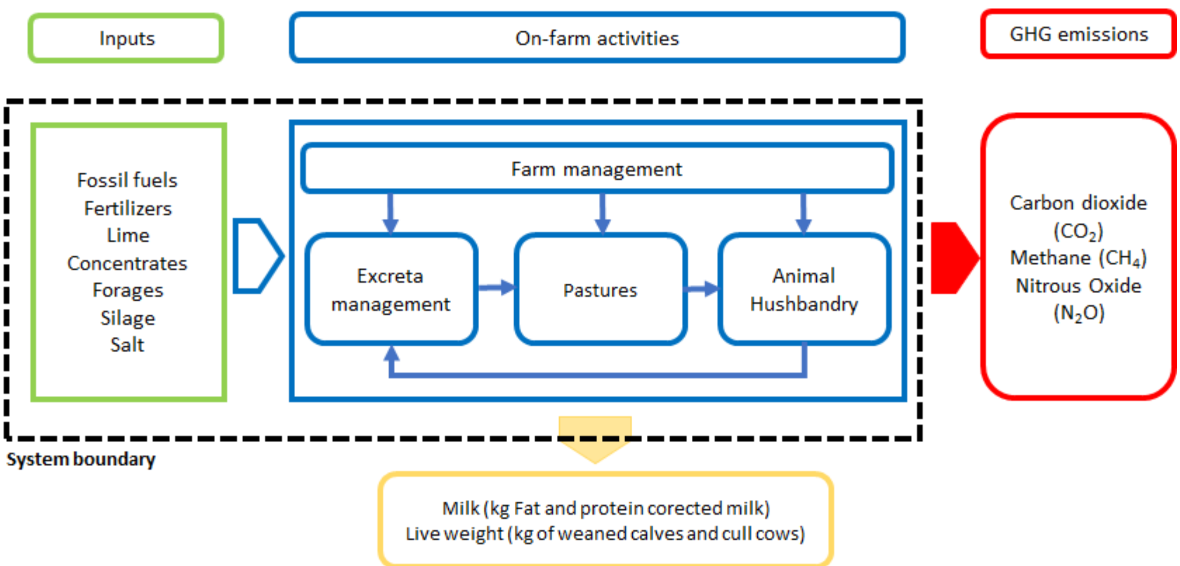

Figure 1. System boundaries and flows accounted for in the estimation of the impact categories in the small-scale dairy farms in a “cradle to farm-gate” approach.

Farm efficiency and environmental impact of dairy sheep

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1. INTRODUCTION

A close and direct relationship between farm efficiency and environmental sustainability is largely reported in the literature (Lovarelli et al., 2019). So far, data on the environmental impact of small ruminants are scarce compared to that on large ruminants and with a number of non-harmonised approaches and methodologies (Mancilla-Leytón et al., 2023).
The aim of this work was to study the relationships between environmental impacts and farm efficiency of dairy sheep production.

2. METHODS

A Life Cycle Assessment (LCA) procedure was applied to calculate the environmental impact of 10 dairy sheep farms in the Tuscany region (a Mediterranean region in central Italy). The selected farms were spread across the Tuscany territory and showed high variability in land area, flock size and milk production (Table 1). Three breeds are reared in these farms: two autochthonous Italian breeds, 'Sardinian' and 'Massese', and the French breed 'Lacaune'. LCA performed complied with the ISO 14040-44 standards and the FAO LEAP guidelines (2016). The selected functional unit was 1 kg of fat and protein corrected milk (FPCM), and the system boundary was "from cradle to farm gate". Primary data referred to the cropping season 2021/22 were collected onsite through a specific survey, whereas secondary data were taken from Ecoinvent 3.9.1 and Agrybalise 3.1 databases. Following the PEFCR for Dairy Products (2019), relevant impact categories were assessed using Environmental Footprint 3.1 and the OpenLCA software. A correlation analysis between environmental impacts and some farm efficiency variables was performed, setting the statistical significance at $p \leq 0.05$; in particular, the productivity (kg FPCM per year), feed self-sufficiency (%, dry matter produced on farm on total dry matter intake, DMI), feed efficiency (kg FPCM kg DMI^{-1}) and protein efficiency (kg FPCM kg nitrogen intake-NI^{-1}) were analysed.

3. RESULTS AND DISCUSSION

The results of the impact assessment are reported in Table 2. Although productivity is considered a priori as the main driver for low emissions intensity (Gerber et al., 2011), in the present study, a significant correlation between impacts and milk production was found only for Biogenic Global Warming Potential (GWPb), Erosion Potential (EP) and

Groundwater Regeneration Reduction Potential (GRRP), which means that these impacts decrease as productivity increases. Instead, significant correlations were found for the feed and protein efficiency and GWP, GWPb, 'Particulate Matter', 'Water Use', EP, 'Infiltration Reduction Potential', 'Physicochemical Filtration Reduction Potential', 'GRRP', 'Soil Organic Carbon Reduction Potential' and 'Biodiversity Loss Potential' (Table 2). Notably, 'Freshwater Eutrophication' was correlated only with protein efficiency. Finally, only for the impact category 'Water Use' the correlation has an opposite trend, i.e. feed and protein efficiency increase as water consumptions increase. The explanation is that the only three farms that irrigate crops are those with the highest efficiencies.

4. CONCLUSION

The results of this study suggest that feed self-sufficiency is not decisive in reducing the environmental impacts, while feed and protein efficiency are relevant drivers of the environmental performance of the farms. These factors should thus be carefully considered at both the farm and regional level when aiming to improve the sustainability of the dairy sheep sector.

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Table 1. Main characteristics of the analysed farms.

	Mean value	Standard deviation	Min	Max
Farmland (ha farm^{-1})	119.50	106.54	9.00	364.00
Total animals (n farm^{-1})	513.82	315.82	175.00	1014.00
Lactating sheep (n)	400.00	234.80	100.00	800.00
Milk production (t FPCM farm^{-1})	186	201	17	599
Feed self-sufficiency (%)	78.87	20.74	38.10	100
Feed efficiency (kg FPCM kg DMI^{-1})	0.42	0.14	0.25	0.63
Protein efficiency (kg FPCM kg NI^{-1})	19.81	8.02	8.74	29.13

Table 2. Environmental impacts and correlations analysis with farm efficiency parameters.

Impact categories	Impact assessment results				Correlation analysis			
	Mean value	Standard deviation	Min	Max	Productivity (kg FPCM)	Feed self-sufficiency (%)	Feed efficiency (kg FPCM kg DMI^{-1})	Protein efficiency (kg FPCM kg NI^{-1})
GWP	2.41	1.15	0.88	4.09	ns	ns	**	***
GWPb	1.53	0.79	0.73	2.89	*	ns	**	***
FE	2.18×10^{-4}	9.98×10^{-5}	7.48×10^{-5}	3.54×10^{-4}	ns	ns	ns	*
ME	5.17×10^{-3}	3.10×10^{-3}	2.15×10^{-3}	1.21×10^{-2}	ns	ns	ns	ns
TE	1.84×10^{-1}	1.00×10^{-1}	6.00×10^{-2}	3.00×10^{-1}	ns	ns	ns	ns
AE	4.13×10^{-2}	2.43×10^{-2}	1.00×10^{-2}	7.00×10^{-2}	ns	ns	ns	ns
PM	1.67×10^{-7}	1.09×10^{-7}	4.50×10^{-8}	3.94×10^{-7}	ns	ns	*	**
ADP	7.76	3.62	2.51	11.62	ns	ns	ns	ns
W	6.37	8.54	0.14	20.84	ns	ns	**	*
EP	11.05	6.82	3.42	23.39	*	ns	**	***
IRP	5.70	3.05	2.52	9.56	ns	ns	*	*
PFRP	1247.27	657.99	564.05	2040.33	ns	ns	**	**
GRRP	0.36	0.22	0.12	0.79	*	ns	**	***
SOCRP	92.71	52.18	36.42	160.88	ns	ns	**	*
BLP	87.55	51.55	26.81	155.44	ns	ns	***	***

GWP: Global Warming Potential (kg CO_2 eq), GWPb: Biogenic Global Warming Potential (kg CO_2 eq), FE: Freshwater Eutrophication (kg P eq), ME: Marine Eutrophication (kg N eq), TE: Terrestrial Eutrophication (mol N eq), Acidification (mol H^+ eq), PM: Particulate Matter (disease incidence), ADP: abiotic depletion potential (MJ, net caloric value), W: Water Use (m^3 world eq. deprived), EP: Erosion Potential (kg soil/m^2), IRP: Infiltration Reduction Potential (m^3 water/m^2) , PFRP: Physicochemical Filtration Reduction Potential (mol/m^2), GRRP: Groundwater Regeneration Reduction Potential (m^3 groundwater/m^2), SOCRP: Soil Organic Carbon Reduction Potential (kg SOC/m^2), BLP: Biodiversity Loss Potential (PBR/m^2), ns: non-significative correlation, * significative correlation per $p \leq 0.05$, ** significative correlation per $p \leq 0.01$, *** significative correlation per $p \leq 0.001$.

LCA unveils positive contribution from traditional sheep-farming

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1. INTRODUCTION

Ruminants, including sheep, contribute significantly to methane emissions, thus resulting in high emissions per kg of product. However, they can utilise plant material unsuitable for human consumption, thereby transforming it into valuable, protein-rich food. Grazing also preserves cultural landscapes and can contribute to carbon sequestration. Understanding the balance between these factors within the climate change context is crucial. This study investigates the environmental impact of meat, milk, and wool production from sheep farming in Norway and Slovenia.

2. METHODS

Data regarding inputs and production were sourced from eight sheep farms in central Norway and one farm in the south-west of Slovenia, (Table 1). LCA-calculations were undertaken using the LCA software Umberto©, with assess to the ecoinvent© database for incorporating emissions related to purchased inputs. On-farm emissions were modelled in line with ISO standards and IPCC (2007, 2021) guidelines. Feed demand for animal groups was determined for winter barn feeding and for the grazing period, based on energy requirements for maintenance, activity, lactation, pregnancy, growth, and wool. Allocation was biological based on energy demand for meat, milk, and wool. Carbon sequestration estimates for grasslands were adapted from Chang et al. (2015). An uncertainty analysis was conducted using Monte Carlo simulations for all input variables and emission factors to ascertain their effect on the results.

3. RESULTS AND DISCUSSION

Norway's longer winters limit the grazing period to 163 days, compared to Slovenia's 240 days in (Table 1). This results in increased demand for winter feed, thereby elevating emissions from e.g. machinery use and diesel combustion. Moreover, Norwegian farmers purchased more concentrates. Climate gas emissions, calculated as GWP_{100} (IPCC 2007), were comparable in both countries with 19.2 kg CO_2-equivalents and 19.6 kg CO_2-eq per kg slaughter-weight, which is lower than the world average (Clune et al. 2017). Emissions related to the production of edible energy from both meat and milk, were less in Slovenia, producing both milk and meat as well as wool, at 1.00 kg CO_2-eq/MJ, compared to 1.45 kg CO_2-eq/MJ in Norway. Using GTP as the matrix, as suggested by IPCC for the discussion to limit global warming (IPCC 2021), emissions were lower, and when including sequestration values (Chang et al. 2015) for both countries, the Norwegian production sequestered more CO_2 than they emitted (-0.57 kg CO_2-eq/MJ), and Slovenian production was about carbon neutral (-0.02 kg CO_2-eq/MJ). The high uncertainty of carbon sequestration significantly influenced the calculated GTP_{100} emissions per MJ edible energy.

4. CONCLUSIONS

This study offers insights into the balance between methane emissions, the ability to utilise areas not suitable for direct food production by grazing to produce meat, milk, and wool, while sequestering carbon. Despite climatic differences, both countries showed comparable greenhouse gas emissions as GWP_{100} per kg meat. Slovenian farms, producing both milk and meat in addition to wool, demonstrate lower emissions per MJ of edible energy. The GTP_{100} results emphasise that grazed areas can sequester carbon in an amount that can offset emissions from sheep production, highlighting the potential of sustainable and responsible sheep farming in climate change mitigating and emphasising the need for more knowledge on carbon sequestration in agricultural soils. The positive effects from ruminants are only attainable when winter feed is produced with low emissions, and areas are grazed predominantly where no industrial inputs are used, and carbon can be sequestered in the soil.

5. ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the project ROAM-Free (Contract No. 727495) provided by funding bodies, partners of the H2020 ERA-NET CORE Organic Cofund, under the 2021 Call and the Norwegian Research Council, project number 332815 and the Amazing grazing project, no 669308.

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Table 1: Main data for the farms and LCA-results

	Unit	Commercial farms	Vremščica ICSR
Country		Norway (NO)	Slovenia (SI)
Number	n	8	1
Data	year	2018-2020	2023
Altitude	m above sea	50-600	800-1000
Farm area	ha	29.4	260
Meadows	ha	29.4	90
Grazing period	days/year	163	240
Winter feed, main		silages	hey
Concentrates	kg/year	16,531	15,000
	kg/ewe	115.6	35.7
Diesel	l/year	2715	5000
	l/ha meadow	92.3	55,6
Animals			
Breed		Norsk kvit sau and Old Norwegian Short Tail Landrace	Istrian pramenka
Ewes	n	143	420
Liveweight	kg/ewe	85	75
Lambs, born	n/ewe	2.2	1.2
Breeding, replacement	n/farm	55	75
Rams	n/farm	included in n. ewes	5
Production, annual			
Lambs for slaughter	n/farm	256	429
Sheep-milk	litre/farm	no milking	24,000
LCA-results			
GWP_{100} (IPCC 2007)			
allocated to milk	kg CO_2/kg milk	no milking	2.27 ± 0.18
allocated to meat	kg CO_2/kg meat[1]	19.2 ± 1.3	19.6 ± 1.9
allocated to wool	kg CO_2/kg wool	42.2 ± 3.7	28.7 ± 3.7
all edible energy	kg CO_2/MJ	1.45 ± 0.1	1.00 ± 0.08
all edible energy	kg CO_2/MJ, sequestr. incl.	0.12 ± 0.03	0.63 ± 0.14
GTP_{100} (IPCC 2021)			
allocated to milk	kg CO_2/kg milk	no milking	0.78 ± 0.06
allocated to meat	kg CO_2/kg meat[1]	10.11 ± 0.6	5.70 ± 0.6
allocated to wool	kg CO_2/kg wool	21.8 ± 1.7	10.9 ± 1.5
all edible energy	kg CO_2/MJ	0.77 ± 0.04	0.34 ± 0.03
all edible energy	kg CO_2/MJ, sequestr. incl.	-0.57 ± 2.8	-0.02 ± 0.11

[1] Slaughter-weight is used as weight of meat.

Sustainable livestock systems (II)

Can milk and beef footprint reductions deliver national climate targets?

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1. INTRODUCTION

Dairy and beef production in highly developed, pasture-based livestock systems such as Denmark, United Kingdom, New Zealand, France or Ireland are competing to achieve the lowest possible carbon footprints. However, in most of these countries, this has not led to a decrease in national agricultural greenhouse gas (GHG) emissions over the past decade owing to an expansion of more efficient production (Eurostat, 2024). In Ireland, environmental targets are not being met, despite several readily available and well-researched farm level emission mitigation measures (Henn et al., 2023; Lanigan et al., 2023). Here, we explore the out-scaling mitigation measures from farm to national level in relation to achieving net-zero emissions across Ireland's Agriculture, Forestry and Other Land Use (AFOLU) sector by 2050. Focus is placed on integration of white clover (*Trifolium repens*) into pastures, cattle herd profiles, grassland management, methane inhibitors and afforestation.

2. METHODS

GOBLIN, a bio-physical land balance model that builds scenarios to determine 2050 GHG emissions from the AFOLU sector, is used with a modified version of the GLAM grassland model (Duffy et al., 2022, Henn et al., in review). Based on data collected from 39 farms across Ireland in 2022 and 2023, a grass-clover yield response curve was incorporated into GLAM. In addition to grass-clover, six other mitigation measures were modelled at three different levels of ambition, resulting in a total of 2,187 scenarios: (1) different livestock herd compositions keeping cattle protein production constant, (2) reductions of cattle slaughter ages, (3) applying nitrogen fertiliser as protected urea, (4) increasing grassland use efficiency, (5) decreasing emissions sources and increasing sinks within the land use sector through afforestation of spared grassland and rewetting organic soils, and (6) methane inhibitors and slurry acidification.

3. RESULTS AND DISCUSSION

Net-zero GHG emissions on a GWP_{100} basis were achieved in 120 scenarios, which required grassland sparing of at least 1.5 million hectares (Figure 1). Despite this, the 2020 level of milk-plus-beef-protein output was maintained. In scenarios with the lowest emissions, afforestation rates of up to 40,000 ha $year^{-1}$ were required. If afforestation rates were limited to 20,000 ha $year^{-1}$ (based on precedent), outlined mitigation measures were not sufficient to reach net-zero emissions. The most important drivers to reduce net emissions were found to be livestock numbers and tree species composition used for afforestation. Grass-clover swards and methane inhibitors were the most effective mitigation measures for agricultural emissions.

4. CONCLUSIONS

A focus on reducing milk and beef footprints needs to be translated into attainment of national climate targets. In Ireland, this will require grassland sparing from livestock production and a policy framework that supports diversification of land use. Grass-clover swards can play an important role by reducing fertiliser inputs and increasing productivity. Scenarios indicate that achieving net zero AFOLU emissions need not necessarily entail a loss of protein production, but only if unprecedented levels of afforestation can be realised out to 2050. Could the resources needed to maintain comparatively efficient bovine protein production in Ireland within future national GHG constraints achieve greater mitigation if directed towards transformation of inefficient livestock systems in developing countries?

5. ACKNOWLEDGEMENTS

The authors are grateful to the Department of Agriculture, Food and the Marine for funding provided to undertake this research (LoCAM-dairy project, 2019R521).

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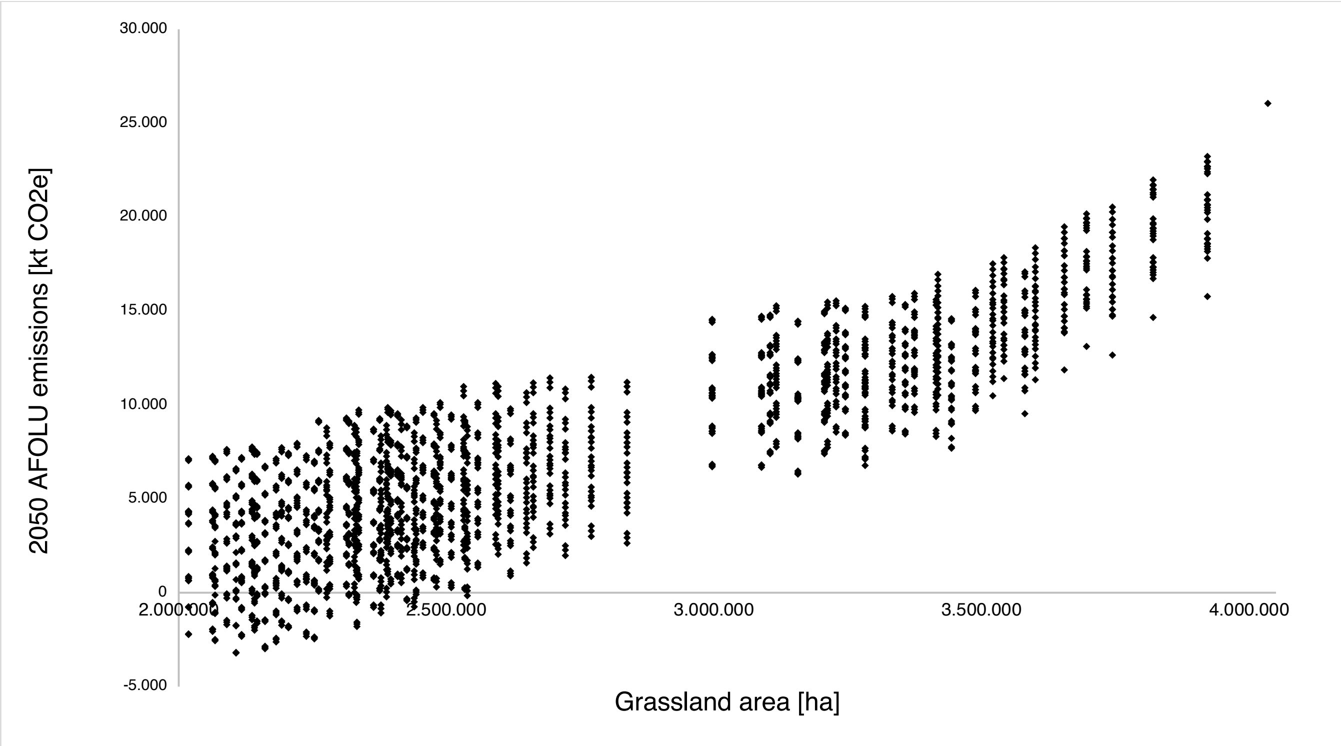

Figure 1. Preliminary scenario results from GOBLIN scenario analysis showing net greenhouse gas flux from Ireland's AFOLU sector in 2050 (y-axis) against area of grassland required for livestock production (x-axis) across 2187 scenarios.

Integrating ecosystem services into LCA of livestock far ming: a comparative analysis of beef production syste ms in Galicia (NW Spain)

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1. INTRODUCTION

Many livestock systems serve multiple functions by providing ecosystem services (ES) not typically considered in Life Cycle Assessment (LCA) studies (Salvador et al., 2016). LCAs on cattle farming often focus on primary products like beef and milk. So, integrating ES into LCA still remains uncommon due to challenges in modelling production systems, gathering inventory data, and interpreting results (Alejandre et al., 2019). However, recent frameworks are approaching such integration through combination of results applying economic allocation where non-provisioning ES are considered as co-products of the system (Bragaglio et al., 2020; von Greyerz et al., 2023). *RURALtXA!* project (https://ruraltxa.com/) promotes the rural bioeconomy by giving new value to extensive livestock grazing in mountain landscapes such as those present in Galicia (NW Spain). This work compares different beef production systems: extensive, mixed and intensive. The formers use forests and shrublands for grazing, differing in feed composition, external input intensity, animal density and commercial orientation; while the latter relies on early weaning, milk replacers, and grain-based diets. Economic allocation is used to integrate non provisioning ES to capture the complete picture of the environmental costs associated to beef production (i.e. provision ES) from the different production systems.

2. METHODS

EM is an extensive grass-based system which relies on local well-adapted *Cachena* breed. Farms are usually small (10-50 heads), production is not coupled to forage cultivation on the farm and the feeding of the calves is based on breast milk, grass and forage. Pastures are characterized by their high productivity and minimal human intervention.

M-CON and **M-SUP** are mixed systems which complement grazing with a fattening phase on birth farm. Farms are medium (50-150 heads) and adults (specialized beef breed *Rubia Gallega*) stay half of the year in extensive grazing regime. The contribution of external inputs is low to moderate and the main difference relies on calf´s lactation period: while M-CON calves are weaned at 3 months, M-SUP prolongs weaning until 7 months. Early weaning reduces interval between calvings and wear on the suckler, and thus obtains a greater number of offspring per cow throughout its life, at the cost of a greater feed intake to achieve the desired weight in calves. Benefits of late weaning lie on the reduced external inputs to the calf.

IL represents an intensive production system that relies on surplus calves from dairy farms. *Holstein* breed is used and calves are weaned at 14 days of life and transferred to feedlots. Breast milk is replaced by a milk replacer. The animals are stabled throughout the fattening phase. The diet is based on 90% concentrated grain complement with variable amounts of forage.

To characterize the four systems, interviews, questionnaires and field visits were conducted, and information complemented when need with literature. 1kg of live weight (LW) was chosen as functional unit and a cradle to farm-gate scope was applied.

Direct emissions were obtained using IPCC 2019 guidelines complemented with national emissions and excreta factors (MAPA, 2019). The World Food LCA Database (WFLDB) v3.5.1 (Nemecek et al., 2019) was applied as reference for the agricultural products inventory, where food baskets and archetypes have been adjusted to the local systems conditions. ReCiPe 2016 Midpoint (H) V1.08 was applied for the impact assessment stage and five impact categories evaluated. Following the IDF (2022) , economic allocation was applied for milk (86.8%) and calves (13.2%) at IL. And economic allocation was also applied to integrate non provisioning ES based on the Common Agricultural Policy (CAP) 2023-2027 payment schemes.

3. RESULTS AND DISCUSSION

Overall results match with Western Europe performance (Gerber et al., 2013). Environmental profile (Figure1) in EM is influenced by low weight gain due to grass-based diets, while M-CON and M-SUP obtained lowest impacts by combining grazing, on-farm forage and high weight gain at fattening phase. IL showed intermediate values due to weight gain but penalized for high external feed inputs.

When considering non provision ES in the comparison (Table 1), EM reduces its overall impact by 49%, while M-CON and M-SUP by 26 and 22%, respectively, and IL is not affected as only beef is produced there. EM achieved best performance at 3 out of 5 categories, while IL ended obtaining worst performance at all. M-CON, M-SUP and EM obtained similar results at LU and AP. These results are in line with previous literature that applied similar approaches to ES integration.

4. CONCLUSIONS

The preliminary results here presented can guide rural promotion measures, such as strengthening grazing, adjusting CAP payments or adopting sustainable feeding strategies for livestock. *RURALtXA!* is working to include cultural ES in next integrations, as well as empirical regulating ES valuations rather than based on CAP payments. Also, the approach applied (economic allocation) has several limitations as apply uniform reduction to all the impact categories evaluated, spatial or temporal variability (which is inherent to ES) is ignored, and the valuation method is based on political decisions and compensations for the loss of productivity of European agriculture rather than on empirical observations and ES assessments.

5. ACKNOWLEDGEMENTS

RURALtXA! is supported by Fundación Biodiversidad (MITECO) within the framework of the recovery, transformation, and resilience plan funded by the EU – nextgeneration funds. Local farmers are deeply acknowledged for their time during the interviews. Authors belong to a Galician Competitive Research Group (GRC ED431C 2021/37), programme co-funded by FEDER (UE).

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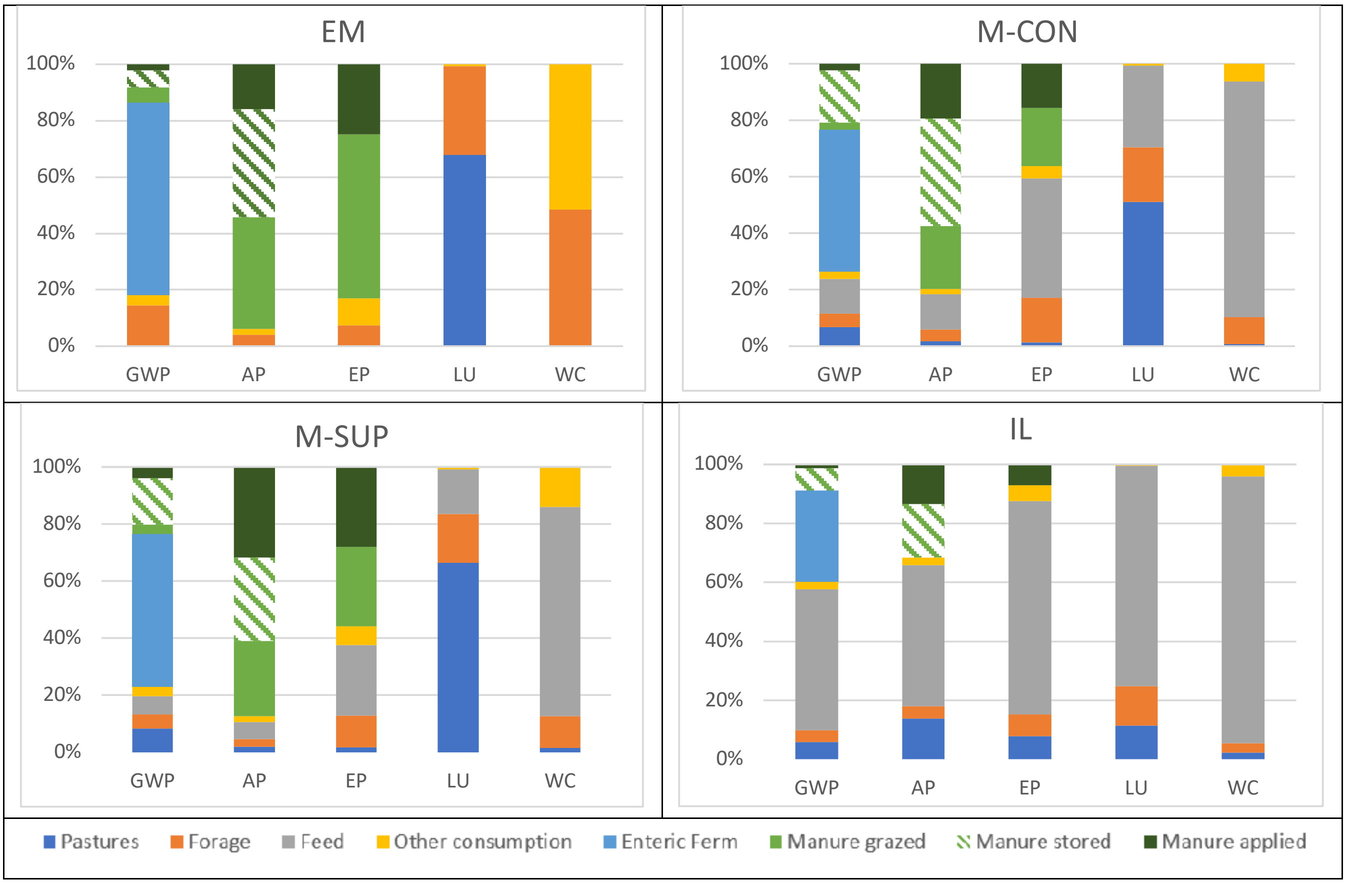

Figure 1. Characterized profile of the production systems before non-provisioning ES integration

Category	Units	EM		M-CON		M-SUP		IL	
FU: 1 kg LW		Before	After	Before	After	Before	After	Before	After
GWP	kg CO_2 eq	21.32	10.72	16.16	11.90	16.47	12.86	18.73	18.73
AP	g SO_2 eq	118.47	73.98	85.28	70.96	118.47	73.98	85.28	70.96
EP	g P eq	2.96	1.49	3.50	2.57	2.82	2.21	3.55	3.55
LU	m^2 año^{-1} crop eq	22.93	11.53	14.03	10.33	13.97	10.91	17.70	17.70
WC	liters	72.23	36.31	336.44	247.80	205.04	160.13	476.68	476.68

Table 1. Characterized results before and after non-provisioning ES integration

Assessing the Overall Sustainability Performance of the Meat Processing Industry Before and After Wastewater Valorization Interventions

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1. INTRODUCTION

The meat industry is one of the fastest-growing sectors in the food industry and a crucial economic factor expected to rise from 897.5 billion U.S. dollars in 2021 to over 1.3 trillion dollars by 2027 [1]. This growing industry has significantly contributed to improvingthe accessibility and affordability of meat products, gradually meeting the needs of the increasing population. However, several studies have revealed that the meat sector is responsible for numerous environmental problems, prompting a shift towards more sustainable strategies. While sustainability encompasses environmental, economic, and social practices, few studies have assessed the sustainability degree of the sector. Life Cycle Sustainability Assessment is a methodology that offers a comprehensive approach to addressing the three pillars of sustainability: environmental, economic, and social aspects [2]. The examined meat industry plant consists of the production process plant and a Wastewater Treatment Plant (WWTP) installed on-site. The WWTP includes certain equipment, which is partially replaced by several innovative processes, aiming to mitigate the energy and water consumption, while valorizing wastes. The interventions include a wastewater reclamation system, anaerobic digestion to produce biogas for a Combined Heat and Power system, and biodrying of sludge solid biofuel production. Using the LCA tools, the new processes were assessed by evaluating different scenarios, regarding the proportion of wastewater directed to the new treatment system.

2. METHODS

The analysis was conducted in OpenLCA, which is a LCA software. For the full sustainability assessment SOCA v2 database is utilized, which combines PSILCA v3 and Ecoinvent v3.7.1 databases [3]. SOCA database allows complete comprehensive assessment, because it takes into account all the three crucial dimensions of sustainability. The functional unit used for the comparative sustainability LCA is 1 kg of meat products at gate. The boundaries of the system analyzed focus on the meat industrial processing and the waste treatment, thus the impacts of the pig farming phase, the consumption and the end-of-life phase are not considered.

3. RESULTS AND DISCUSSION

The assessment emphasized on four environmental impact categories closely aligned to the goals of the interventions, on four key social risk indicators for the social assessment and on the economic evaluation. Firstly, a comparison between the base case and the scenario where 50% of the wastewater were directed to the interventions system was conducted through an LCSA, which revealed significant environmental, social and cost alleviation. More precisely, a substantial reduction of Freshwater Eutrophication and Human Carcinogenic Toxicity indicators was observed (i.e., 25.9% and 31.5% respectively), while a milder, but still important decrease of the impacts associated to Global Warming and Fossil Resource Scarcity was noticed (i.e., 9.2% and 8.8% respectively). Similar behavior was identified in the endpoint impact categories, achieving critical reductions in the range of 6.3% to 18.2%. As far as the social aspect is concerned, for all the social risk categories considerable reduction was accomplished varying between 33.7% to 37.0%. Regarding the economic view of the interventions, a major cost saving of 484,484€ was reached. To study the impact of each intervention, three scenarios were created with varying proportions of wastewater directed to the new treatment system. The interpretation of the results demonstrated that for higher percentages of wastewater treated in the interventions, the environmental, social and economic categories were all improved.

4. CONCLUSIONS

Consequently, the sustainability assessment has determined that achieving sustainable developmentrequires significant modifications and interventions in the meat processing industry. By introducing the new treatment system in the meat production process, the sustainability of the industry is overall highly promoted.

5. ACKNOWLEDGEMENTS

This research was funded by the project AccelWater, funded from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 958266.

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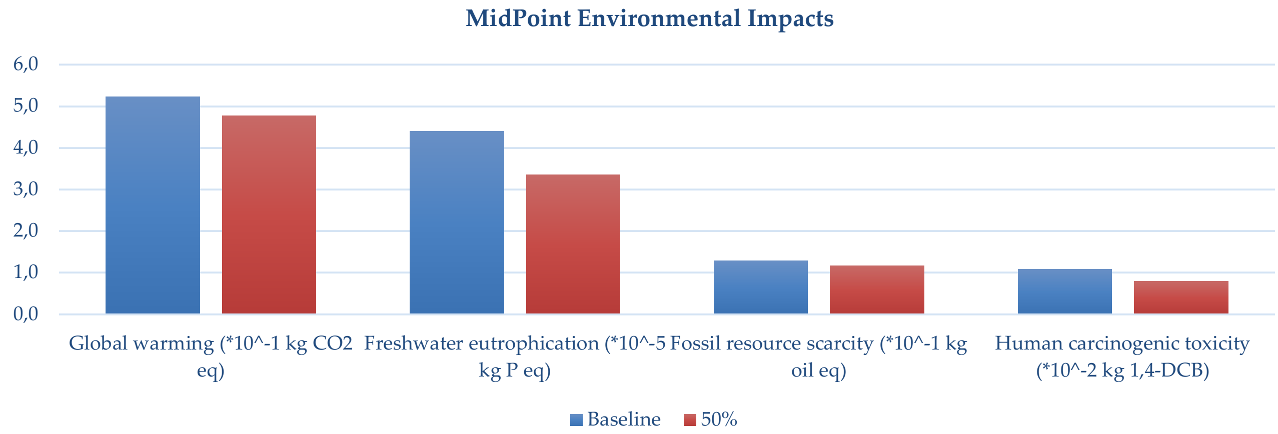

Figure 1Figure 3. Selected indicators of midpoint environmental impacts from the baseline of meat industry compared with the ones after the operation of the interventions

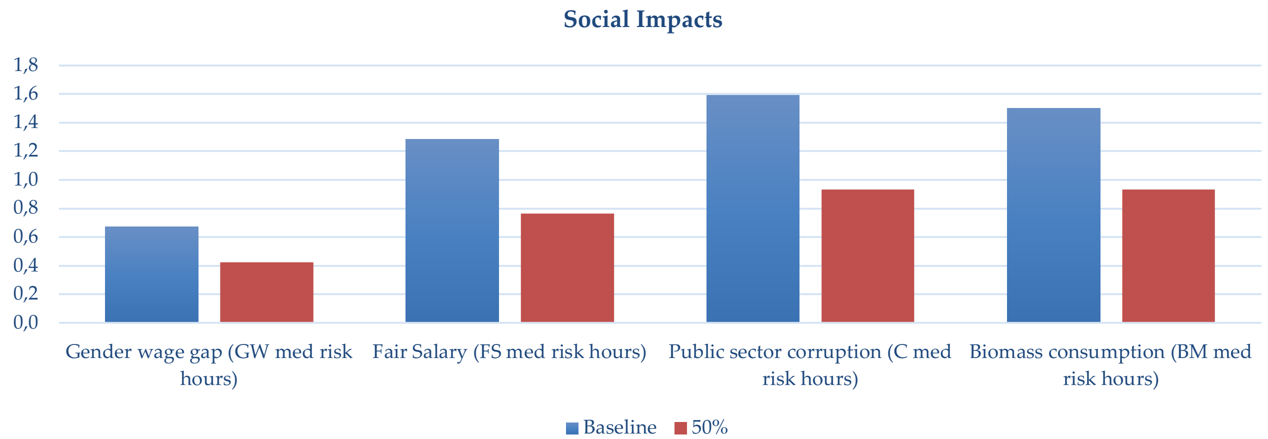

Figure 2 Selected indicators of social impacts from the baseline of meat industry compared with the ones after the operation of future interventions

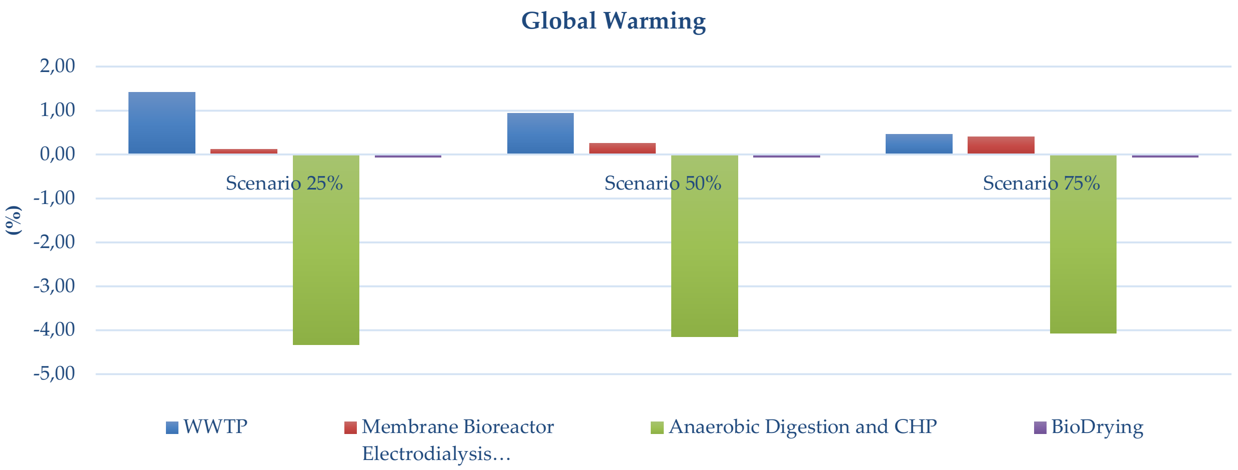

Figure 3 Global warming contributions of the different process of the waste treatment for the three scenarios

Hunting for meat with low greenhouse gas emissions- a case study of wild boar in Sweden

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1. INTRODUCTION

Meat from wild boar (*Sus scrofa*) and other game are often claimed to be climate-smart meat alternatives, since game is considered an elementary flow from nature, and emissions arising from farming such as feed production, digestion, and manure handling, are avoided. Compared to other meats, very few studies have quantified the greenhouse gas (GHG) emissions of game meat. In a previous report, we assessed the GHG emissions of meat from wild boar and fenced fallow deer (Behaderovic & Berglund 2019). The results indicated relatively low GHG emissions from wild boar meat compared to other meats, but the results were based solely on three case studies from Sweden. In this study, we have improved the analysis by including a larger geographical dataset and more parameters. We have also refined the method by including the impact of damage caused by soil uprooting and elaborated on allocation procedures for dividing emissions arising from hunting activities between meat and other benefits that hunting provides.

2. METHODS

The purpose of this study was to quantify the GHG emissions of Swedish wild boar meat, reflecting a national average and, as far as possible, provide results that are comparable with other types of meat. Hence, the method and functional unit (*1 kg of edible meat exiting the game handling facility*) are adapted to facilitate comparability. The system boundary included transportation to and from the hunting area, hunting activities, support feeding and enteric fermentation coupled to support feeding, and activities at the game handling facilities. Data was mainly based on national statistics regarding culled wild boars, edible yield, number of hunters and hunting trips per year. GHG emissions from hunting were fully allocated to the meat, i.e. not considering other benefits of hunting such as recreation or crop protection. However, a sensitivity analysis was conducted on allocation choices.

3. RESULTS AND DISCUSSION

The GHG emissions of wild boar were calculated to be 5 kg CO_2e per kg of edible meat, varying between 2 and 8 kg CO_2e per kg meat in a best- and worst-case scenario, respectively, Figure 1, which can be compared to 4 kg CO_2e per kg edible meat for Swedish domestic pigs. The higher value is explained by the high input demands for generating 1 kg of wild boar meat, compared to farmed pig meat where the inputs are divided by a large meat output. Most emissions arise from transportation of hunters in passenger cars/vans to and from hunting areas. The result is highly determined by the distance driven per kg of meat. Compared to domestic pigs, the results are associated with high variation, as a result of differences between regions in terms of driving distances, amount of meat obtained per hunter and day, etc.

The study also approached the aspect of quantifying damage effects caused by uprooting. While the extent of damage was quantified, the effect converted to kg of carbon dioxide equivalents per kg of wild boar meat was not included in the main results, as we concluded that this cannot be considered anthropogenically caused emissions.

4. CONCLUSIONS

There is potential to reduce the GHG emissions of wild boar meat. One important measure is to reduce the number of km driven per kg of meat, e.g. through more hunters per car or a more efficient hunt. Further, a transition to fossil-free transport by switching to biofuels or electric cars, would enable GHG emissions close to zero. Emissions unavoidable for farmed animals, such as methane and nitrous oxide from digestion and manure, are generated to a very little extent by wild boar. However, the emissions can also increase significantly if few wild boars are killed, if the slaughter yield is low and/or if many long-distance hunters participate.

This study only assessed GHG emissions, and it is worth emphasising that boar meat generates several other benefits. Animal welfare can be considered good as the animals live in the open and no antibiotics are used. In addition, hunting generates recreational value and is needed to control the growing wild boar population. Hence, from a resource perspective, it can be argued that it is important to make use of the meat.

5. ACKNOWLEDGEMENTS

This project has been funded by the Swedish Board of Agriculture, through support for the promotion of wild boar meat in Sweden.

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Figure 1. Greenhouse gas emissions of wild boar meat hunted in Sweden, expressed as CO_2-eq. The worst- and best-case scenario represent data from regions with the longest travelled distances to and from hunting areas and highest support feeding levels respectively regions with the shortest travelled distances and highest support feeding levels.

Evaluation of the ecoefficiency of post-weaned swine production

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1. INTRODUCTION

Considering the importance of pig farming for rural and regional development in various Brazilian states, it becomes essential to conduct studies that seek to link assessments of environmental performance to the economic performance of pig production. Due to the urgency of this theme in livestock chains, especially in swine farming, this study aimed to evaluate the Eco-efficiency of the productive process of a post-weaning piglet-producing property. The Eco-efficiency was analyzed using the Economic Value Added as a measure of the environmental performance of the activity, both assessed for the functional unit of 1 kg of live weight of piglet.

2. METHODS

The present study analyzed the Eco-efficiency of confined piglet production in the post-weaning phase, ranging from 5 to 30 kg, with a stay of 45 to 50 days in the phase. To estimate environmental impacts, the results of greenhouse gas emissions from the Life Cycle Assessment of the production process were used. Economic performance was measured using the Economic Value Added of production. Seven production cycles corresponding to one year of production were evaluated.

3. RESULTS AND DISCUSSION

Overall, the evaluated system showed negative Eco-efficiency (Table 1). Achieving a positive Economic Value Added should be a long-term goal of the activity, aiming at reinvestment in the business to finance technologies and management practices that mitigate environmental impacts (Prates e Bandeira, 2011; Alencar et al., 2019), thereby achieving the expected Eco-efficiency of production. It was observed that the combination of weight gain and days in the phase as a performance indicator has the potential to improve productive Eco-efficiency.

4. CONCLUSIONS

Finding the balance between these two indicators (LCA and EVA) should be the goal of post-weaning piglet production. Evaluating environmental and economic aspects separately is not sufficient to assess the sustainability of a business. From the perspective of joint economic and environmental assessment, eco-efficiency has proven to be a decision-making support tool. Furthermore, the use of Life Cycle Assessment in Eco-efficiency analysis enables swine farmers to identify critical points for improvement in achieving sustainability in their activities.

5. ACKNOWLEDGEMENTS

We thank CAPES and CNPq for the financial support.

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Batch	EVA/ kg WG ($)	CO_2eq./ kg WG	Eco-efficiency ($/ kg CO_2eq.)
1	-0.0339	9.2669	-0.0037
2	-0.0624	7.9142	-0.0079
3	-0.0296	10.8569	-0.0027
4	-0.0456	9.5643	-0.0048
5	-0.0636	9.9021	-0.0064
6	-0.0815	13.825	-0.0059
7	0.0018	9.3389	0.0002

Table 1. Evaluation of the Eco-efficiency of post-weaning piglet production.

Developing a climate scan for pig farms without overlooking the regional policies on nitrogen emissions

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1. INTRODUCTION

There is an increasing demand from governmental bodies, industry, supermarkets and consumers to understand and reduce the climate impact of food. This is particularly true for meat products. Nonetheless, farmers have no insight in their environmental impact and do not know which climate measures are feasible and effective at their farm. Additionally, the Flemish government[1] is actively enforcing the reduction of nitrogen emissions from pig farms. Through co-creation with all involved stakeholders (farmers, scientists, government, meat processors, farmers' union, feed industry, extension officers, etc.), we developed an LCA-based farm-specific climate scan and action plan for pig systems (Klimrek) in Flanders, Belgium. The focus lies on the carbon footprint and how to reduce it, but we include additional impact categories to identify trade-offs. For the acidification/eutrophication impact, ammonia emission reducing techniques[2] (e.g., air scrubbers and specialised housing systems) can play a significant role but are often overlooked. The Klimrek scan accounts for the effect of these techniques.

2. METHODS

The LCA-based climate scan for pig systems consists of an inventory that is completed by a trained consultant during a company visit. Data is collected on feed purchases and production, herd composition, manure management, energy use and water use. Greenhouse gas emissions were calculated using IPCC 2019 guidelines[2] complemented with Flemish-specific data. National emission factors and reduction percentages are used to account for ammonia emission reducing techniques, which were endorsed by an independent scientific body[3]. The average livestock density of six animal categories (piglets, farrowing sows, dry and pregnant sows, fattening pigs, boars and gilts) has to be known for each housing system present at the farm. The system boundary ends at the farm-gate. The functional unit is expressed per kg live weight to the slaughterhouse. After the climate impact is calculated, the consultant proposes climate measures to reduce this impact. Other impact categories are shown on a dashboard to visualize potential trade-offs associated with the proposed climate measures.

3. RESULTS AND DISCUSSION

Five scans were completed for the year 2021. For the year 2022, the scans at those five farms were repeated and four new scans were completed. In total, there are 14 scan results for nine farms.

Figure 1 shows the climate scan results for the nine farms. When looking at the average of the 14 scans, feed (purchase and production) accounts for 65% of the total impact. For this reason, several climate measures that are advised to the farmer are related to optimising the feed conversion ratio. For example, a first quantification at one of the farm shows that fattening intact boars instead of castrated boars (which improves the feed conversion ratio[4]) reduces the climate impact with 3.36%.

The second most contributing subsystem is manure storage with 22%. This subsystem showed an increase in impact for four farms that were scanned for 2021 and 2022 because of the rising temperatures, leading to a higher methane conversion factor[5] for slurry.

Figure 2 shows the effect of taking ammonia emission reduction techniques into account for the acidification impact. For Farm 2, we saw an increase of 35% when we took the reduction of air scrubbers and specialised housing systems out of the equation. This highlights the importance of taking these types of techniques into account.

4. CONCLUSIONS

The scan primarily focusses on the carbon footprint of the farm. Nonetheless, it is important to give a complete and correct message to farmers in order to enable effective and sustainable environmental trajectories. It is therefore necessary to also include other environmental impacts if one wants to avoid trade-offs and comply with a wide range of policies – such as those related to nitrogen pollution and their corresponding mitigation techniques.

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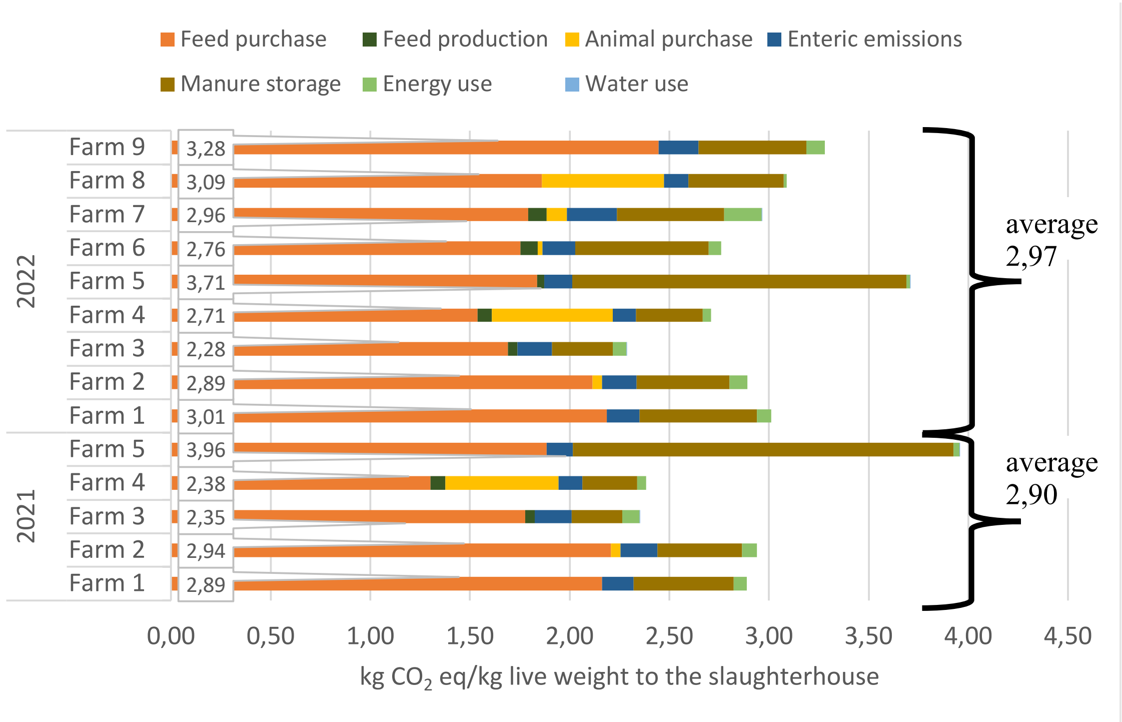

Figure 1. Climate scan results for 14 scans conducted for years 2021 and 2022 at nine pig farms in Flanders, Belgium using the Environmental Footprint 3.1 (adapted) V1.00-method.

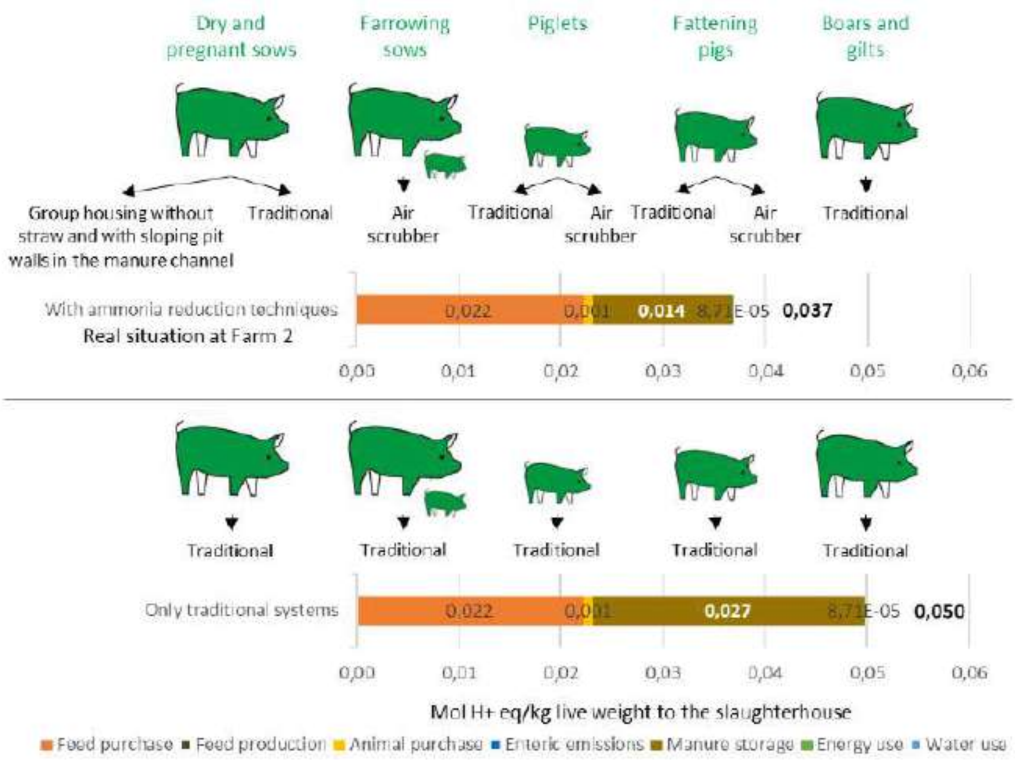

Figure 2. Acidification impact of Farm 2 for the real housing system situation (including ammonia emission reduction techniques) and if only traditional systems were used, calculated using the Environmental Footprint 3.1 (adapted) V1.00-method.

Sustainable livestock systems (III)

1/3

Cropland and carbon footprints of global crop demand for animal feed

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1. INTRODUCTION

Globalization has contributed to the increase in animal products consumption and associated environmental pressures (Lassaletta et al., 2014). Livestock production is a major contributor to the greenhouse gas (GHG) emissions from the global food system, with a large share of feed being traded internationally (Xu et al. 2021). Identifying the sourcing regions, import mixes, and major feedstocks is not easy as supply chains are opaque and complex. This study assesses cropland footprints (LFPs) and carbon footprints (CFPs) of global feed demand in 2013-2020.

2. METHODS

We employ a new Multi-Regional Input-Output model based on FAOSTAT (2024) that traces agri-food supply chains up to food, feed, and non-food uses of 640 products in 181 countries for 2013-2020. Further conversion steps are not covered for meat, dairy, and non-food products. LFPs are calculated under the Leontief approach, applying mass allocation. LFPs capture the total harvested areas needed to produce feed products, considering all intermediate inputs used upstream and their origin. The CFPs are derived from LFPs, countries' feed imports, and GHG emissions from crop production (on-field and input production emissions). N_2O and CH_4 emissions from crop residues decomposition, burning crop residues, and paddy rice production are taken from FAOSTAT. N_2O emissions from synthetic fertilizer application are estimated based on average fertilizer doses in 2016-2019 (FAOSTAT 2024; IFA, 2024) and IPCC 2006 Tier 1 coefficients. GHG emissions from fertilizer and pesticide manufacturing are obtained from FAOSTAT. Fertilizer origin is assumed from FAOSTAT fertilizer export and import data.

3. RESULTS AND DISCUSSION

In 2013-2020, total crop-based feed consumption was 51.6 Gt (compared to 62.9 Gt for food), with China accounting for 10.1% (5.2 Gt vs. 1.72 Gt in EU). The global share of imported feed over total consumption was ~14% through the period. Major grain-producing countries (e.g., Argentina, Brazil, Russia, Australia, USA) show feed import dependencies <5% across years, in contrast to e.g., China (>18%). EU countries rely on imported feed crops to a larger extent: e.g., >40% for Netherlands; >30% for Spain and Ireland; >20% for Austria. EU's imported feed share increased from 13.4% in 2013 to 17.8% in 2019. Grass fodder, maize, maize forage, and alfalfa are the major feedstuffs used worldwide. The largest trade flows are *soybean cake* from Brazil and USA to China, and *brewing or distilling waste* from USA and Canada to China.

China has the largest LFP across the period (78.8 Mha on average), followed by India (37.4 Mha), USA (33.6 Mha), Russia (20.5 Mha), and Brazil (19.0 Mha) (Fig. 1). In the EU, the largest LFPs are for Spain (9.2 Mha), Germany (7.5 Mha), and France (6.5 Mha). Similarly, the largest CFPs (CO_2eq) are estimated for the leading feed consumers, being on average: 130.9 Mt for China, 44.7 Mt for India, 36.7 Mt for USA, 20.6 Mt for Brazil, and 14.5 Mt for Indonesia (Fig. 2). When estimated per unit of feed consumed, the largest CFPs (t CO_2eq t^{-1}) are found for countries in Sub-Saharan Africa and Southeast Asia, e.g., Guinea (0.76), Madagascar (0.53), and Myanmar (0.41) (Fig. 3). These countries use broken rice and rice residues for animal feed in large amounts, with a relatively high GHG emission intensity (tCO_2eq ha^{-1}). It must be noted that CFPs are only associated with primary production and exclude emissions from agricultural machinery operations and industrial processing (work-in-progress). Fertilizer production emissions and CH_4 from rice respectively account for the largest CFP shares in Fig 2. and 3.

4. CONCLUSIONS

Animal feed is highly dependent on the production and trade of agricultural commodities. Crop demand for feed applications has been on the rise in the period 2013-2020, with a relative increase of ~8%. Approximately 14% of the global feed demand is met with imports. This also translates into cropland and GHG emissions associated with crop production being virtually traded from producer countries to the destination countries where feed is ultimately consumed. The largest LFPs and CFPs are found for major livestock producers (China, India, USA, Brazil).

5. ACKNOWLEDGEMENTS

María de Maeztu CEX2021-001201-M, BERC 2022-2025 program; MSCA-IF #101029457.

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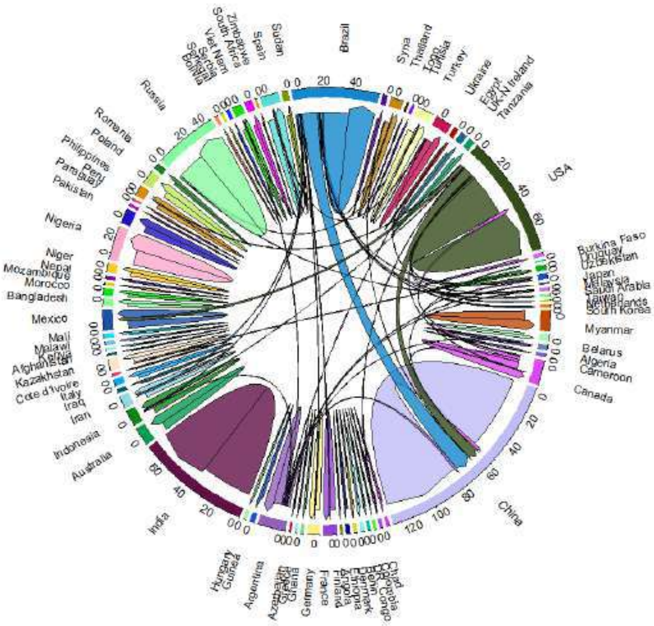

Figure 1. Mean cropland area flows (Mha) between countries (>99[th] percentile) in 2013-2020.

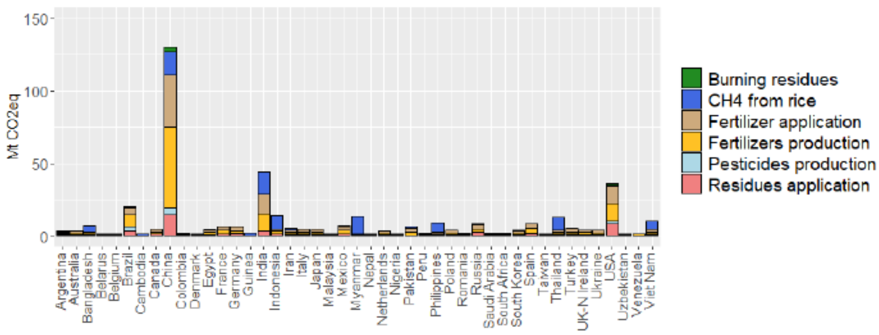

Figure 2. Mean carbon footprints (Mt CO_2eq) of countries (>75[th] percentile) in 2013-2020.

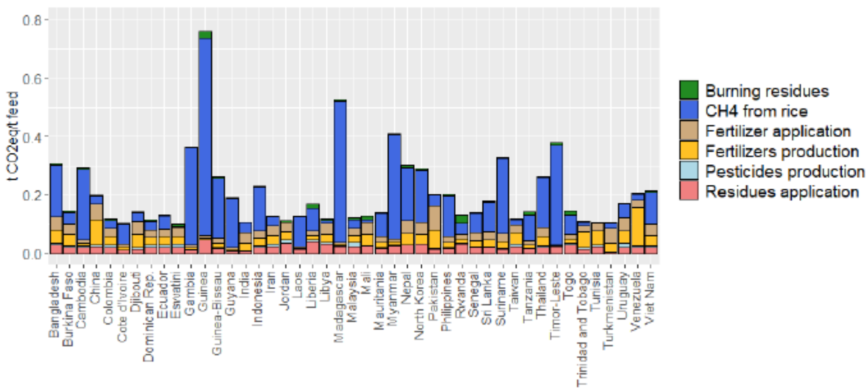

Figure 3. Mean carbon footprints (t CO_2eq t^{-1}) of countries (>75[th] percentile) in 2013-2020.

Spent Coffee Grounds as a sustainable livestock feed ingredient.

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1. INTRODUCTION

There is a worldwide consumption of over 10 million tons of coffee annually, with approximately 2.52 million tons being consumed in Europe. It is estimated that each kg of coffee consumed generates 2 kg of wet Spent Coffee Grounds (SCGs), a sub-product considered food waste (San Martin et al., 2023). SCGs, due to its chemical composition, serve as a rich source of sugars, proteins, oil and lignin, components that are valuable in applications such as animal feed production (Stylianou et al., 2018). However, it´s worth noting that, nowadays, approximately 46% of the total SCGs end up in landfills (San Martin et al., 2021).
The goal of this study was to assess the environmental impact of the valorisation of SCGs as a dehydrated feed ingredient for sheep livestock, an innovative management approach for this sub-product. Furthermore, the results were compared with the environmental impact generated by landfilling and incineration of SCGs.

2. METHODS

The assessment of the environmental performance of the different management systems was conducted following a Life Cycle Assessment approach in order to stablish system boundaries that allow setting a starting point for the comparison between systems. The functional unit was defined as 1 metric ton of managed SCGs, and the system boundaries were defined as follows.
A gate-to-gate of the valorisation plant approach was selected for the valorisation as dehydrated feed ingredient for sheep livestock. An innovative and low energy demanding drying process was included (San Martin et al., 2023) and the impact resulting from the substitution of other feed ingredients was carefully considered.
A gate-to-grave approach was used for the landfilling and the incineration. In the first case, the gate of the landfill was considered and long-term emissions from the aerobic decomposition of organic material were included. In the second, the gate of the incineration plant was considered and burning of organic material in industrial furnace was included.
The 16 environmental impacts assessed were selected following the PEF methodology.

3. RESULTS AND DISCUSSION

The valorisation of SCGs as feed ingredient involves an energy-intensive process that has a notable impact on the environment (+ 208 kg CO_2 eq.). However, the addition of this sub-product to the formulation of the feed prevents the cultivation and production of ingredients such as oat grain and rapeseed meal (- 936 kg CO_2 eq.) and, therefore, the overall environmental impact of the proposed management approach is calculated to be negative (-728 kg CO_2 eq.) (Table 1). A significant reduction is observed when comparing the calculated environmental impact with that of the current management options (landfill and incineration). It is worth mentioning that opting for the proposed management alternative could lead to a reduction of 1500 and 778 kg of CO_2 eq. per ton of SCGs compared to landfilling or incineration, respectively.

4. CONCLUSIONS

The results of this study have demonstrated that valorisation of SCGs as livestock (sheep) feed ingredient is more sustainable than current waste management practices (landfill or incineration). Further environmental gains could be achieved if the impact of the consumed energy is reduced by, e.g., shifting towards renewable sources of energy.

5. ACKNOWLEDGEMENTS

The project Life ECOFFEED (LIFE19ENV_ES_000186) is co-funded by LIFE European Environment Programme, which is the EU's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU.

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Table 1 Environmental impact characterization of the valorisation of 1 ton of SCGs as dehydrated livestock (sheep) feed ingredient

Impact Category	Unit	Valorisation of DSCG	Processing DSCG	Substituted ingredients
Climate change	kg CO2 eq	-7,28E+02	2,08E+02	-9,36E+02
Ozone depletion	kg CFC11 eq	-1,35E-05	1,97E-05	-3,32E-05
Ionising radiation	kBq U235 eq	-4,05E+01	6,16E+00	-4,67E+01
Photochemical ozone formation	kg NMVOC eq	-2,52E+00	2,45E-01	-2,77E+00
Particulate matter	disease inc.	-1,56E-04	2,37E-06	-1,59E-04
Human toxicity, non-cancer	CTUh	-1,31E-05	1,72E-07	-1,32E-05
Human toxicity, cancer	CTUh	1,54E-07	2,50E-08	1,29E-07
Acidification	mol H+ eq	-1,75E+01	3,47E-01	-1,78E+01
Eutrophication, freshwater	kg P eq	-3,81E-01	6,01E-03	-3,87E-01
Eutrophication, marine	kg N eq	-4,07E+00	5,70E-02	-4,13E+00
Eutrophication, terrestrial	mol N eq	-7,45E+01	6,06E-01	-7,51E+01
Ecotoxicity, freshwater	CTUe	-1,35E+05	1,04E+03	-1,36E+05
Land use	Pt	-1,60E+05	1,05E+02	-1,60E+05
Water use	m3 depriv.	-6,56E+04	3,67E+02	-6,60E+04
Resource use, fossils	MJ	-6,43E+03	3,15E+03	-9,59E+03
Resource use, minerals and metals	kg Sb eq	3,32E-03	2,17E-04	3,10E-03

Multi-objective optimization of Canadian laying hen feed formulation for least-carbon footprint and -economic costs

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Keywords: Life cycle optimization; poultry; laying hen

1. INTRODUCTION

Laying hen feeds are traditionally formulated to minimize economic costs subject to nutritional constraints. Optimization of feed formulations for both environmental and economic objectives could lead to large reductions in impacts without commensurate increases in feed price [1] which may translate to large impact reductions in Canadian egg production systems, where feed is an environmental impact hotspot [2]. This work develops a multi-objective optimization model for Canadian laying hen feed formulations, taking into account carbon footprint and economic costs. Regionalized sourcing of potential ingredients is considered, taking into account regional differences in ingredient production practices, estimated soil carbon dynamics and transportation-related impacts and costs.

2. METHODS

Regionalized carbon footprint models representing production of possible ingredients in Canadian laying hen feed were developed based on current best publicly available data [3,4], or derived from third-party life cycle inventory databases. Economic data on ingredient procurement and transportation costs were sourced from the literature. Greenhouse gas emissions, and costs associated with production, procurement, and transportation of potential ingredients to a reference feed mill location were quantified using the CML-IA Baseline impact assessment method. Optimization was performed using the Non-Dominated Sorting Genetic Algorithm II [5], subject to constraints on hen nutritional requirements, and maximum allowable ingredient inclusion rates. Both single- and multi-objective optimizations were performed to investigate how the optimal formulation may change given different objectives.

3. RESULTS AND DISCUSSION

Preliminary results indicate a distinct trade-off between economic cost and environmental impacts. When optimizing for lowest cost, feed formulations include large amounts of high-impact animal co-products, and other ingredients that have low procurement and transportation costs, such as those produced closer to the feed mill location. When GHG emissions are incorporated, almost all animal co-products are removed, with ingredients preferentially sourced from regions predicted to be sequestering carbon dioxide in agricultural soils, despite their relatively higher costs associated with transportation. Depending on how different objectives are prioritized, feed formulation optimization including environmental impacts could result in reductions in GHG emissions per tonne of eggs from approximately 7 – 73% (figure 1). Optimization including GHG emissions may even result in carbon-negative feeds, depending on the methodological choices made regarding modeling of soil organic carbon fluxes.

4. CONCLUSIONS

Optimal feed formulations accounting for GHG emissions and economic costs may lead to large reductions in carbon footprint per tonne of eggs produced. Future model refinement is necessary to take into account a larger array of constraints, particularly related to hen health, additional environmental impact categories, and to incorporate low-impact, alternative ingredients such as black soldier fly larvae, and valorized food waste products.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge Egg Farmers of Canada for providing funding with this study.

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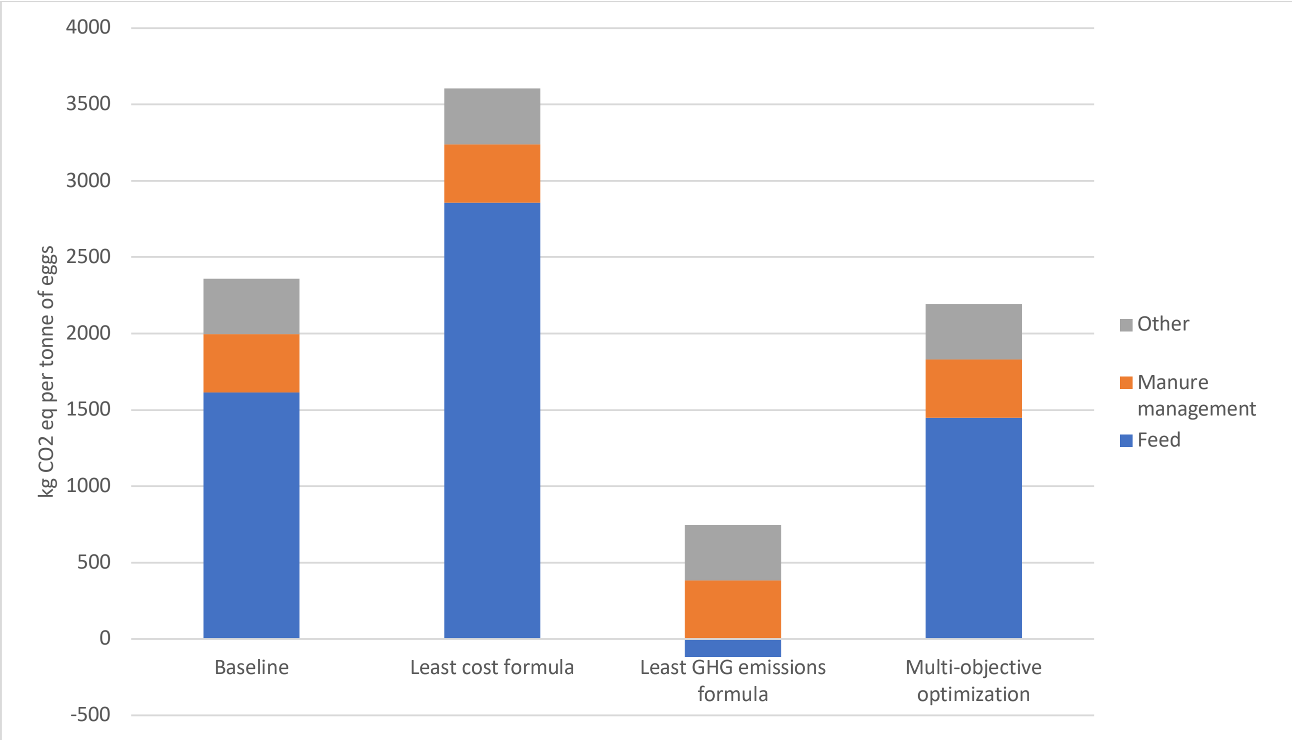

Figure 1. Estimated GHG emissions per tonne of eggs produced in conventional cage systems in Canada using baseline, least economic costs, least GHG emissions optimized feed formulations, and a formula optimized for both economic and GHG emissions, including estimated fluxes of soil orgànic carbon.

Investigation of lay cycle extension as an environmental sustainability improvement strategy for the Canadian egg industry using LCA and predictive modeling

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Keywords: Machine learning; predictive modelling; laying hen; poultry

1. INTRODUCTION

Recently, Egg Farmers of Canada made a commitment to reach net-zero GHG emissions status by 2050 [1]. One potential strategy for reducing environmental impacts, including GHG emissions, is the extension of lay cycle lengths beyond the current 52-week average, which is considerably shorter than industrial production norms elsewhere in the world [2]. If lay persistency and egg quality can be maintained, increasing productivity could lead to reductions in environmental impacts [3]. This analysis therefore sought to investigate the potential changes in environmental impacts associated with extension of Canadian lay cycles from 52 to 100 weeks in length.

2. METHODS

Predictive models were generated for productivity, mortality, feed and water consumption, and losses due to deteriorating egg quality for hypothetical lay cycles of each length from 53 to 100 weeks in caged and cage free production systems. These models were developed using a combination of primary data from Canadian and U.S. egg farmers, scientific literature, and relevant hen breed management guides. Different strategies for filling data gaps, data augmentation, and predictive frameworks were explored to determine the combination best suited for the available data. The predicted data were used to generate LCA models of Canadian egg production in caged and cage free systems for lay cycles of each length from 53 to 100 weeks, and environmental impacts per tonne of eggs sold were estimated using the CML-IA Baseline impact assessment method. A sensitivity analysis was performed in which cumulative losses were assumed to be zero for all cycle lengths to investigate the degree to which observed trends in impacts per tonne of eggs were driven by increases in cumulative losses as hens age.

3. RESULTS AND DISCUSSION

Predictive modeling revealed that, as cycle lengths increase, rate of lay and feed consumption per bird are expected to decrease, while cumulative losses are expected to increase. Despite the predicted decreases in individual feed consumption, predicted decreases to rate of lay and increasing losses as hens age resulted in net losses to feed use efficiency at the flock level. This led to net increases in environmental impacts per tonne of eggs sold (figure 1) as lay cycles were extended. While impacts related to pullet inputs were predicted to decrease as cycles extend due to increased productivity, these decreases were more than offset by increases in feed-related impacts. When cumulative losses were assumed to be zero across all cycle lengths, the magnitude of increases in impacts from 53 to 100 weeks was reduced (figure 2), but the trend of increasing impacts with cycle lengths persisted, suggesting that maintenance of rate of lay is the key determining factor in the efficacy of lay cycle extension as an environmental impact mitigation strategy.

4. CONCLUSIONS

These results suggest that extension of lay cycles beyond current norms may not be an efficacious strategy for improving environmental sustainability outcomes in the Canadian egg industry, unless considerable improvements with respect to maintaining lay persistency and egg quality are achieved. Further expansion of this project is currently proposed to integrate data from Canadian farms currently operating extended lay cycles to compare estimated impacts generated from predicted, and real-world data. Potential economic and social impacts, including animal welfare impacts, must also be assessed to further examine the efficacy of lay cycle extension as a sustainability improvement strategy for the Canadian egg industry.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge Egg Farmers of Canada, Egg Farmers of Alberta, and Results Driven Agricultural Research for providing funding with this study, as well as Dr. Maurice Doyon and Dr. Ousmane Z. Traoré for their collaboration on this project.

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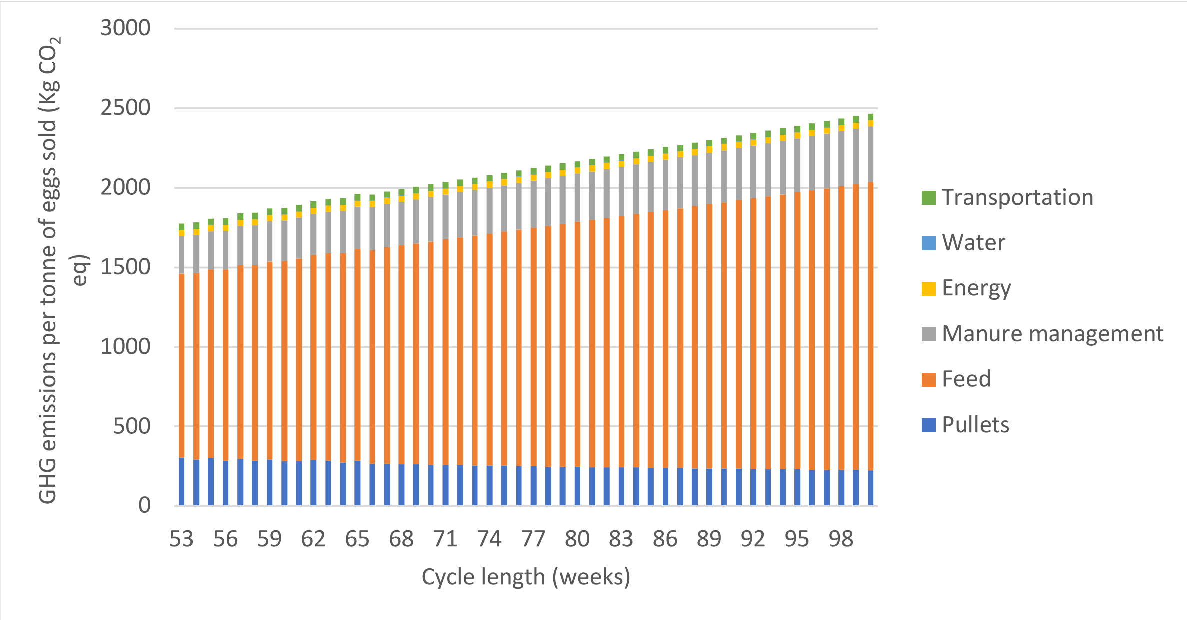

Figure 1. Estimated greenhouse gas (GHG) emissions per tonne of eggs sold from conventional cage systems operating cycle lengths from 53 to 100 weeks

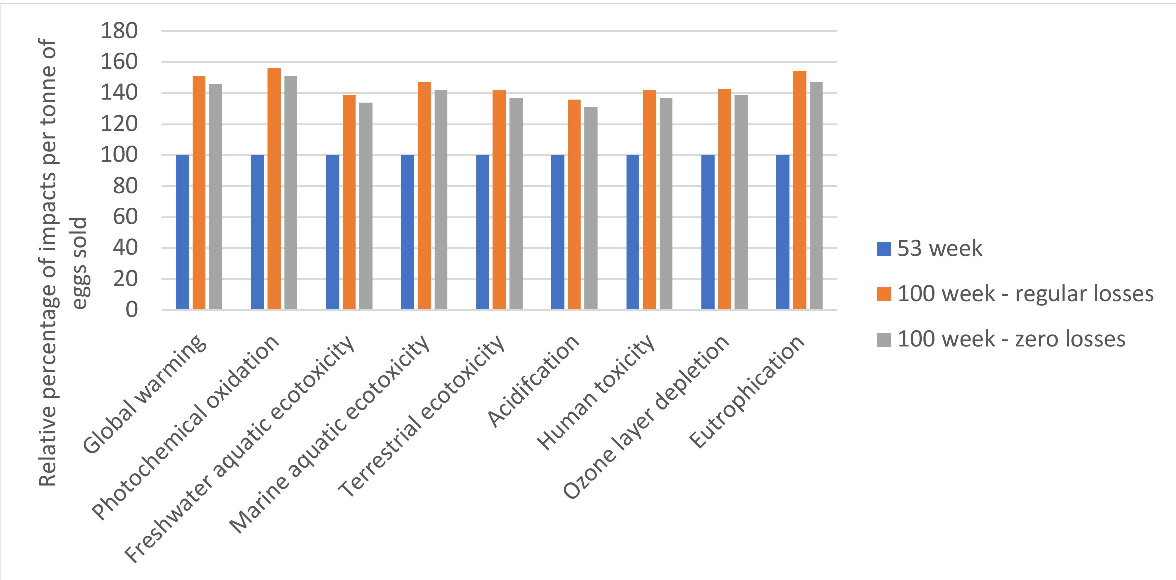

Figure 2. Relative increases in estimated impacts per tonne of eggs sold from conventional cage systems when lay cycles are extended from 53 to 100 weeks, assuming both regular increases in loss rates and zero cumulative losses as hens age

Ecosystem services and life cycle assessment frameworks provide opposite assessments of animal-production systems

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1. INTRODUCTION

Life cycle assessment (LCA) and ecosystem services assessment (ESA) are often used for environmental evaluation. LCA is a product-based method commonly used to assess negative impacts of human activities, whereas ESA is ecosystem-based and focuses on positive effects. According to LCA, high-input animal-production systems tend to perform better per unit of product than low-input ones (van der Werf et al., 2020), whereas it is presumably the opposite for ESA (Dumont et al., 2018). The choice of the assessment framework can therefore have major implications on the choice of the most pertinent animal production system to produce human edible proteins, in the global agri-food system. Here, we applied both assessment frameworks to a range of contrasting meat production systems to assess the extent of their presumable antagonism.

2. METHODS

We used a selection of twelve contrasting French meat-production systems from the Agribalyse 3.01 database. We selected two ruminant species (sheep and cattle) and two monogastric species (chickens and pigs), and used Agribalyse inventory data to estimate the LCA environmental impacts of the systems, using OpenLCA 1.11 software and the Environmental Footprint (EF) 3.0 method. We also used the inventory data to describe the range of land covers involved in the animal production, e.g. cropland, temporary or permanent grasslands. We calculated the areas of each land cover type required to produce one kg of human edible protein (m2yr) and from these areas, we estimated scores of provisioning and regulating ecosystem services (ES). We defined the provisioning ES score as the inverse of the total area*time used to produce one kg of protein; and the regulating ES score as the average score of all covers, weighted by their area*time. The score of each cover was defined based on an extensive literature review and expert adjustment, following the methodology by Campagne and Roche (2018).

3. RESULTS AND DISCUSSION

We found that the mean environmental impact of ruminant meat per kg edible protein was higher for all the usual LCA EF midpoint categories (Tab. 1), which is consistent with numerous previous studies (e.g. Poore and Nemecek, 2018). We also found very distinct land covers for both types of animal, with ruminant systems requiring larger areas of land than monogastric systems (Tab. 1). As a result, monogastric systems had on average higher provisioning ES scores than ruminant ones (Tab. 1). However, ruminants had grasslands in their land cover profile, whereas monogastrics mostly had croplands. As grasslands have higher regulating ES scores than croplands, ruminant systems had higher mean regulating ES scores than monogastric ones (Tab. 1 and Fig 1). We thus observed that animal types had opposite trends in terms of LCA impact and regulating ES.

4. CONCLUSIONS

Our results confirm the antagonism between the LCA and ESA results for our meat production systems. They indicate that evaluations based on LCA or ESA only would be incomplete, and stress the urgent need to reconcile these frameworks, as they can guide decision-making in opposite directions. Some methods have been proposed over the last decades by academics in this aim (e.g. (Boone et al., 2019)), but as far as we know, they are not yet fully deployed.

5. ACKNOWLEDGEMENTS

This study was funded by Interbev, the French inter-branch organisation for the livestock and meat industry.

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Table 1. Land covers and combined environmental assessment of the studied meat production systems per kg of human edible protein

Meat production systems	Ruminant	Monogastric
Mean land covers (from Agribalyse inventory data)		
Total area per kg human-edible protein (m^2yr)	856	62
% Grasslands (temporary and permanent) and meadows	0.90	0.03
Ecosystem Service Assessment		
Mean provisioning ES score (-)	0.25	2.61
Mean regulating ES score (-)	2.42	1.15
Life Cycle Assessment (mean of a selection of EF Method 3.0 indicators)		
Acidification (mol H+ eq)	3.53	0.90
Climate change (kg CO_2 eq)	279.68	31.84
Human toxicity, cancer (CTUh)	6.06E-08	3.27E-08
Human toxicity, non-cancer (CTUh)	1.97E-06	1.67E-06
Ionising radiation (kBq U-235 eq)	4.58	3.08
Ozone depletion (kg CFC11 eq)	4.32E-06	1.78E-06
Particulate matter (disease inc.)	2.35E-05	6.15E-06
Photochemical ozone formation (kg NMVOC eq)	0.34	0.08
Resource use, fossils (MJ)	351.31	188.74
Resource use, minerals and metals (kg Sb eq)	8.52E-05	3.32E-05
Water use (m^3 depriv.)	44.52	32.64

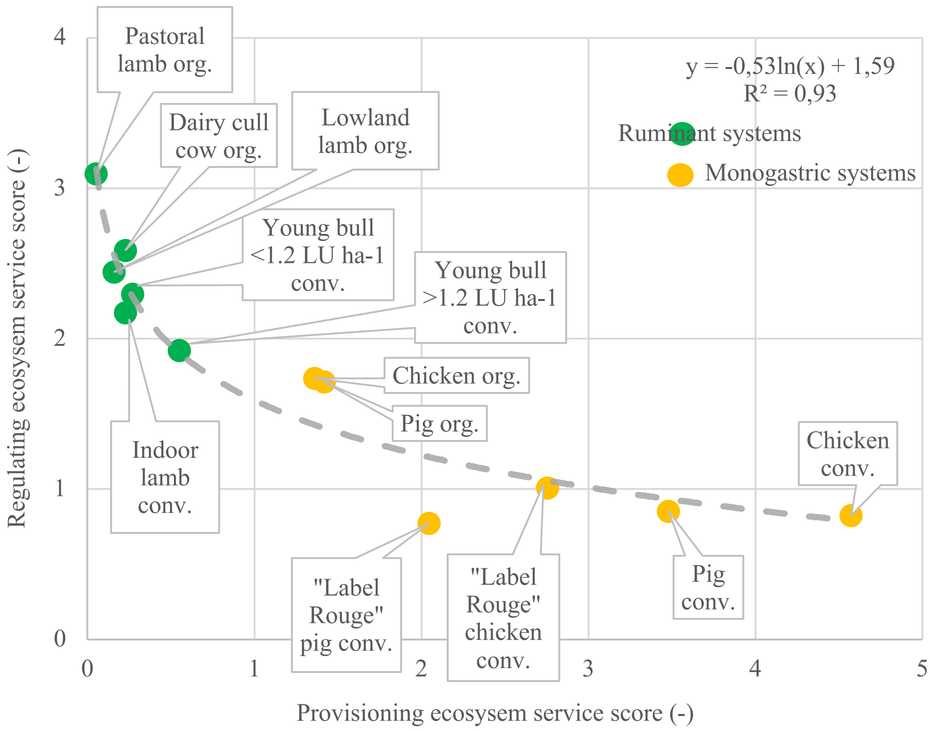

Figure 1. Ecosystem service scores of the twelve studied meat production systems. Org. organic, conv. Conventional. LU: Livestock units. “Label Rouge” is a French line of products of quality.

Food loss and waste: environmental impacts and solutions

Sensor-based solution in retail food waste reduction: an LCA perspective on uncertainties and impacts

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1. INTRODUCTION

A report estimates that 10–50 million tons of food will be saved in distribution if the *Internet of Things* (IoT) is implemented in 50-75% of developed countries' supply chains by 2030. Innovative technologies are often presumed to prolong the shelf life of perishable foods, but the intricate relationship between the sensor-based system and losses reduction and their embodied environmental consequences is not well understood due to uncertainties in environmental conditions (e.g., temperature) along the value-added chain. Therefore, this study aims to provide a computer-simulated multi-commodity accounting framework to quantify *food loss and waste* (FLW) savings and their environmental impacts potentially by stage by product from digital sensor-based solution in China's fresh food chains.

2. METHODS

Figure 1 provides a snapshot of a standard food supply chain, highlighting the path of fresh food as it travels from suppliers to retail stores until consumers. Our study introduced a shelf-life prediction model that describes fresh food's shelf life as a function of temperature and time based on the Arrhenius law. We calculated FLW avoidance between the novel *Dynamic Shelf Life* (DSL) and the traditional *Fixed Shelf Life* (FSL) systems by evaluating the extended usable life of various food categories under optimal conditions under the process-based *Life Cycle Assessment* (LCA) approach. The percentage of waste savings for different life-cycle stages is shown in **¡Error! No se encuentra el origen de la referencia.**. The objective enabled a comprehensive understanding of the potential impact of DSL systems on reducing FLW in the context of perishable food chain in China. The function unit was defined as its waste reduction used 1-ton products avoided ("farm-to-retail") and then scaled up to the total input of fresh produce and the corresponding output for the China food system. Food consumed in households or during out-of-home consumption was excluded from our computations.

3. RESULTS AND DISCUSSION

3.1 Food waste estimation

Figure 2 displays the percentage of avoided food waste for various food categories, including vegetables, fruit, meat, fish & seafood, and dairy (milk). Food waste avoidance in vegetables is primarily distributed between 6.1% to 8.2% (Q1-Q3). This suggests a moderately narrow distribution with consistent food waste prevention methods applied for this category. However, variance occurs among avoidable food waste categories, which could stem from different storage conditions, product types, or inconsistencies in quality control.

3.2 Climate change impact of FLW savings

This abstract only displays the greenhouse gas impacts of FLW savings. As shown in Figure 3, the DSL system showed significant potential in reducing the carbon footprint (CF) associated with FLW across the food supply chain in China. A reduction of approximately 58.73±10.46 $MtCO_2$-eq was observed, which is around 9.4% of China's FLW-associated CF and 6.4% of total CF from the Chinese agricultural system. Notably, the largest contributions to CF reduction came from beef, fish & seafood, and pork.

4. CONCLUSIONS

A critical aspect of this study is the comparison between DSL and FSL, revealing that DSL could reduce food waste to some extent. On a national scale, the implementation of a sensor-based DSL system in China's fresh food chain could potentially avoid approximately 58.73±10.46 $MtCO_2$-eq annually.

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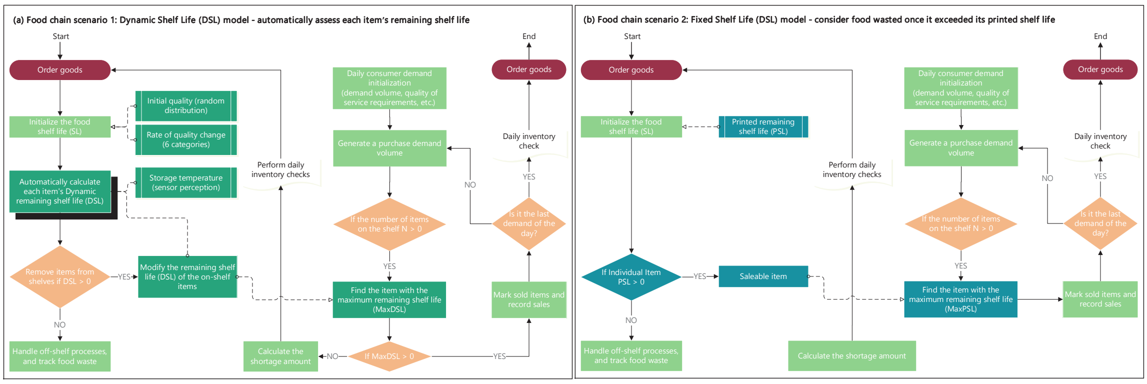
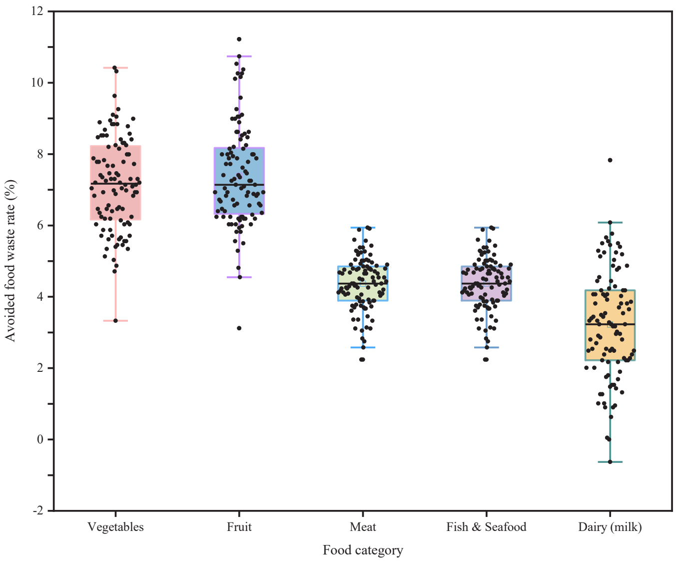
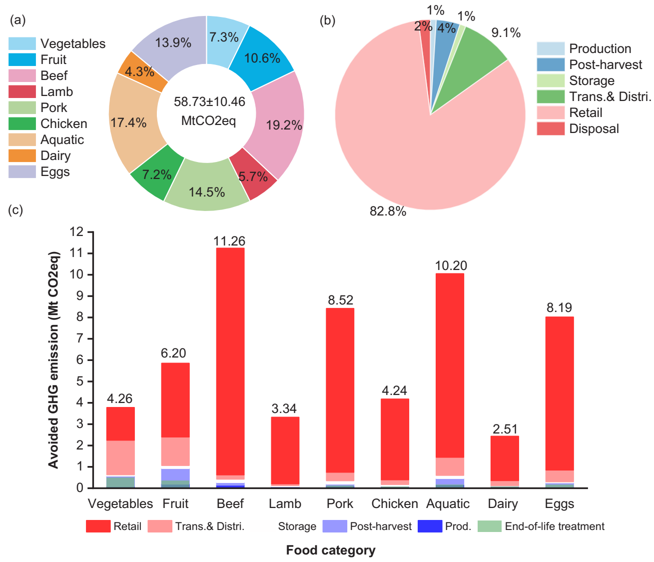


[Figure 1](#) Comparisons of the conventional FSL and DSL models for temperature-sensitive food systems



[Figure 2](#) Avoided food waste rate of different food categories



[Figure 3](#) Estimated climate change mitigation due to FLW avoided by sensor-based DSL system in China

[Table 1](#) Avoided food waste rate along the FSC based on the sensor-based DSL system

Category	Production, %	Post-harvest, %	Storage, %	Trans & Distri., %	Retail, %
Vegetable	5.95	6.4	4.0	4.1	6.45 ±1.30
Fruit	5.95	6.4	4	4.1	5.54 ±1.22
Meat	1.33	1.22	1.44	2.43	4.31±0.56
Aquatic	2	3.33	0.79	4.08	4.14±0.54
Milk	0.3	0.6	0.77	2.89	3.43±1.78
Eggs	0.66	0.41	0.65	2.35	6.53±1.63

Consequential Life Cycle Assessment of a Novel Resource Recovery Solution for Food Waste Management

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1. INTRODUCTION

Annual GHG emissions from food waste (FW) in the UK was estimated as 27 Mt CO_2eq, accounting for 5.9% of national GHG emissions (Jeswani et al. 2021). Anaerobic digestion (AD) can not only produce biogas for renewable energy but also nutrients from digestate, which can mitigate GHG emissions (Chozhavendhan et al. 2023). Perspective assessments of strategies can support decision making for policies and investments (Adrianto et al. 2021), while consequential life cycle assessment (cLCA) method has been suggested as one of the methods (Weidema et al. 2018). However, studies of cLCA application on FW management with resources recovery in the UK's AD industry is not well established to inform decision-making.

2. METHODS

This study follows ILCD guidance (European Commission 2010), defining the goal as to assess impacts of climate change, freshwater eutrophication, terrestrial acidification, and water consumption of the proposed resource recovery (RR) solution, supporting decision making for UK's FW management with the AD. The scope of this study covers AD activities and RR processes, as shown in Figure 1 (system boundary). The AD activities include FW collection and pretreatment, biogas production and use, and water use for equipment management. The RR unit designed by the project NOMAD (https://www.projectnomad.eu/), consists of solid-liquid separation, antibiotic removal, and nutrient recovery processes, to generate organic fertiliser and water. Two scenarios were established, a Business-As-Usual (BAU) scenario and a RR scenario. BAU scenario includes the AD activities, and the pasteurised liquid digestate was delivered for storage and land application. RR scenario also covers the AD activities, but the digestate is treated in the RR unit. Generated water was used onsite while recovered nutrients (organic fertiliser) were applied to lands. The RR unit was powered by electricity produced by biogas. The surplus water and power were exported to the market. The functional unit (FU) is processing one tonne FW. The environmental impacts were assessed, following the ReCiPe 2016 method (Huijbregts et al. 2017). The average data for foreground of the system boundary was collected from the AD plant, project NOMAD, and literature, while marginal data from Ecoinvent database (Wernet et al. 2016) was used for the background.

3. RESULTS AND DISCUSSION

The overall results show that, with the proposed RR solution, FW management with the AD in the UK has more environmental advantages than the BAU scenario in all studied impact categories (see Figure 2). Introducing the RR unit brings negligible impacts for FW management with the AD. Turning digestate into organic fertiliser, the RR scenario saves impacts caused by digestate storge, reducing impacts of 4.5 kg CO_2eq/FU and 1.8 kg SO_2eq/FU. Credits claimed for avoidance of mineral fertiliser in the RR scenario are more than that in BAU scenario for all impact categories, due to high-quality organic fertiliser produced. Exported water can further offset impacts for water consumption impact categories (-0.3 m^3/FU).

4. CONCLUSIONS

This study assessed the environmental impacts of a novel solution for FW management with the AD, and better environmental impacts were observed. Recovering nutrients and water from digestate can reduce impacts by avoiding digestate storage and offset impacts by credits claimed for exporting high-quality organic fertiliser and water. However, further studies are recommended to provide insights economically and socially.

5. ACKNOWLEDGEMENTS

This work was supported by the European Union’s Horizon 2020 research and innovation programme [grant number N° 863000].

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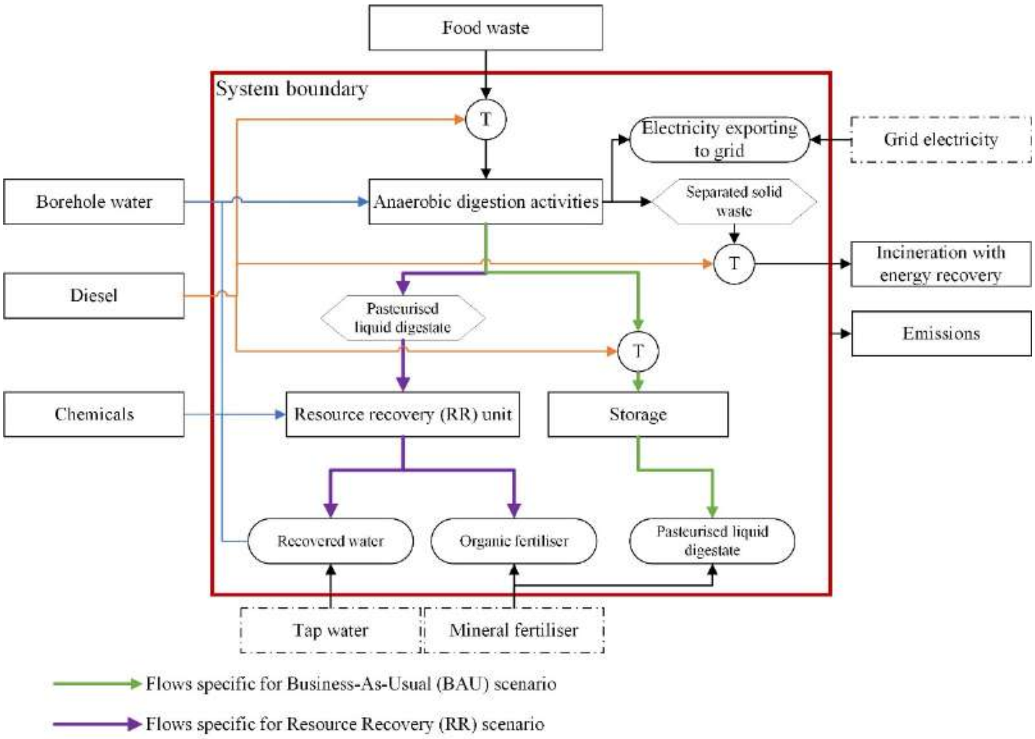

Figure 1. System boundary in this study.

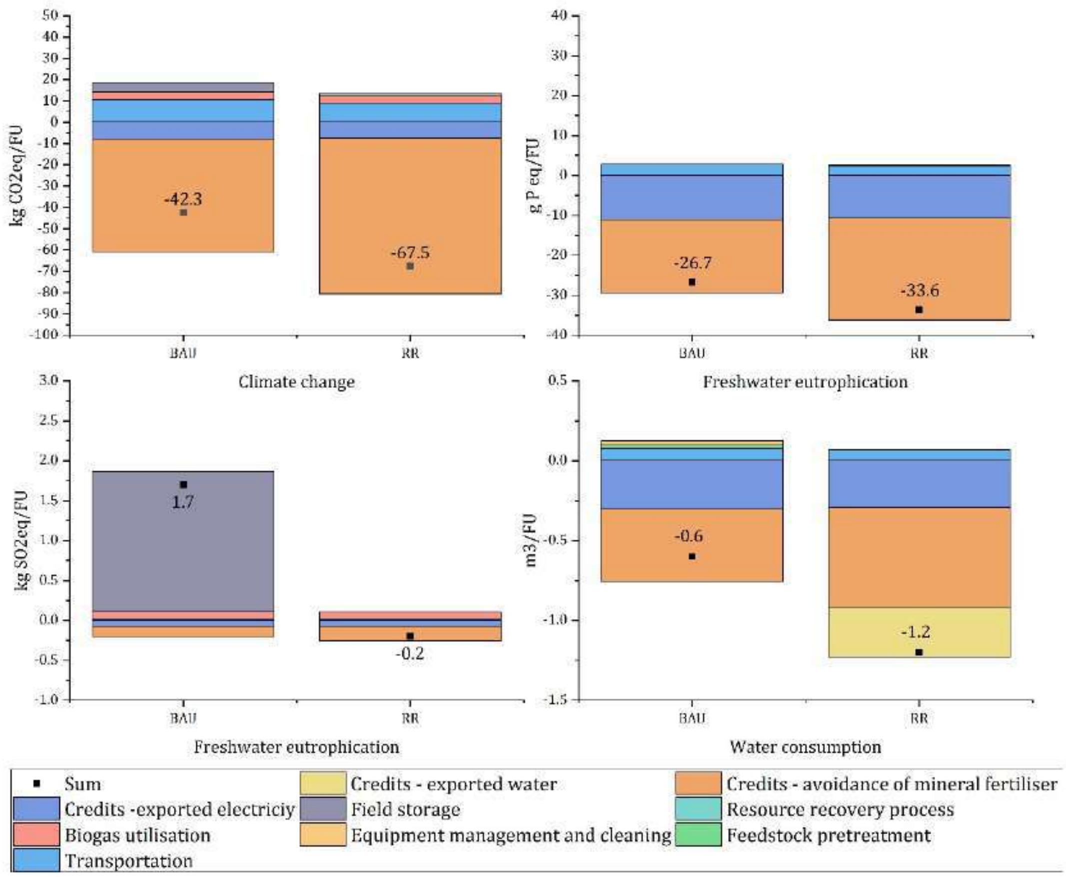

Figure 2. Breakdown results of the impact categories studied.

Evaluate environmental impacts of uneaten food in the food chain

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1. INTRODUCTION

The environmental impacts of our food system are substantial, and a great share of this can be attributed to food that is being lost and wasted (FAO, 2014, Poore and Nemecek, 2018). Reducing Food Loss and Waste (FLW) along the supply chain and at the consumer level is put forward as one of the main solutions to reduce our dietary impacts (Willett et al., 2019). To better evaluate our dietary impacts, the present paper analyses methodological approaches for assessing the environmental impact of diets and dietary scenarios, and how FLW can be considered in the calculations.

2. METHODS

The impacts of the food we eat, have to be calculated based on the premise that a higher amount of this food needs to enter the post-harvest chain in order to account for FLW. When calculating dietary impacts, decisions on which dietary data source is used to formulate a diet and which system boundaries are chosen for the assessment determine which Food Quantities (FQs) travel through the food chain, how impacts are calculated and how FLW is being included in the calculations (Table 1). The aim of this scenario analysis was to show how these decisions affect the FQs that spread along the food chain and thus affect the calculated impacts.

3. RESULTS AND DISCUSSION

As shown in the left part of Figure 1, impacts of a food availability-based diet are calculated for a FQ equal to this Food Availability Amount (FAA). In a cradle-to-retail approach, impacts are calculated for FAA at retail-gate (where usually food expenditure amounts appear). Next, if Supply Chain FLW (SC-FLW) would be considered, an additional amount of food is assumed to enter at farm-gate to obtain the FAA at retail-gate, which does not correspond to reality, resulting in too high FQs and thus an overestimation of impacts. If SC-FLW would not be considered, an amount equal to FAA enters the food chain at farm gate. However, this approach would then assign all supply chain impacts to the whole of FAA. In reality though, not all FAA reaches the retail-gate as a share of FAA ends up as SC-FLW. Those FQs that go wasted, accumulate only a share of the supply chain impacts. The moment they become FLW, an additional waste treatment impact is to be expected. Depending on where along the chain the food ends up as SC-FLW and how big the waste treatment impacts are, the calculated impacts would under-/or overestimate real impacts. Using the cradle-to-farm approach avoids this issue as it places the FAA at farm gate, right where it belongs. However, both approaches would underestimate real impacts as not all life cycle stages are considered (left part of Figure 1). Even though the cradle-to-mouth approach would include all life cycle stages, the fact that this would place the FAA at the consumer-gate (and not at farm-gate where it belongs) would result in an over- or underestimation of the impacts.

With food intake data, the FQ for which impacts are calculated refers to the consumer-gate (case study not depicted here). Using a cradle-to-farm/retail approach would place these FQs at farm- or retail-gate resp. Using the same line of argumentation as above, only a cradle-to-mouth approach which considers Consumer FLW (Co-FLW) and SC-FLW, would result in an accurate calculation of the dietary impacts.

4. CONCLUSIONS

The environmental assessment of diets is based on a range of methodological decisions. The interplay between the dietary data sources a diet is built on, the chosen system boundary and whether or not FLW is considered in the assessment, determines for which FQs impacts are calculated and how impacts are assigned to these FQs. Only a cradle-to-mouth assessment of a diet based on food intake data and which considers both Co-FLW and SC-FLW, would result in an accurate dietary impact calculation.

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Table 1. Dietary data sources used for defining a diet: food quantities included in each of the data sources and entry points in the food chain the total food quantity refers to.

Dietary data source	**Food quantities included**			**Entry point along the food chain to which this food quantity refers to**
	Food that is eaten	Food that is lost and wasted at the consumer (Consumer FLW)	Food that is lost and wasted along the supply chain (Supply chain FLW)	
Food availability data	x	x	x	Farm-gate = the food quantity entering the post-harvest chain
Food expenditure data	x	x		Retail gate = the food quantity entering the consumer stage
Food intake data	x			Consumer-gate = the food quantity entering the consumer mouth

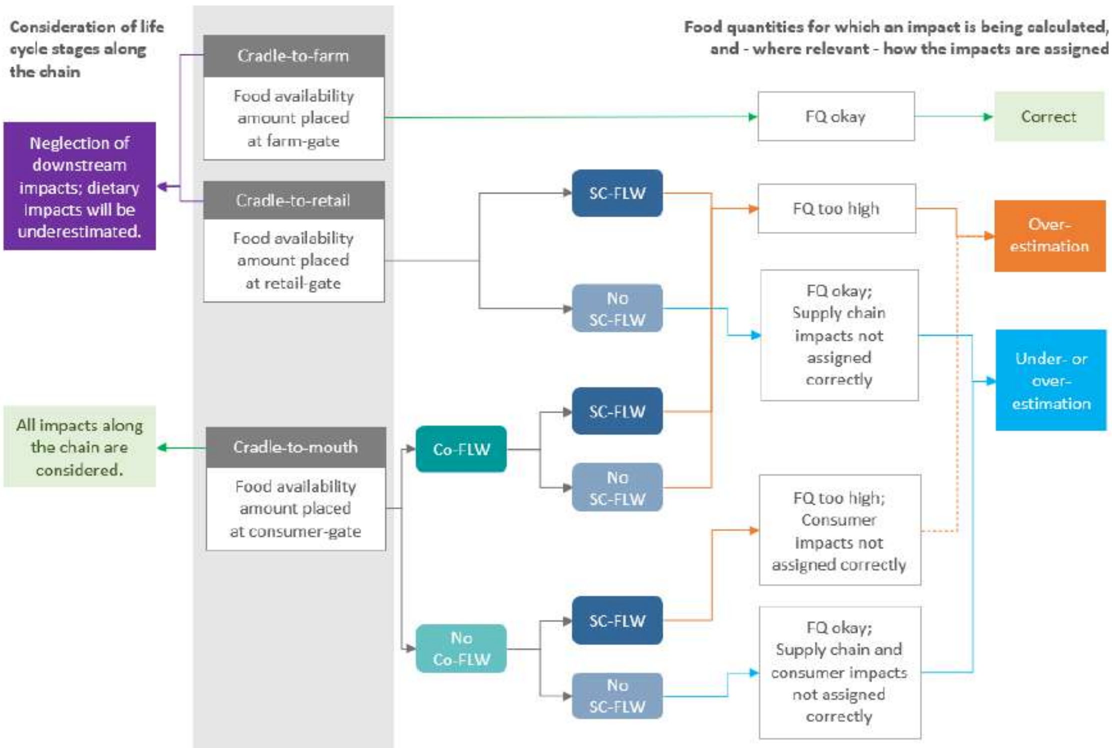

Figure 1. Case study of using food availability data to formulate a diet: flow of food quantities (FQ) for each of the three system boundary choices and for each choice of inclusion of supply chain or consumer FLW (resp. SC-FLW and Co-FLW) in the assessment. Dotted arow lines hereby stand for likely consequences, for which the outcome is not certain.

Environmental impact of food losses and food waste of the milk sector in Catalonia, Spain

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1. INTRODUCTION

This study aims at quantifying the environmental impact of food losses and waste in the context of a broader project that the government of Catalonia (North-Eastern Spain) is running since 2019. The list of products assessed in the project is the following: apple, peach, pear, orange, zucchini, tomato, artichoke, UHT whole cow milk, fresh whole cow milk, plain yoghurt, and fresh pork meat. However, due to abstract length constraints, its content focuses on the dairy sector only. The presentation in the conference will encompass all products assessed.

2. METHODS

The functional unit of the study was 1 kg of final product (UHT milk, pasteurized milk, and plain yoghurt), excluding packaging weight. The scope of the study was from cradle to retail gate, including industry and distribution centres. For each product and stage, an inventory was developed from primary data (2022) collected through interviews, online questionnaires, field visits, and literature following the PEFCR of Dairy Products (European Commission, 2018). Secondary data were retrieved from Ecoinvent 3.9 (Wernet et al., 2016) and Agribalyse 3.1.1 (Asselin-Balençon et al., 2020). Food waste was quantified using the same sources consistently (CREDA-UPC-IRTA et al., 2024 under review). The environmental assessment was performed using the Environmental Footprint method v3.1 (European Commission, 2013).

3. RESULTS AND DISCUSSION

Focusing on climate change, farms contributed with around 65% of the impact for plain yoghurt and around 80% for UHT whole milk production (Table 1). The industry stage was the second largest contributor to climate change (15% to 25% of the total). All the impact to the water use category comes from the farm stage. This is explained by the water recovery with a water treatment plant in industry stage, resulting in a small irrelevant water loss. Focussing on farm stage, due to their optimisation in the use of resources and other technological improvements, the impact of producing raw milk in farms with greater capacity is lower than the ones with less than 140 heads of livestock (approximately 0.3 kg CO_2 equivalent more per kg of fat protein corrected milk for the smaller farms). In this stage the processes with a larger contribution to the environmental impact are the feed and fodder production, the enteric fermentation emissions, the manure management emissions, the diesel consumption, and water consumption. Regarding food losses and food waste, a greater amount of milk losses occurs in industry stage during milk processing (mostly because of internal quality milk analysis, errors in product labelling, and sanitary causes). The industry stage has a greater contribution in three impact categories, all of them specially related to the use of different types of energies and plastic packaging.

4. CONCLUSIONS

Project results show that farm stage is the one with the greatest contribution in 11 out of 16 environmental categories except for plain yoghurt production, for which it is the greatest in 9 out of 16. In consequence, efforts to improve environmental impact should start in this stage, for example, applying best available techniques to reduce emissions or considering different feed ingredients to improve animal production environmental performance. On the other hand, although the industry stage is not the major environmental impact contributor per kg of product, it is the stage in which a greater milk loss occurs, efforts should be made to improve the milk processing chain.

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Table 1. Cumulative impact of kg of product, food losses, and food waste for climate change and water scarcity for each milk product and stage included in 2022 in Catalonia.

Product	**Stage**	**Climate change (kg CO_2 eq)**		**Water use (m^3 depriv.) (user deprivation potential, deprivation-weighted water consumption)**	
Unit		**Per kg of product lost or wasted**	**Per the total amount of food losses or waste produced along the production and distribution chain (accumulated)**	**Per kg of product lost or wasted**	**Per the total amount total tons of food losses or waste produced along the production and distribution chain (accumulated)**
UHT Milk	**Farm**	1.17	9.61E+06	7.84	2.19E+11
	Industry	1.38	2.14E+07	7.55	1.17E+08
	Distribution centre	1.40	1.22E+05	7.56	6.59E+05
	Retail	1.42	9.55E+05	7.58	5.09E+06
Pasteurized or fresh Milk	**Farm**	1.17	9.61E+06	7.84	2.19E+11
	Industry	1.47	2.04E+07	7.57	1.05E+08
	Distribution centre	1.50	1.64E+05	7.65	8.39E+05
	Retail	1.58	2.56E+05	7.73	1.25E+06
Plain yoghurt	**Farm**	1.17	9.61E+06	7.84	2.19E+11
	Industry	1.66	2.37E+07	7.48	1.07E+08
	Distribution centre	1.73	1.56E+06	7.58	6.83E+06
	Retail	1.80	5.89E+05	7.64	2.49E+06

Direct valorization of grocery food waste for poultry feed: opportunities to improve sustainable egg production

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Keywords: Food waste; feed; valorization; egg production; avoided landfill emissions; LCA

1. INTRODUCTION

Food waste remains a major sustainability challenge of our time, characterized by high environmental burdens as food is often the end product of complex processing and supply chains. Furthermore, landfilling is a common method of disposing of food wastes, which generate potent greenhouse gases (GHGs) and significantly exacerbates climate change. On the other hand, feed use has been identified to contribute the largest share of the environmental impacts of livestock production (Turner et al., 2022). The direct valorization of food wastes to livestock feed therefore has the potential to reduce the environmental impacts of both food waste disposal and livestock production. There exists a lack of case studies evaluating the environmental performance of such systems operating at a commercial scale. This study aims to fill that knowledge gap by evaluating a direct grocery food waste to poultry feed production system based in the US through Life Cycle Assessment (LCA).

2. METHODS

This study follows the procedures of the ISO 14044 standard for LCA. The goal of this study is to quantify the environmental performance of a commercial scale grocery food waste to poultry feed valorization system in Pennsylvania and evaluate the environmental impacts and benefits of using the product for conventional egg production in Canada. The system boundary for this study is cradle to egg farm gate as depicted in **Figure 1**. The functional unit is 1 tonne of eggs produced on conventional Canadian egg farms. Foreground data was collected directly from the feed product manufacturer. Background data were obtained from Ecoinvent, Agrifootprint 6.3, and the European reference Life Cycle Database (ELCD). Conventional Canadian egg production activities were modelled as per Turner et al. (2022). The 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR6) characterization factors were used for Global Warming Potential (GWP) impact assessment. The TRACI 2.1 impact assessment suite developed by the US EPA was used for acidification, eutrophication, and fossil fuel depletion impact categories. The GWP emissions were reported over 20-year (GWP20) and 100-year (GWP100) time horizons. Parameter uncertainty was quantified using the pedigree matrix and monte-carlo simulation. Contribution analysis was used to identify hotspots, and strategies to mitigate impacts were discussed.

3. RESULTS AND DISCUSSION

The optimal rate of inclusion of the valorized food waste feed inputs into conventional feed was determined to be 5% by weight based on a feeding trial conducted by the manufacturer. At the 5% inclusion rate, emissions per tonne of eggs produced dropped by ~15.5% and ~8% for GWP20 and GWP 100 respectively, as shown in **Figure 2(a)**. These reductions were primarily due to avoided landfill GHG emissions. Acidification emissions dropped by ~8% as shown in **Figure 2(b)**, and eutrophication emissions dropped by ~11% as shown in **Figure 2(c)**. However, fossil fuel depletion increased by ~58% as shown in **Figure 2(d).** This large increase in fossil fuel depletion was primarily driven by three hotspots: natural gas use, grocery waste transportation, and electricity use in the Pennsylvania-based valorization system. Use of more efficient transportation and route planning, and renewable energy sources such as biogas, hydro or wind electricity could mitigate these hotspots.

4. CONCLUSIONS

The direct valorization of food waste to poultry feed was found to hold significant potential to drive down the climate burden of Canadian conventional egg production. Such systems can be further optimized by substituting fossil fuels with clean renewable energy and more efficient transportation.

5. ACKNOWLEDGEMENTS

We acknowledge Egg Farmers of Canada for funding this study.

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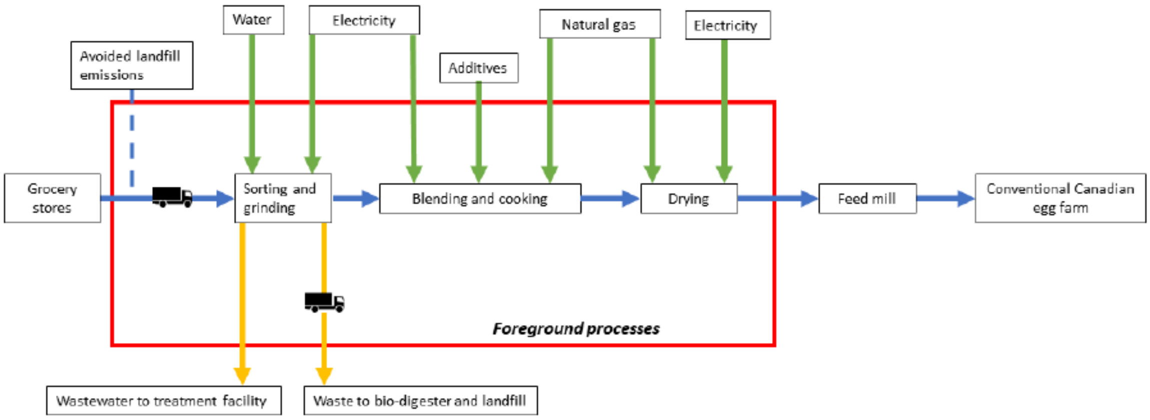

Figure 1. System boundary of the study

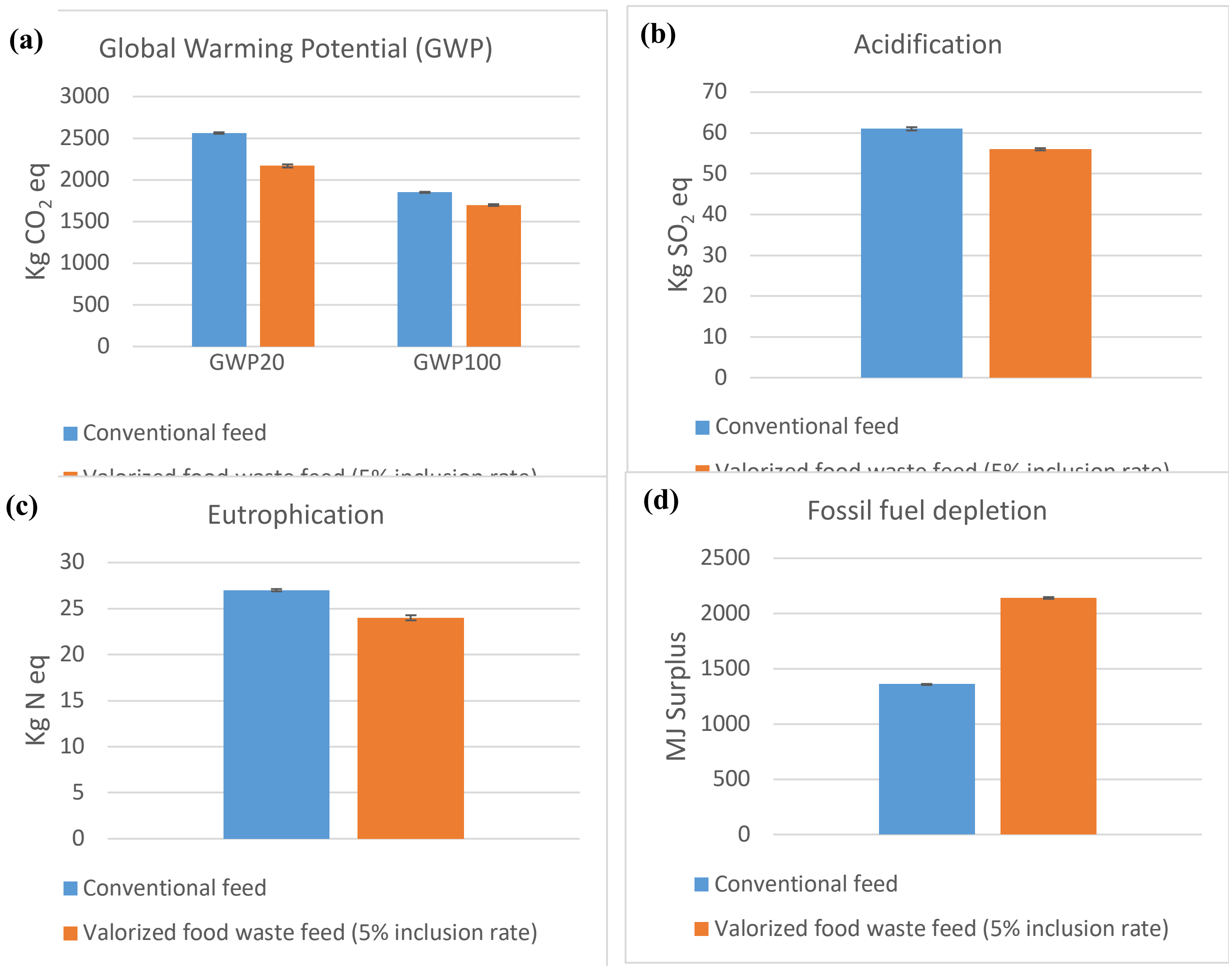

Figure 2. Impact assessment results for (a) Global Warming Potential, (b) Acidification, (c) Eutrophication, and (d) Fossil fuel depletion impact categories. Error bars represent standard error

Food waste reduction strategies in independent restaurants from the eco-efficiency perspective

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1. INTRODUCTION

The growing population raises serious challenges for the agricultural system due to the increasing food demand. To satisfy this demand modern approaches allowing to improve the food productivity and quality are constantly developing. However, around a third of produced foods is lost or wasted contributing to the pressure on the environment and food insecurity[1]. To address these issues, Sustainable Development Goal 12 developed by United Nations proposes multiple targets including halving per capita global food waste by 2030. The foodservice sector plays an important role in attaining this target since it has great potential in reducing food waste. However, there is a lack of studies related to the hotspots regarding the environmental and economic impacts of food waste, which hampers the development of appropriate management strategies. Thus, the main purpose of the present work is to assess the environmental and economic impact of the waste generated in the restaurant sector as well as to model the impact of different strategies allowing waste reduction from the eco-efficiency perspective. Additionally, the factors affecting the implementation of waste reduction strategies were explored.

2. METHODS

Data acquisition related to food waste generation was carried out in an independent high-end hotel restaurant in Montreal (Canada). The environmental impact and economic burden of the generated food waste were assessed according to ISO 14045 and its specifications. The Life Cycle Assessment was used to evaluate the environmental impacts associated with food waste the value component of the eco-efficiency was the food waste costs associated with FW itself and with the implementation of food waste reduction strategies (FWRS). To study the factors affecting the implementation of FWRS, semi-structured interviews with sixteen independent restaurant owners, managers and head chefs of the province of Quebec were conducted.

3. RESULTS AND DISCUSSION

The categorization of food waste generated in the independent restaurant under the study taking into account its quantity demonstrated that more than 50% of it is represented by vegetables followed by meat at about 10%[2]. However, when looking at the food waste costs and environmental impacts vegetables represent about 30% and 10% respectively and meat represents about 20% and 70% respectively. The major part of this waste was generated at the preparation level followed by the plate waste. The 20 FWRS aiming to have economic and environmental benefits were modelled. The most interesting FWRSs in the long term were planning the menu to reuse FW, setting up a co-creation workshop, conducting food waste training for staff and adding working time to reuse FW (economic benefits can attain almost 5000 $ while reducing greenhouse gas emissions of about 1000 kg of CO_2 eq. in 6 months). The interviews with the restaurant owners, managers and head chefs revealed multiple factors affecting the FWRS implantation including consumer perception of certain strategies, senior management vision, staff qualification, lack of time and issues with infrastructure[3]. The restaurant type was identified as a key element allowing to distinguish the best way of operationalizing the reduction of food waste. For instance, a corrective approach requiring qualified staff and allowing a high waste recovery and reuse is mostly suitable to the fine dining restaurant types while a preventive approach is needed less experienced staff requires thorough menu planning and food waste mitigation management.

4. CONCLUSIONS

This study demonstrates the relevance of assessing the environmental and economic pillars of food waste generated in the foodservice sector. The presented eco-efficiency look on food waste generation and reduction strategies seems to be promising in order to operationalize sustainable practices in independent food restaurants. Further studies should focus on other foodservice types and understanding the factors affecting the food waste generation and strategies of its management in each particular context including the regional specificities.

5. ACKNOWLEDGEMENTS

The financial support of the Mitacs Accelerate program with Société des casinos du Québec [grant number IT12400], and the Fonds québécois de la recherche sur la nature et les technologies (FRQNT) [grant number 301900] is acknowledged.

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Sustainable cropping systems (I)

Urbanization of food production: Can indoor vertical farming reduce the environmental footprint of kitchen herbs?

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1. INTRODUCTION

Climate change, population growth and loss of arable land threaten the resilience of global and local food systems. Recent events have further exacerbated pressures on agriculture and trade, leading to a rise in food prices worldwide. Urbanizing food production is one of the hot topics in the food industry. Vertical farms (VF) are one approach. It is often claimed that indoor VFs can produce significantly more food per square meter than traditional farming methods, while using less water, no soil, no chemical pesticides, and being independent of the outdoor climate. Despite these potential benefits, VFs require large amounts of electricity, technological equipment, and infrastructure to provide suitable conditions for plant production. The VF industry is challenged to further improve production efficiency to reduce the environmental impact of its products and bring them to market at competitive prices. The environmental impacts of VF production of culinary herbs are currently being investigated as part of a science-based innovation project aimed at optimizing the production efficiency and plant quality of a Swiss VF.

2. METHODS

A life cycle assessment was conducted to evaluate and compare the production of Italian basil (Ocimum basilicum) in a Swiss VF and conventional open field and greenhouse production. A standard packaging unit of 20 g of basil, packaged at retailer was defined as functional unit (FU). The studied VF has a production capacity of approximately 20 tons of herbs per year on a cultivation area of 600 m^2. The system model includes infrastructure, lighting, irrigation and air conditioning, energy supply, fertilizer, harvesting, packaging, and transportation to the retailer. Information and data provided by farm operators, as well as calculations made by the authors, were used for system modeling. The global warming potential (GWP) was calculated according to IPCC 2021[1]. The total environmental impact was calculated according to EF 3.1[2]. The results of the GWP analysis and selected EF impact categories will be presented at the LCA Food Conference.

3. RESULTS AND DISCUSSION

The GWP of current basil production in the analyzed system is at 0.14 kg CO_2-eq/FU with electricity consumption and packaging (cardboard packaging with plastic window) being the main drivers of GWP impacts. Electricity consumption is responsible for almost 30 % of the GWP, even though a mix of 100 % renewable electricity is used in production. If the average European electricity mix were used instead, the GWP would rise to 0.7 kg CO2-eq/FU (see

Figure 1). This underscores the critical role that the type of electricity mix used to operate the VF plays in the GWP of the manufactured products. Compared to conventional production methods and different countries of origin, basil from Swiss VF production has a lower GWP than basil imported by air over a distance of 2800 km and with a Radiative Forcing Index (RFI) of 3 applied to the stratospheric CO_2-emissions during the flight. However, the GWP is higher than for basil imported by road from Spain or basil grown in Switzerland during the summer months (see **Figure 2**). To enhance the unit economics of the product and enable competitive vertical farming, it is essential to improve production efficiency. Process optimization and increase in energy efficiency could lead to further impact reduction and lower production costs. But even if production targets are met, the global warming potential is likely to be significantly higher than that of conventionally grown basil, unless it is imported by air or grown in greenhouses heated by fossil fuels.

4. CONCLUSIONS

While the GWP of open field or unheated greenhouse production will still be significantly lower than the GWP of VF, further reductions in greenhouse gas emissions would further reduce the impact of VF production. Energy efficiency and renewable electricity mixes are critical factors for VF production. Even small amounts of electricity generated from fossil fuels will inevitably lead to a significant increase in GWP. The cardboard packaging has a significant impact on the footprint of kitchen herbs due to its weight relative to the weight of the contents. Switching to lighter weight packaging could further reduce this footprint.

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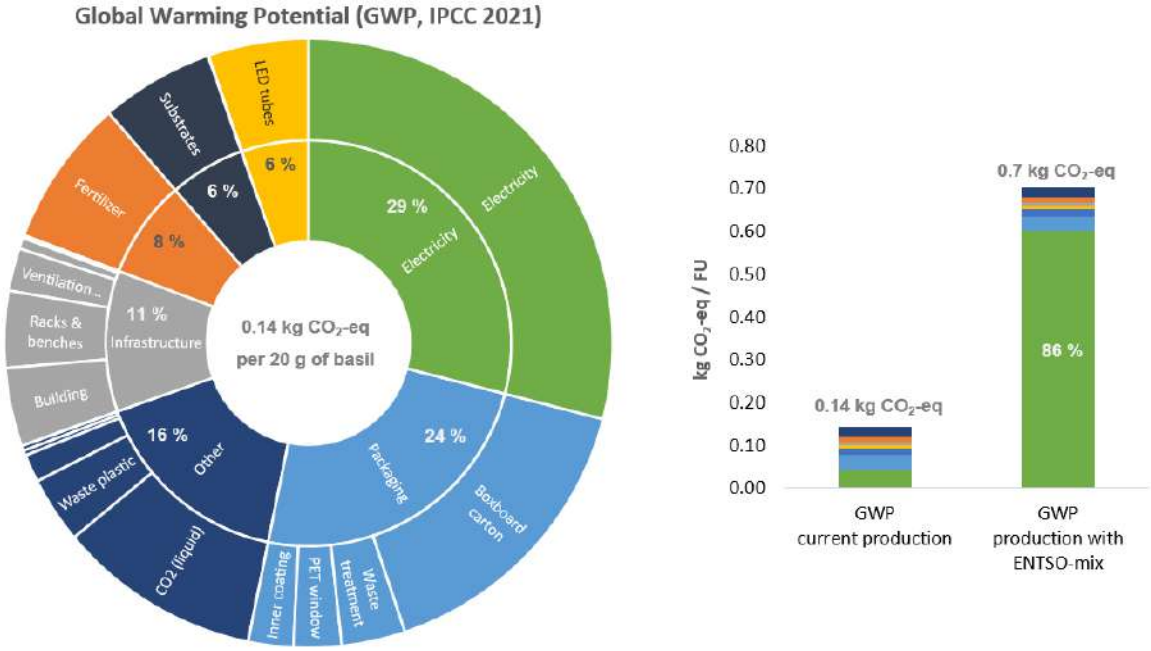

Figure 1: Left: Contributions of components and processes to the global warming potential (GWP, IPCC 2021) for current VF production of 20 g of basil, packaged at retailer in Switzerland. Right: Comparison between the GWP impact of current VF production using electricity from 100 % renewable sources and production using the European electricity mix (ENTSO mix).

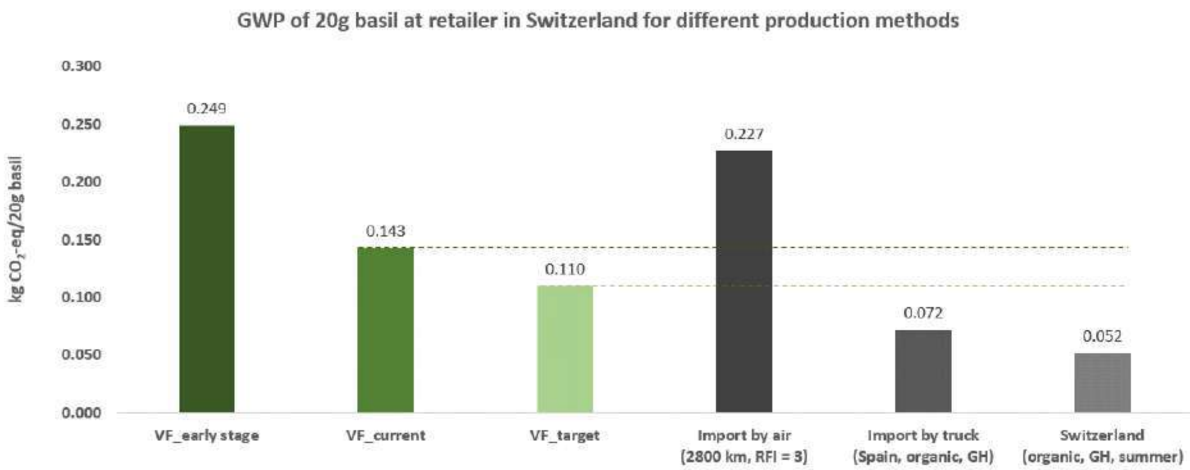

Figure 2: GWP of 20 g of basil, packaged at retailer, for different production methods and origins. GWP of vertical farm (VF) production at different stages of the research project is shown in green.

LCA comparison of vertical and rooftop farming with conventional agriculture

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1. INTRODUCTION

Urban Agriculture (UA) presents as a promising strategy to improve urban resilience, food security, and sustainability through innovative practices like rooftop greenhouses (RTG) and indoor vertical farms (VF). Lettuce is a popular cultivation crop in the Mediterranean area, a base product of the food basket, and has high losses in transportation.. However, to date, an environmental assessment comparing several lettuce production systems in the Mediterranean area has not been conducted before. This study aims to calculate and compare the environmental impacts of these Urban Agriculture production soilless systems (RTGs and VFs) with the traditional food production in soil systems, a conventional greenhouse system (GH), and an open-field lettuce crop. Moreover, we aim to provide a range of circular strategies to improve UA systems, taking profit of their improved controlled environment that facilitates the recirculation of urban streams.

2. METHODS

We used Life Cycle Assessment (LCA) to identify the environmental impacts in the different life cycle stages of the four lettuce production systems. For the UA systems, inventory data was retrieved from on-site measurements on the RTG and VF facilities, whereas secondary data was used to model the impacts of GH system (Martínez-Blanco et al., 2011) and the OF system (Foteinis & Chatzisymeon, 2016). The LCIA Scores tool (Muñoz-Liesa et al., 2024), based on Brightway2, has been used to calculate impact assessment results using Ecoinvent 3.8 as a background database. The functional unit considered: 1 kg of lettuce delivered at the market gate, considering yearly average productivity rates to cover seasonal variations.

3. RESULTS AND DISCUSSION

Preliminary results show that there is not a specific system that produced higher overall in the environmental impacts categories. However, in the climate change category, results indicate that lettuce production systems from UA systems produced impacts between 2,12 kg CO_2 eq/kg of lettuce (VF) and 1,08 kg CO_2 eq/kg of lettuce (Figure 1). Regarding the VFs impacts, these were mainly due to the electricity requirements for both LED lightning and HVAC systems. To this respect, RTG benefit from the hosted building waste heat and thus, it is not actively heated. These impacts do not have a significantly lower environmental impact than the traditional production system in the Mediterranean area (with 0,66 kg CO_2 eq/kg of lettuce for the OF and up to 2,02 for the GH system). This can be provably explained with the difference of agricultural settings and because of the different maturity levels of the compared systems. Further results will provide circular and improvement measures to further analyze the potential improvements.

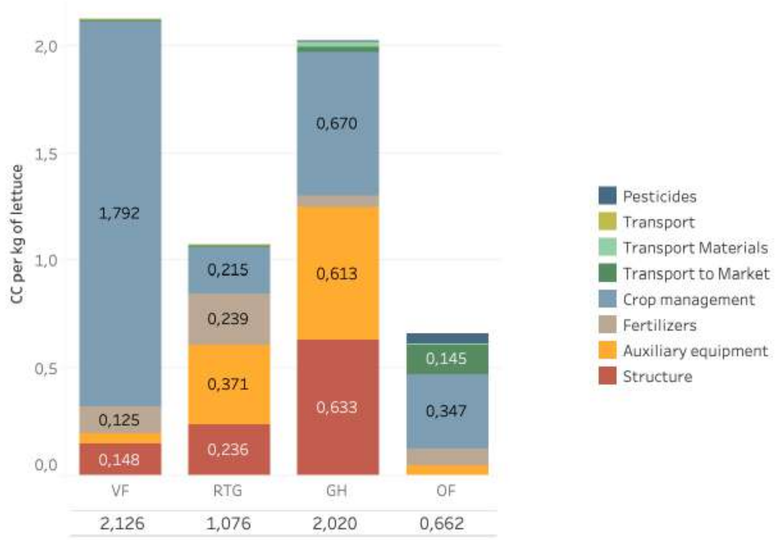

Figure 1. Climate change impacts per kg of lettuce for all assessed systems

4. CONCLUSIONS

This study shows that the local lettuce production of UA in the Mediterranean area does not compensate for the transport impacts of traditional food production systems. However, further research is needed to determine if UA can be greatly optimized when it changes to a large industrial scale.

5. ACKNOWLEDGEMENTS

This research has received financial support from FORMAS, the research council for sustainable development .

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LCA to inform detailed agricultural practice ecodesign at farm scale, example of viticulture

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1. INTRODUCTION

As an agricultural sector, viticulture has a responsibility to identify its impacts in order to address the most significant impact contributors. Built on a methodological framework for the application of LCA for a detailed assessment of practices in viticulture (Renaud-Gentié, 2015), the framework proposed by Czyrnek-Deletre *et al.*, (2018), permits, through the use of typologies elaborated with the farmer, the calculation of an LCA at farm level, taking into account the diversity of practices and environmental conditions of the different plots. We tested this framework for ecodesign of viticultural practices at farm scale and to explore the applicability of the ecodesign levers with the farmer.

2. METHODS

In an 80-ha domain producing mainly rosé wines in the Anjou region, France, a main pathway of technical operations (PTO) i.e. his most common way of managing his vineyard (T1) and six secondary types of PTO (T2 to T7) were identified with the wine grower by highlighting what differed from the main type (Table 1). The plots were identified on the farm map to define their slope (2 classes) and clay content (3 classes), which influence direct emissions. This resulted in 13 types after crossing PTOs and environmental conditions (Table1). Based on the detailed inventory of practices implemented in 2018, 2019 and 2020, the life cycle inventories and LCAs were calculated for the 13 types using the Vit'LCA® calculator (Renouf *et al.*, 2018) and ILCD 2011 characterisation method, with selection of 6 impact categories. The ecodesign levers were identified and new PTOs were ecodesigned for the main type to be proposed to the farmer and their possible implementation discussed with him.

3. RESULTS AND DISCUSSION

The different impacts are not sensitive to the same levers (Figure 1). For example, climate change is mainly sensitive to PTO (fuel use), while freshwater eutrophication reacts mainly to variations in environmental conditions (slope, related to erosion of phosphorus).

We focused the ecodesign on the T1-50- type (53% of the vineyard area). The major contributors to its impact were: 1) fuel combustion (machinery operation) for resource depletion, climate change, and photochemical ozone formation, 2) the production and emissions of the organic fertiliser, when applied, freshwater ecotoxicity (heavy metal emissions) and climate change (nitrogen emissions); and 3) pesticide production, mainly copper, glyphosate and disodium phosphonate. Pesticide emissions, mainly from copper-based products, are the first contributor to freshwater ecotoxicity impact.

The ecodesigned strategies targeted the main contributors, considered as ecodesign levers, 1) Replacing fossil fuel tractors, where possible, with two types of electric tractor or robot (scenarios 1 and 2); 2) Changing the pesticide active ingredients to less ecotoxic substances (limiting copper) in scenario 3 and the use of a confined sprayer to minimise the use and drift of pesticides in scenario 4; 3) An optimised scenario 5 implemented a combination of levers.

On this latter scenario, the net reduction in impacts ranges from 11% for freshwater eutrophication to 75% for freshwater aquatic ecotoxicity, and includes 20% for climate change, 36% for resource depletion and 55% for photochemical ozone formation. Only water consumption is increased by using electrical machines, due to of lithium batteries.

4. CONCLUSIONS

This first approach shows the effect of practices and vineyard characteristics on LCA impacts at the farm scale, and the efficiency of the ecodesign levers. It needs to be completed by ecodesign of fertilisation and the effect of the environmental characteristics of the plots on the results, and the discussion of the proposed solutions with the winegrower.

5. ACKNOWLEDGEMENTS

Funding: FEDER (Avatec project) and OFB (Vitarbae project) and data : La Petite Roche.

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					Fuel use (l/ha/y)			Manual work (h/ha/y)		
Type	Type of vineyard management	Clay content (%)	Slope (%)	Area (ha)	2018	2019	2020	2018	2019	2020
1-7-	1 = main PTO, i.e. 10 pest management operations+ organic fertilisation every 2 years + 12 other mechanical operations + manual operations + mechanical harvest	0-7	0-5	3,6	92	88	88	134	128	128
1-13-		7-13	0-5	2,3						
1-50-		13-50	0-5	42,3						
1-50+		13-50	5-10	5,8						
2	2 = main PTO + mechanical tillage	13-50	0-5	3,5	117	110	111	133	128	128
3-7-	3 = main PTO + manual harvest 3 times including machinery use	0-7	0-5	0,8	99	95	96	284	278	278
3-50-		13-50	0-5	4,8						
3-50+		13-50	5-10	3						
4	4 = Main PTO + manual harvest including machinery use	13-50	5-10	1,0	120	116	116	234	228	228
5-13+	5= main PTO + more manual operations	7-13	5-10	1,2	92	88	88	194	188	188
5-50-		13-50	0-5	6,1						
6	6 = main PTO + mechanical tillage +more manual operations	7-13	0-5	1,6	117	113	113	194	188	188
7	7 = main PTO + mechanical tillage + manual harvest incl. mach. use	13-50	0-5	4	145	138	139	234	228	228
Total for the farm				80	7780	7436	7474	13012	12540	12540

Table1 : Characteristics of the types of vineyard management and of the plots' environment, and fuel and labour use for the three years studied.

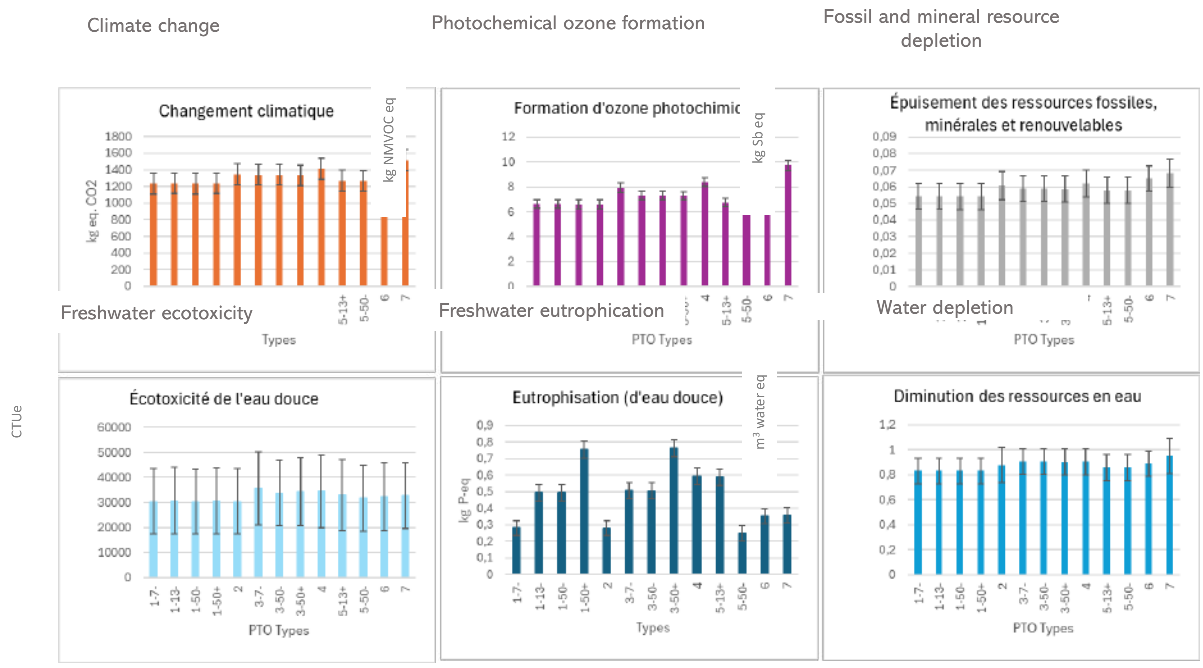

Figure 1. Comparison of the thirteen types of pathways of technical operations of the farm for six impacts categories (average of the three years). Standard deviation on the three years is indicated by the bars (ILCD 2011, FU: 1ha of vineyard cultivated for one year).

Life Cycle Assessment of Frost Protection Methods in Viticulture: A Framework to Compare Different Technologies

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1. INTRODUCTION

An increase in the frequency of extreme climatic events, including spring frost events, has been observed in the last decades and is predicted to continue. In viticulture, the risk of spring frost is mainly due to earlier budbreak, increasing the vulnerability of buds and green organs to freezing temperatures. Active Spring Frost Protection Methods (ASFPMs) aim to mitigate this risk by increasing the temperature in a given area (Rochard, Monamy et al. 2019). ASFPMs are often seen as highly labor-intensive and resource consuming practices (Liu and Sherif 2019). Only two studies address partially the environmental impacts of ASFPMs; (Thiollet-Scholtus and Bockstaller 2015, Frota de Albuquerque Landi, Di Giuseppe et al. 2021). ASFPM technologies are diverse and influenced by different external drivers, affecting differently their application strategies and the required equipment for efficiency. This study proposes a conceptual framework for analysing and comparing ASFPMs' potential environmental impacts using LCA methodology. The methodology is described first, followed by its application with four contrasted ASFPM technologies applied in the Loire Valley, France, context.

2. METHODS

We modelled the attributional LCAs with Impact world + characterisation method using Abribalyse 3.1 and Ecoinvent 3.8 databases. Application and climatic scenarios were elaborated to set conditions of ASFPMs use. The overall combination of attributional LCAs and external scenarios designs the contextual LCA with the following Functional Unit (FU): "to protect 1 ha of vines during one spring" (Figure 1). Winter cover, wind machine, sprinkler and anti-frost candles are compared in Loire Valley conditions. Required time of application for each ASFPM to protect 1 ha during frost hours was determined using linear regression of ASFPM application time in function of total seasonal frost hours based on a recent decade (2013-2023). Sensitivity analysis consisted in varying frost hours theoretically with a step of 1 unit, using the lowest and highest frost hour numbers from 2013-2023 as boundaries.

3. RESULTS AND DISCUSSION

The wind machine has the lowest impacts on climate change, mineral resources use and water scarcity, as shown in Figures 2.A, 2.B and 2.C, respectively. The anti-frost candles show the highest scores for the climate change and land occupation indicators after 1 and 5 hours of frost events, respectively. The sprinkler has the highest impact on water scarcity. The winter cover has the highest impact on land occupation when the occurrence of frost hours is less than 5 (Figure 2.D). In overall, the ranking between ASFPM environmental scores changes in function of the theoretical frost duration.

4. CONCLUSIONS

The implementation of contextual elements allowed for the expansion of system boundaries in attributional LCA, enabling the analysis and comparison of different types of technologies. The conceptual framework of this study showed its relevance in the context of ASFPM technologies through a concrete example in Loire Valley viticulture. Future research may consider other contextual elements and ASFPM technologies. This framework could be used in different fields of study to analyse and compare contrasted technologies in term of environmental impacts.

5. ACKNOWLEDGEMENTS

The authors thank Thomas Chassaing from the Maine-et-Loire Chamber of agriculture for identifying winegrowers using different ASFPM technologies, and the interviewees for sharing their knowledge about frost protection systems and strategies. This project is funded by Pays de la Loire region, France.

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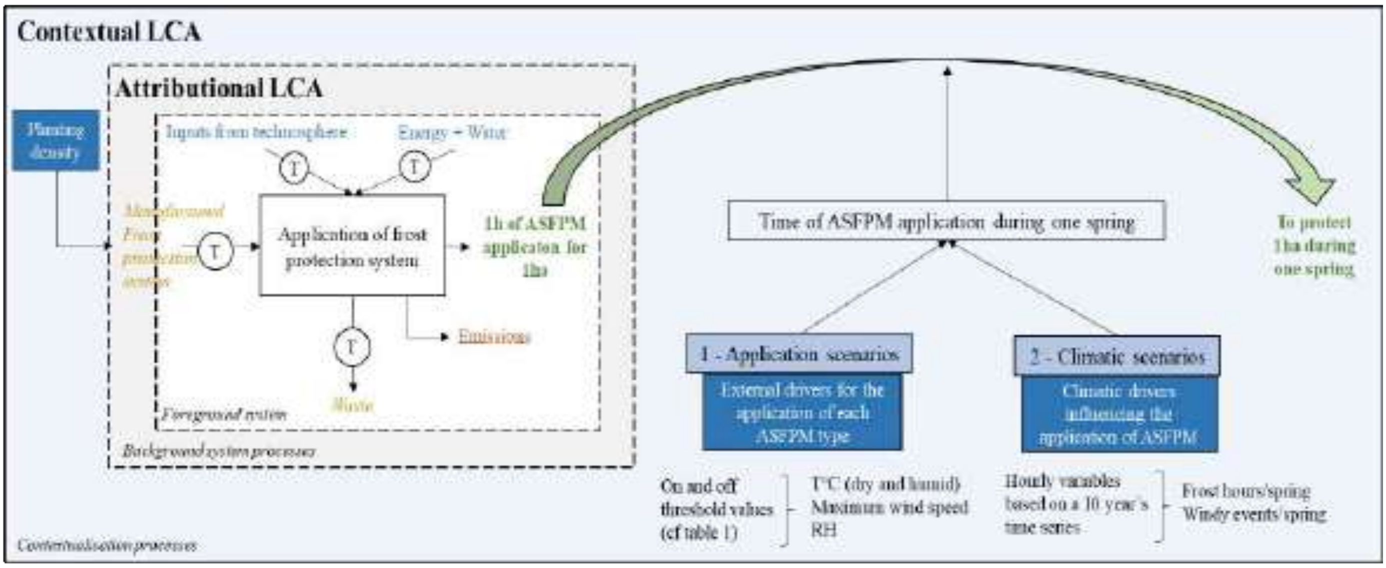

Figure 1. From an attributional LCA to a contextual LCA. The attributional and contextual LCA boundaries are respectively represented by the blue and grey rectangles. The dark blue rectangles present the different scenarios from the contextual LCA. The green text and arrow respectively are the functional unit and its change through the contextual scenarios. The blue, yellow and orange texts in the attributional LCA respectively display the inputs, the product/co-product transitions, the direct emissions.

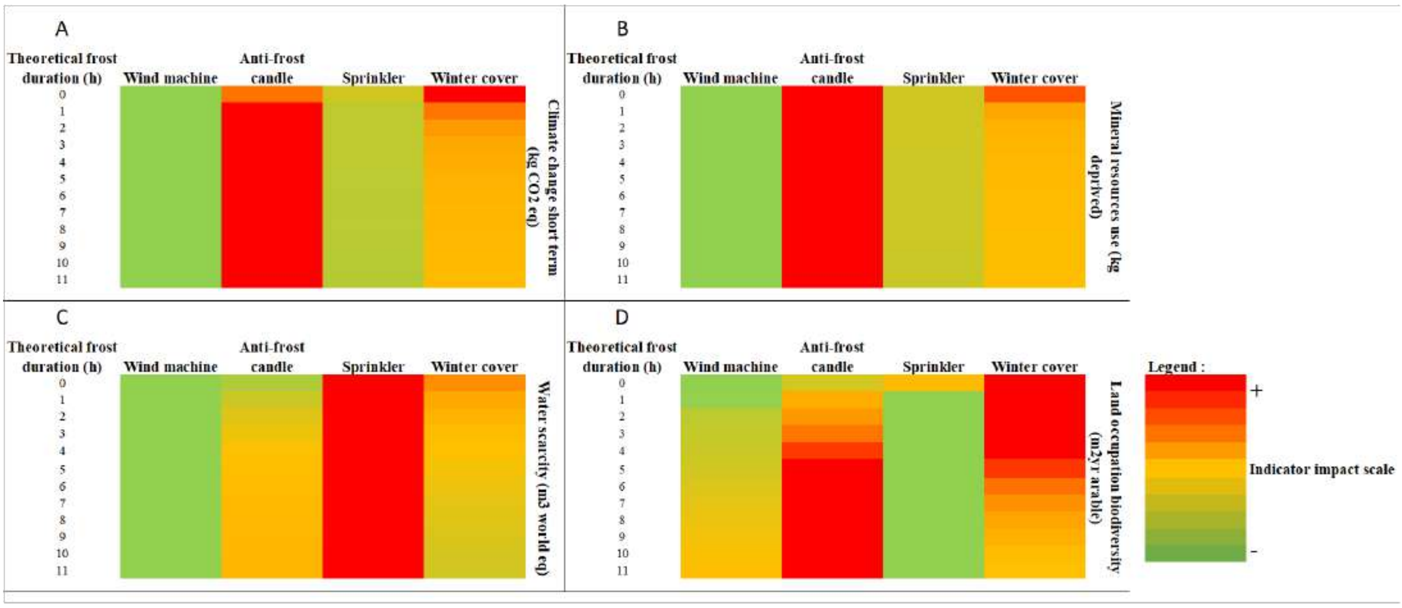

Figure 2. Comparison of the four ASFPM technologies through four LCA indicators with a theoretical frost duration variation (h). The pattern scales are normalised for each theoretical frost duration value. Fig A. Climate change short term. Fig B. Mineral resources use. Fig C. Water scarcity. Fig D. Land occupation biodiversity.

Winery 4.0: technology innovations to improve grape production sustainability

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1. INTRODUCTION

Pesticide distribution in vineyards presents environmental and economic issues (Paleari et al., 2024). However, information regarding the use of agricultural inputs such as fertilizers and pesticides are rarely included in environmental impact studies on wine and vineyards (Casolani et al., 2022). Digital technology could help farmers in reducing environmental and economic impact of crop protection. The goal of the smartDEFENSE project is to develop a new digital technology implemented in a mobile app which suggests when to treat and the optimal amounts of active ingredients and dilution water, by forecasting the risk of infection (Paleari et al., 2024). In this study, the comparison of two treatments: without (BASE) and with the support of technology for pesticide distribution (SMART) in terms of environmental performances is presented. Moreover, a preliminary multi-criteria decision model (MCDM) for the evaluation of economic, environmental, and social sustainability of the winery sector is presented.

2. METHODS

The environmental impact was determined through Life Cycle Assessment. Two functional units (i.e., one area based – 1 ha – and one mass based – 1 ton) and a "from cradle to farm gate" approach were considered. Primary data were collected about vineyards operations, working times, machine characteristics, inputs used in two farms producing grapes in conventional (A) and organic (B) agriculture. Secondary data were used regarding to the emissions of active ingredients, fertilizers and pollutants related to diesel combustion. The analysis of impacts was conducted using the EF 3.0 Method (V1.03) using SimaPro. The MCDM chosen was DEX, implemented in the open access software DEXi (Craheix et al., 2015). Based on expert opinions, a preliminary version of the DEXiWine tool was built (Figure 1).

3. RESULTS AND DISCUSSION

The adoption of SMART technology has led to a reduction in the distribution of pesticides and the impact associated with grape production (Table 1). In general, the impact categories (ICs) in which a greater reduction is observed were freshwater ecotoxicity and resource use, minerals and metals. These two ICs, in fact, were strongly related to the emissions of active ingredients to water, air and soil and to the production of pesticides, respectively. On farm A, the average reduction was 4.99 % in all ICs considered, ranging from 0.56 % in marine eutrophication to 13.64 % in freshwater ecotoxicity. On farm B, the average reduction in impacts was lower (0.67 %) ranging from 0.02 % in ozone depletion to 2.29 % in freshwater ecotoxicity. The LCA analysis allowed to identify the major hotspots involved in the grape production process and to define the preliminary indicators implemented in the DEXiWine tool (Figure 1), in particular in the environmental sustainability attribute. The MCDM will help to quantify the overall sustainability of wine production, considering also qualitative attributes such as farmer willingness to adopt digital technology solutions.

4. CONCLUSIONS

In conclusion, the new digital technology for pesticide distribution in vineyards determines a reduction of the environmental impact. However, further data regarding also the economic and social impact of the application of digital technologies in the wine sector are required.

5. ACKNOWLEDGEMENTS

The present study was supported by SmartDEFENSE project (*Tecnologie digitali innovative per aumentare l'efficienza e la sostenibilità dei sistemi di difesa in vigneto*) and Winery 4.0 project (*Farming Data Implementation: definition of smart solutions for the effective implementation of Agriculture 4.0 in winery production*).

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Table 1. Environmental impact associated to production of grape with (SMART) and without (BASE) the use of SMARTdefense app in conventional (A) and organic (B) farms. CC, climate change (kg CO2 eq); PM, particulate matter (disease inc.); AC, acidification (mol H+ eq); FE, eutrophication, freshwater (kg P eq); ME, eutrophication, marine (kg N eq); TE, eutrophication, terrestrial (mol N eq); FEt, Ecotoxicity, freshwater (CTUe); RU-mm, resource use, minerals and metals (kg Sb eq).

FU	FU 1 ha				FU 1 ton			
IC	BASE A	SMART A	BASE B	SMART B	BASE A	SMART A	BASE B	SMART B
CC	1483.26	1461.27	1564.96	1564.22	134.60	90.76	144.64	89.67
PM	1.18E-04	1.16E-04	3.57E-05	3.55E-05	1.07E-05	7.19E-06	3.30E-06	2.04E-06
AC	20.36	19.84	12.22	12.16	1.85	1.23	1.13	0.70
FE	0.46	0.42	0.22	0.21	0.04	0.03	0.02	0.01
ME	9.04	8.99	3.51	3.51	0.82	0.56	0.32	0.20
TE	65.96	65.56	38.70	38.67	5.99	4.07	3.58	2.22
FEt	1.42E+06	1.22E+06	1.36E+06	1.33E+06	1.29E+05	7.60E+04	1.26E+05	7.61E+04
RU-mm	4.35E-02	3.76E-02	4.77E-02	4.67E-02	3.95E-03	2.33E-03	4.41E-03	2.68E-03

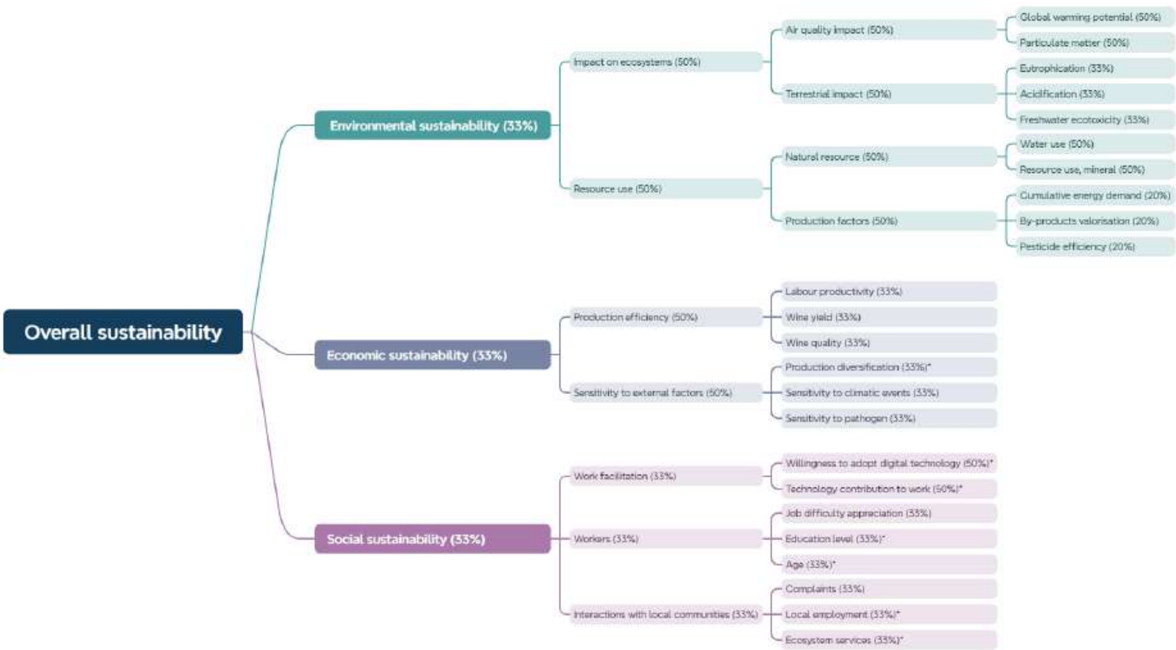

Figure 1. Preliminary attributes and indicators included in the DEXiWine multi-criteria analysis. Vàlues within brackets represent the provisional weight assignat to each attributes and indicators.

Assessing the environmental performance of valorisation opportunities for sunflower hulls

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1. INTRODUCTION

Food processing companies produce large volumes of agro-industrial waste that can be further valorised. Sunflower mills exploit co-products from oil production, such as sunflower meal, in animal feed. They may optionally separate the seed from the sunflower hull (SFH) through dehulling. This separation improves the protein content of the resulting meal due to the lower SFH share. Europe has low self-sufficiency of protein-rich animal feed ingredients, justifying dehulling in sunflower milling. Yet, this additional step leads to large SFH quantities, raising questions regarding possible waste management options and their environmental impacts. In this case study, we explore the environmental performance of SFH valorisation opportunities. We compare two bioenergy applications: on-site biomass combustion in a bio-boiler and anaerobic digestion at an external facility.

2. METHODS

We utilised lifecycle assessment to compare the environmental impacts of the two bioenergy options. We built scenarios for the functional unit of '*the processing of 1 tonne of sunflower hulls*'. To model combustion, we calculated that 1 tonne of SFHs generates 16 GJ and amended emissions based on the guaranteed thresholds and expected heat efficiency. In this scenario, the resulting heat replaced heat from natural gas, while the residual ash substituted inorganic fertilisers. For anaerobic digestion, we included transport to an external facility and biogas production based on SFH fermentability tests. In this scenario, biogas produced electricity and heat from biomethane, substituting grid electricity and heat from natural gas, respectively. We accounted for the avoided product of inorganic fertilisers from the use of digestate as an agricultural fertiliser. Further, we performed a sensitivity analysis on the fugitive methane emissions in biogas production. We used ecoinvent and Agribalyse databases to match data with background processes and applied the EF 3.1 impact assessment method on SimaPro 9.6.

3. RESULTS AND DISCUSSION

Overall, the characterised results show a mixed picture regarding environmental impacts and benefits (Table 1). After normalisation and weighting, biomass combustion has a lower score (10.64 mPt) than anaerobic digestion (16.96 mPt) (Figure 1). In SFH combustion, significant environmental benefits exist in climate change and resource use (fossils), with the two categories contributing 40% to the single score. In anaerobic digestion, these two categories are also significant with a 46% contribution; yet, climate change leads to environmental impacts rather than benefits due to fugitive methane emissions in biogas production. In a sensitivity analysis, we built 3 scenarios regarding the share of fugitive methane emissions compared to biomethane production: 3%, 5%, and 10%. Anaerobic digestion (10.45 mPt) is about equal to combustion when methane leakage is at 3%. Further, allocation difficulties for the substitution of inorganic fertilisers introduce some uncertainty on the avoided environmental impacts.

4. CONCLUSIONS

Sunflower hull co-products can be valorised in bioenergy applications. Energy recovery from biomass combustion is preferred from a heat efficiency and environmental perspective, assuming that fugitive methane emissions in biogas production are higher than 3%. The results depend on the selected substitute products, data assumptions and methodological choices, illustrating their case-specificity. The findings support a waste-to-energy perspective in fossil-fuel-based economies, as replacing fossils leads to environmental benefits. Context-specific environmental assessments using lifecycle thinking can support waste management decision-making in the food processing sector, going beyond the classical, static food waste hierarchy.

5. ACKNOWLEDGEMENTS

We would like to thank the participating companies for providing data for this research.

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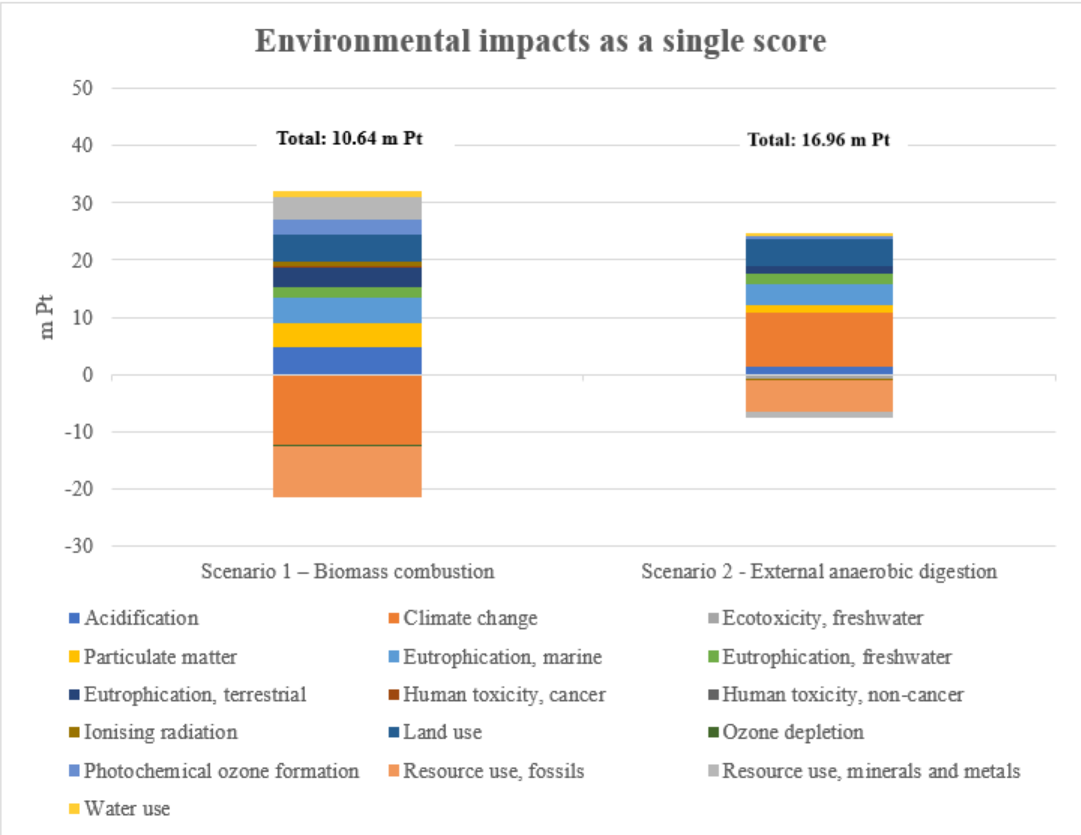
Table 1. Environmental impacts at impact category level

Impact category	Unit	Scenario 1 - Biomass combustion	Scenario 2 - External anaerobic digestion
Acidification	mol H+ eq	4,18E+00	1,21E+00
Climate change	kg CO2 eq	-4,37E+02	3,36E+02
Ecotoxicity, freshwater	CTUe	-3,18E+02	-1,90E+03
Particulate matter	disease inc.	2,84E-05	9,80E-06
Eutrophication, marine	kg N eq	2,96E+00	2,41E+00
Eutrophication, freshwater	kg P eq	1,02E-01	9,63E-02
Eutrophication, terrestrial	mol N eq	1,67E+01	7,13E+00
Human toxicity, cancer	CTUh	1,15E-07	-2,78E-08
Human toxicity, non-cancer	CTUh	-3,29E-07	-3,82E-07
Ionising radiation	kBq U-235 eq	7,08E+01	-2,63E+01
Land use	Pt	5,05E+04	4,76E+04
Ozone depletion	kg CFC11 eq	-1,03E-04	-4,96E-06
Photochemical ozone formation	kg NMVOC eq	2,05E+00	5,56E-01
Resource use, fossils	MJ	-6,95E+03	-4,30E+03
Resource use, minerals and metals	kg Sb eq	3,40E-03	-8,12E-04
Water use	m3 depriv.	1,35E+02	2,79E+01



Sustainable cropping systems (II) and Innovations in food production beyond the farm gate

Improving rice production sustainability through variable rate fertilization and alternative water management

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1. INTRODUCTION

Italy is the Europe's largest rice producer, accounting for more than 50% of European production. However, although rice-growing is a sector of excellence for Italy, it presents some environmental concerns, such as methane emissions due to the degradation of organic matter in flooded fields (anaerobic conditions), the use of inputs (e.g. N-fertilisers and pesticides) and the uptake of heavy metals (Zoli et al., 2021). Therefore, appropriate technological supports for improving agronomic management and systems efficiency could lead to a reduction in the environmental and economic impacts. In this context, the RiceSmart project is based on the use of new digital technologies to improve the nitrogen fertilisers and water managements in the paddy fields. The aim of this study is to compare the environmental performances of different rice cultivations with different fertiliser and water managements. For this purpose, experimental trials were carried out in the first year of project and the Life Cycle Assessment (LCA) methodology was applied.

2. METHODS

Different agricultural practices were tested in experimental field trials: baseline scenario (BS) represented the farmer routinary agricultural management; alternative scenario 1 (AS1) consisted of adding an aeration period to the paddy field during stem elongation phenological stage; alternative scenario 2 (AS2) involved, in addition to the aeration period, a variable rate N fertilisation (VRNF) suggested by a smartphone app (Figure 1, Bacenetti et al., 2020). The functional unit considered was 1 ton of rice grain (14% moisture) and a "from cradle to farm gate" perspective was selected for the system boundary. Data were collected from six farms representative of the Northern Italy context. Primary data regarding the cultivation practice (e.g. field operations, fertilisers and pesticides applied, agricultural machineries) were collected (Table 1) while secondary data were used for the methane, fertilisers, pesticides and fuel combustion emissions. Methane emissions were estimated according to IPCC, (2019) considering the amount of organic matter introduced in the soils, the number of aeration period and the duration of flooding of paddy field. The analysis of impacts was conducted using the Environmental Footprint 3.0 (V1.03) method.

3. RESULTS AND DISCUSSION

The results of the AS1 showed a reduction of the methane emissions and, consequently, the impact on climate change. The benefits of this alternative water management were particularly evident in farms where only one aeration period was conducted in the baseline scenario. However, it should be underlined, that this alternative technique is effective if the yield is not reduced, as farm productivity remain the main driver of environmental impact. The results of the AS2 showed that if VRNF was correctly applied, allowed reducing the environmental impact up to 15% compared to uniform N application. For Climate Change, eutrophication, and acidification, the impact reduction was not negligible. The greatest environmental benefits - mainly due to the improvement in the ratio of grain yield to N fertiliser - came from reduced energy consumption for fertiliser production and lower emissions of nitrogen compounds.

4. CONCLUSIONS

In conclusion, alternative water management mitigated the impact of climate change on rice cultivation without compromising quantity and quality of production. Furthermore, the availability of digital solutions which support farmers in fertiliser application, could be an additional impact mitigation solution with a twofold benefit: impact reduction for all categories considered due to increased productivity and reduced emissions of nitrogen compounds.

5. ACKNOWLEDGEMENTS

The research was funded by Project “Tecnologie digitali per aumentare la sostenibilità e la competitività delle aziende risicole lombarde. RiceSmart”. MISURA 16 – “COOPERAZIONE” SOTTOMISURA 16.1 – “Sostegno per la costituzione e la gestione dei Gruppi Operativi del PEI in materia di produttività e sostenibilità dell’agricoltura” OPERAZIONE 16.1.01 – “Gruppi Operativi PEI”.

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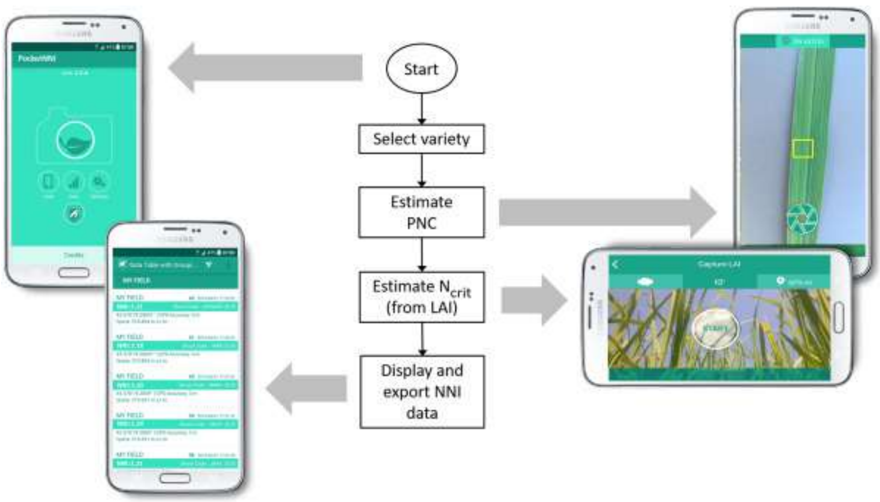

Figure 1: Flow chart of the PocketNNI application used to estimate the actual nitrogen content in the plant and guide variable rate fertilisation

Table 1: Table illustrating a cultivation technique of one of the farms considered. The table contains information on the sequence of cultivation operations carried out and some of the production factors used

Section	Operations	Input other than diesel	Amount (· ha^{-1})
Soil tillage and sowing	Harrowing		3 #
	Weed control pre seeding	Roundup platinum	4.5 kg
	Seeding	Seeds	210 kg
	Weed control pre germination	Clomazone	0.3 kg
		Pendimetalin	1.5 kg
Crop management	Weed control post germination (I)	Profoxidim	0.3 kg
		Methyl oleate	0.6 kg
		Methyl palmitate	0.6 kg
		Florpyrauxiten	1.2 kg
	Mineral Fertilization (I)	NPK 32-0-18	300 kg
	Mineral Fertilization (II)	NPK 23-0-30	160 kg
	Disease control (I)	Azoxystrobin	1 kg
Harvesting and storage	Harvesting	14 % relative humidity	8.07 t
	Transport		16 tkm
	Drying	Water evaporated	0.8 t

Towards climate-neutral agriculture: exploring scenarios for arable and dairy farms

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1. INTRODUCTION

The agrifood sector causes one-third of global greenhouse gas (GHG) emissions. Consequently a transformation in food production practices and systems is urgent (FAO 2022). Focusing on climate-neutral farming in Europe, the EU project ClieNFarms aims to identify agricultural practices and system changes that reduce GHG emissions and/or increase carbon sequestration in soil and biomass, to reach climate neutrality at farm-level. ClieNFarms involves scientists, farmers, and industry stakeholders, aiming for climate-neutral farming in Europe.

2. METHODS

We used the web-based MEANS InOut v 4.4 software to assess pollutant emissions, resource use and life cycle assessment indicators of two arable (Italy and UK) and two dairy farms (Germany and France). Here we present results for the climate change impact. We identified six agro-ecological actions capable of reducing GHG emissions and/or sequestering carbon. These actions were parametrized according to recent literature for biomass (Dassot et al. 2022, Mondière et al. 2024) and carbon sequestration data (Bamière et al. 2023): 1) planting 100 linear meters of hedgerow per hectare, with a 20-year amortization period, at a sequestration rate of 1830 kg CO_2 eq. ha^{-1} yr^{-1}; 2) expanding cover crops temporally and spatially within the rotation, at 1146 kg CO_2 eq. ha^{-1} yr^{-1}; 3) applying organic fertilizer (manure), at 1098 kg CO_2 eq. ha^{-1} yr^{-1}; 4) decreasing tillage by 50%, at 90 kg CO_2 eq. ha^{-1} yr^{-1}; 5) reducing mineral fertilization by 20%, at 188 kg CO_2 eq. ha^{-1} yr^{-1} ; and 6) implementing rewilding, setting permanently aside a part of the farm for unmanaged restoration, at 4758 kg CO_2 eq. ha^{-1} yr^{-1}. Prior to the simulation of climate actions we assessed the baseline scenario by estimating GHG emissions and carbon sequestration due to actions already in place at the farm. Then, we developed two emission reduction scenarios for our farms: Productivity-Constrained (PC) and Climate-Neutral (CN). In the PC scenario, we identified four actions to mitigate GHG emissions and increase carbon sequestration while limiting production loss to 10%. In the CN scenario, we tested two actions without constraints on production loss, in order to identify actions that achieve climate-neutrality and to quantify their potential effect on productivity.

3. RESULTS AND DISCUSSION

None of the assessed systems were climate neutral under baseline conditions, as their GHG emissions exceeded sequestered carbon (Table 1). However, the English arable farm attained climate neutrality within the PC scenario. For the Italian, British, German and French farms, the PC scenario resulted in emission reductions of 46%, 131%, 34%, and 28% compared to the baseline emissions, respectively. When the productivity constraint was lifted (CN scenario), all farms could reach net-zero emissions (Table 1) by a reduction in 20% of mineral fertilizer use and setting aside 46%, 44%, and 61% of land for rewilding in the Italian, German, and French farms, respectively. We acknowledge that the interactions and effectiveness of the presented mitigation actions depend on climatic, edaphic, and management contexts. Thus, further investigations are warranted to comprehend the interactive effects of these actions on yield, implementation feasibility, and the socio-economic adaptability of proposed strategies.

4. CONCLUSIONS

We anticipate our findings will significantly contribute to the understanding of strategies for reducing agriculture's climate change impact. Our results underscore that while maintaining productivity often is a main target within the climate mitigation agenda, efforts to reach climate neutrality will generally come at the cost of reduced production. This emphasizes the need for consensus regarding the urgency of climate action in the agricultural sector and the serious consideration of alternative production scenarios.

5. ACKNOWLEDGEMENTS

The authors thank the funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 101036822.

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Table 1. Climate change impacts (kg CO_2-eq. ha^{-1} yr^{-1}) of baseline scenarios and two emission-reduction scenarios for four farms. Baseline values include sequestration from actions currently applied in the far m. IT: Italy, UK: United Kingdom, DE: Germany, FR: France, PC: productivity-constrained scenario, CN: climate-neutral scenario without productivity constrains. A hyphen indicates inapplicability of the action at the farm.

	Scenario	**IT crop**	**UK crop**	**DE dairy**	**FR dairy**
Mitigation actions	Baseline	7810	2401	5668	10979
Planting 100 m hedge ha^{-1} [a]	PC	5980	571	3838	9149
Establishing cover crops [b]	PC	5430	456	-	-
Applying manure [b]	PC	4330	-644	-	8049
Decreasing tillage by 50% [c]	PC	4240	-734	3748	7959
Total	PC	4240	-734	3748	7959
Percent reduction due to PC scenario (%)	PC	46	131	34	28
Using 20% less mineral fertilizer [c]	CN	4052	-922	3748	7489
Rewilding [d]	CN	0		0	0
Percent of farm area rewilded	CN	46	0	44	61

[a] Dassot et al. 2022. Amortization window of 20 years. [b] Data from Bamière et al. 2023. Action applicable only in 48% of the IT area and 10% of UK farms. [c] Own calculations in the context of IT crop farm. [d] Mondière et al. 2024.

Assessing Organic Waste Products in LCA: Insights from Agribalyse

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1. INTRODUCTION

The ISO standards for life cycle assessment (LCA) allow for flexibility in addressing impact allocation. This study aims to establish guidelines for considering environmental impacts of the production, processing, and application of organic waste products (OWP). The key question is: which environmental burdens should be attributed to OWP? This study falls within roadmap priorities of the REVALIM scientific interest group and focuses on agricultural and food product life cycle inventories (LCIs) of the French Agribalyse database.

2. METHODS

We identified four main approaches and eight methods (in bold): (i) End-of-life allocation methods such as **Cut-off with burden on the upstream process, Cut-off with burden on the downstream process, economical cut-off** [1] (ii) Attributional approaches such as **economic allocation,** allocation based on dry mass (iii) Consequential approaches (i.e. substitution approaches) such as **substitution** (iv) Circular economy approach such as Circular Footprint Formula (CFF), **CFF simplified** for this study. These methods were tested using OWP LCIs from Agribalyse 3.1.1 [2].

3. RESULTS AND DISCUSSION

3.1 Influence of the method on impacts of OWP

Figure 1 andFigure 2 summarize the results for the climate change impact. OWP fall into two groups: fertilizers and soil improvers, according to the classification proposed by [3]. Due to lack of economic data, the economic allocation approach was not applied for commercial fertilizer. The study revealed the limitations of each approach: some of them could not be applied to some OWP LCIs, and for some approaches the required input data were lacking.

3.2 Influence of the method on impacts of agricultural LCIs

Six organic and conventional crops were analysed (Figure 3). The economic allocation method yielded the most important variations in impact, particularly for crops such as maize grain conventional or peach, organic. In the case of the former, this can be explained by the large quantities of OWP as input, and for the latter by the use of industrial organic fertilizers, made up of animal by-products that are largely impacted by economic allocation. For the other methods, impact variations due to the choice of method were rather small.

3.3 Challenges

This study has revealed the challenges of assessing the impacts of OWP in LCA. LCA is a science-based method which deals with physical flows, but also with economic flows in case of multifunctionality. Local factors (supply, demand, economic value) strongly affect OWP production, processing and use and should ideally be considered in choosing the most appropriate method. However, the implementation of different methods according to local factors is difficult in an LCI database focussing primarily on average national LCIs.

4. CONCLUSIONS

Based on these results, the next Agribalyse database update will opt for a cut-off approach, identifying the switchover process that transforms waste material into agronomically valuable OWP, attributing upstream impacts to the system from which the material originated, and downstream impacts to the final product. The study focused on the use of residues as fertilizers or soil improvers, as Agribalyse is an agricultural and food database. However, the same approach could be tested and applied to create inventories adapted to the residues recovery into biomaterials or bioenergy products. The approach adopted aims for methodological consistency and recognizes the lack of available short-term economic data required for economic approaches that could be considered in a subsequent update of the database.

5. ACKNOWLEDGEMENTS

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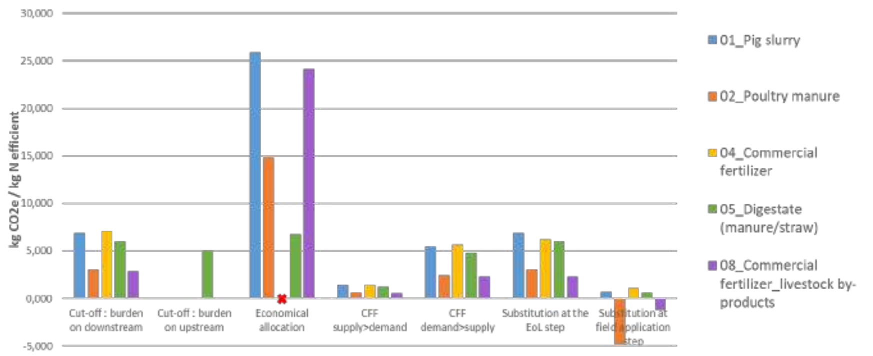


Figure 1. Global comparison of fertilizers on climate change with different approaches

Fertilizers - kg N efficient

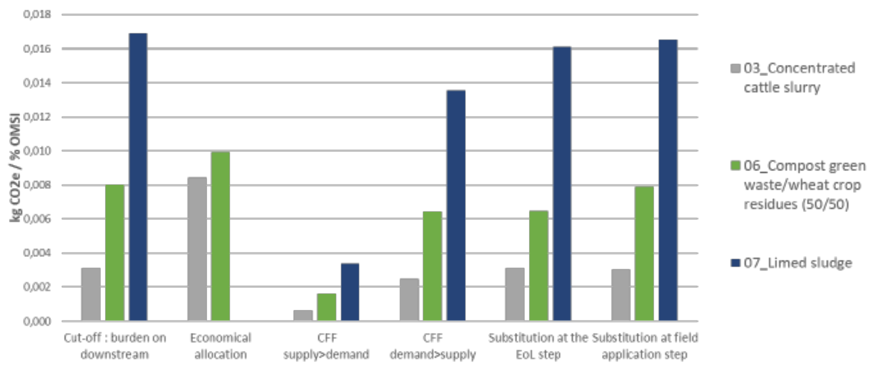
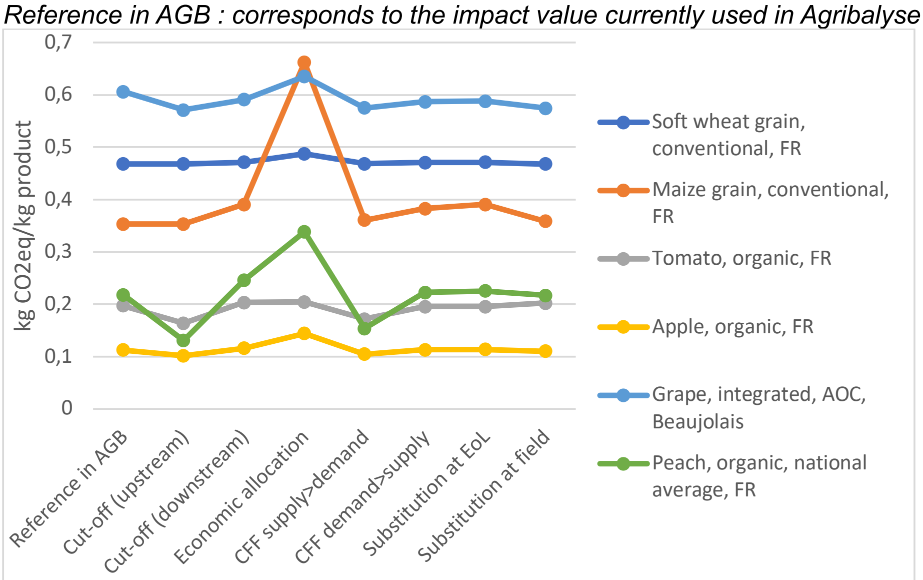


Figure 2 Global comparison of amendments on climate change with different approaches

Amendments - % organic matter stability index

Figure 3 Climate change impact variation for six crops according to the approach used on fertilizers and amendments

Reference in AGB : corresponds to the impact value currently used in Agribalyse



Comparison between a delivery service of ready-to-cook ingredients and a meal prepared by a home helper for the elderly

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1. INTRODUCTION

In France, undernutrition among the elderly living at home is a public health issue (Fleury et al., 2021). It affects almost 10% of those over 70 years old. As independence gradually declines with age, the elderly often delegate shopping and meal preparation, but this does not always bring the expected benefits. Loss of appetite can lead to reduced pleasure in eating, physical difficulties, loss of control, isolation, and loss of the social role of mealtime. This can create a vicious circle that increases the risk of undernutrition. Therefore, it is crucial to address these issues to prevent undernutrition. The Alim'age project aims to help elderly individuals who are losing their independence at home to maintain their involvement in their own diet and enjoyment of eating, thereby combating malnutrition. Different solutions were identified such as ready-to-cook baskets, which is the aim of this study. The aim of the present work is to assess and compare the environmental impact between the ready-to-cook basket services (pre-prepared ingredients, for a single serving recipe, delivered to elderly individuals, allowing for easy cooking without the need for peeling or cutting vegetables) and the same meal prepared by the home helper.

2. METHODS

Two meals that include saithe and summer vegetables were modelled (Table 1). For the Alim'age meal, the elderly only had to cook the fish and heat up the vegetables. The second meal was prepared by a home helper using same ingredients purchased from the supermarket. Both meals included the use of oil and seasoning available from the elderly. LCA is done in SimaPro software (9.1.0.11) with ecoinvent V3.6 and Agribalyse V3.0.1 databases and EF 3.0 method. The functional unit is "provide one meal to the elderly at home".

3. RESULTS AND DISCUSSION

1.1 Analysis and comparison of the impacts of the two meals

The analysis shows that the Alim'age meal (Fig. 1, column 1) and the home-made meal (Fig. 1, column 2) share the same hierarchy of life cycle stages when it comes to contribution to the environmental impact. Ingredient production is the main contributor (respective ranges: 31-95% and 37-95%), electricity consumption for heating the product comes second (1-42% and 1-48%), followed by seasoning (0.5-22.5% and 0.5-22.5%) and delivery of the product (1.2-25.6%, only for the Alim'age meal). The Alim'age meal is especially favourable for ionising radiation, water use, and use of fossil fuels. However, it is especially unfavourable for stratospheric ozone depletion, land use, and use of mineral and metal resources.

1.2 Effect of the delivery's distance

The Alim'age meal has a single score of 232 µPt with a delivery circuit of 200 km, while the home-made meal has a single score of 238 µPt. At a delivery distance of 350 km, the Alim'age meal reaches a single score of 238 µPt. An analysis of the needs of the territories must be conducted before proposing this service, as staying under this delivery distance might not be easily achievable in rural areas for instance.

4. CONCLUSIONS

The results indicate that there is minimal difference between the environmental impacts of the two proposals. A maximum delivery distance of 350 km has to be respected for the Alim'age scenario to be favourable. This life cycle assessment (LCA) will assist decision-makers in selecting the appropriate service for aiding the elderly in maintaining their health and quality of life, while also delaying their transition into retirement homes, which are often short of rooms and not preferred by the elderly.

5. ACKNOWLEDGEMENTS

The present study was part of the “Alim'age” project, funded by the Région Pays de la Loire (France), supported by the Gérontopôle and accredited by Valorial. The authors thank the project partners for providing data.

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	Alim'age meal	Home-made meal
Role of the elderly person in the meal preparation	Active	Passive
Preparation at home	Cooked and heating by elderly	Peeled and cooked by home helper
Home helper	Come to the home to take care of the elderly person	
	Don't cook the meal	Cook the meal
Ingredients	Wholesaler Peeled by semi-craft caterer	Bought at supermarket Row
Seasoning	Home funded	
Delivery	200 km with a refrigerated truck	The home helper purchases the necessary ingredients on their way to the elderly person.
Cleaning	50% handwashed / 50% dishwasher	
Packaging	53 % burned / 47 % landfilled / 0% recycling	
Paper bag	40 % recycled	-

Table 1. Simplified recipe and way of preparation of the meals.

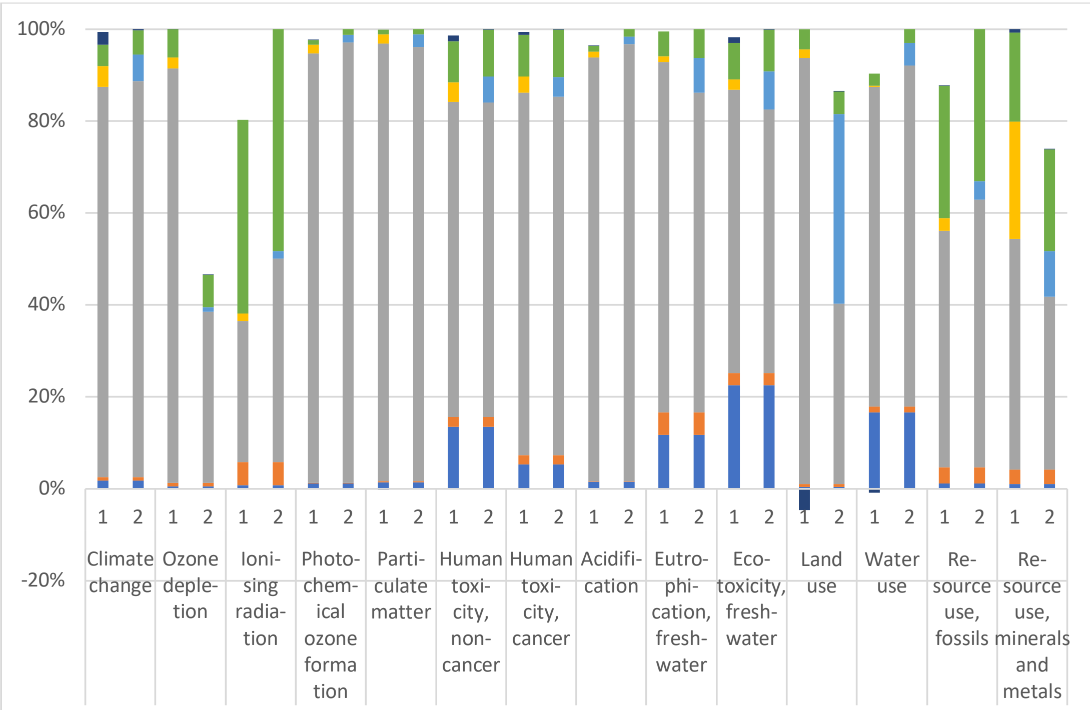

Figure 1. Comparison of the impacts of Alim'age meal (1) and the meal prepared by home helper (2). Seasoning – Washing – Ingredients (fish, potatoes and vegetables) – Delivery – Packaging – Electricity – Waste.

Analyzing the impacts of the production of vegetable oil: understanding the role of packaging impacts

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1. INTRODUCTION

The food production industry contributes significantly to environmental burdens, generating impacts such as deforestation, water consumption and pollution, destruction of habitats due to land use change (Carter et al., 2018), as well as the generation of solid waste during and after the sales process, including plastic packaging. Therefore, the main objective of this study is to analyze the production, packaging, and distribution of a set of different volume formats of vegetable oil marketed in the Peruvian and Bolivian domestic market.

2. METHODS

The study contemplated the production, packaging and transportation to the main warehouse gate, considering a cradle-to-gate scope

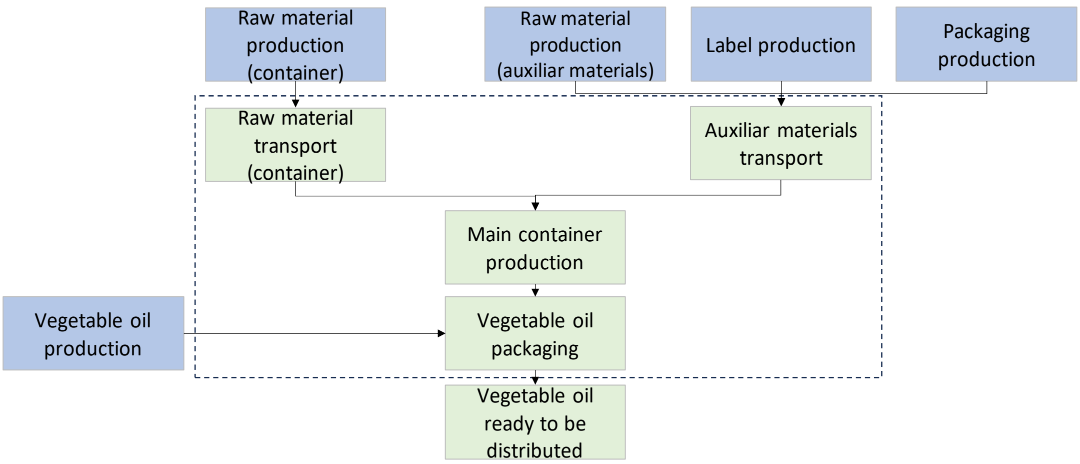

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Figure 1). A Life Cycle Assessment (LCA) was performed in 10 formats for the Peruvian market and 11 for the Bolivian market, with different volumes and materials used for packaging. The environmental impact of oil production was calculated in a previous study (Cucchi et al., 2023). Thus, it was not analyzed in depth here. The functional unit (FU) was 1 L of vegetable oil ready to be distributed and sold. The study collected primary data through direct communication with the producer company and main suppliers. Secondary data were retrieved from scientific literature and the ecoinvent 3.7.1 database. To evaluate plastic waste emissions, the Plastic Footprint Network (PFN) methodology (PFN, 2023) was employed. The impact assessment was performed using the IPCC 2021 100y and ReCiPe 2016 Midpoint (H) methods. The effects of plastic packaging in nature due to waste mismanagement were assessed with new characterization factors (CF) for physical effects on biota (Corella-Puertas et al., 2023; Lavoie et al., 2021).

3. RESULTS AND DISCUSSION

Results for climate change per FU and each format for the Peruvian and Bolivian markets ranged between 0.22 kg CO_2eq for the smallest presentation (i.e., 200 mL), to 0.14 kg CO_2eq in the presentations of 5 L (see Tables 1 and 2). Impact contribution shows that 70% to 80% is related to the production of the main plastic container, including raw material and moulding. Transportation has relatively low impacts in most presentations, except for those produced in Bolivia and transported back to the Peruvian market. For other impact categories, results show similar tendencies, expect for marine eutrophication, where the impact is related to the weight of the cardboard container. Plastic leakage to the ocean, only estimated for Peru, in the shape of microparticles is estimated to be between 0.04 g and 0.85 g per FU among all formats and its impacts to physical effects in biota ranged from 3.5 to 7.4 PAF*m3/day using the midpoint CFs (Table 1). In this case, larger impacts are observed for formats with lower volume, since more plastic is used per liter of oil.

4. CONCLUSIONS

Delving into packaging and transportation processes can provide valuable insights to improve packaging efficiency. Thus, identifying key hotspots can lead to mitigation opportunities to reduce impacts in these stages. Moreover, new CFs for impacts of plastic leakage into the ocean offer a new perspective in LCA. However, impacts analyzed here only consider a single type of effect (i.e., physical effects on biota), whereas mismanaged plastics have a broader range of environmental and social impact pathways (e.g., ecotoxicity of plastic additives, invasive species or abiotic depletion).

5. ACKNOWLEDGEMENTS

The authors thank all personnel at Alicorp S.A.A that provided data for the development of the study and the Pontificia Universidad Católica del Perú. Ms. Claudia Cucchi is acknowledged for valuable scientific exchange.

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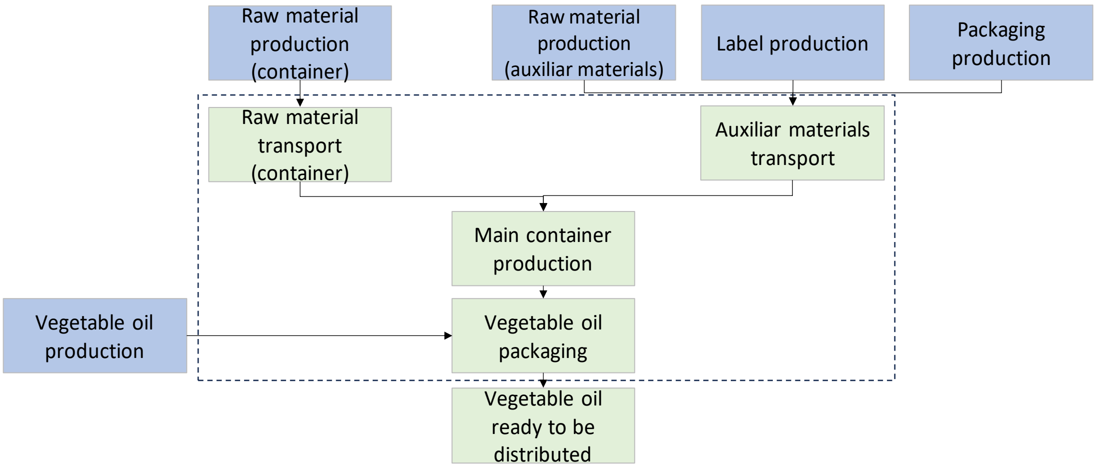

Figure 1. System under study for the production, packaging, and transport of vegetable oil.

Table 1. LCIA results for 1 L of vegetable oil ready to be distributed and sold in Peru for different formats using the IPCC 2021 100a and ReCiPe methodologies and the CFs for the assessment of Physical Effects in Biota caused by microplastics accumulated in the ocean.

Impact category	unit	PET bottle 200mL	PET bottle 500mL (A)	PET bottle 500mL (B)	PET bottle 900mL (A)	PET bottle 900mL (B)	PET bottle 900mL (C)	PET bottle 1L	PET bottle 1.8L(i) (A)	PET bottle 1.8L (i) (B)	HDPE container 5L
IPCC GW	g CO_2 eq	225	191	220	131	139	153	118	484	460	137
FPMF	µg PM2.5 eq	390	319	368	216	229	255	194	815	772	203
TA	µg SO_2 eq	791	655	754	445	473	525	400	1807	1712	424
FWE	µg P eq	64	54	62	38	40	44	34	76	70	38
ME	µg N eq	12	15	17	13	14	14	12	13	14	14
MEx	g 1,4-DCB	11	9	11	6	7	8	6	19	18	5
MRS	µg Cu eq	612	510	590	351	373	414	316	1007	922	284
FRS	g oil eq	99	83	96	56	59	66	50	179	167	70
PhEB	PAF*m3*day	29.6	27.6	23.7	18.5	16.5	15.4	13.9	20.2	15.7	18.7

GW: global warming; FPMF: fine particulate matter formation; TA: terrestrial acidification; FWE: freshwater eutrophication; ME: marine eutrophication; MEx: marine ecotoxicity; MRS: mineral resource scarcity, FRS: fossil resource scarcity; PhEB: physical effects in biota; (i): imported products from Bolivia to Peru

Table 2. LCIA results for 1 L of vegetable oil ready to be distributed and sold in Bolivia market for different formats using the IPCC 2021 and ReCiPe.

Impact category	unit	PET bottle 450mL	PET bottle 900mL (A)	PET bottle 900mL (B)	PET bottle 900mL (C)	PET bottle 1L	PET bottle 1.8L (A)	PET bottle 1.8L (B)	PET bottle 3L	HDPE container 4.5L (A)	HDPE container 4.5L (B)	PET container 4.5L
IPCC GW	g CO_2 eq	247	170	162	178	160	213	214	159	210	197	163
FPMF	µg PM2.5 eq	421	293	279	306	276	360	361	277	335	310	278
TA	µg SO_2 eq	848	585	556	613	551	715	718	549	644	599	555
FWE	µg P eq	68	49	47	51	46	62	62	47	60	55	47
ME	µg N eq	13	11	11	11	10	13	13	12	12	9	9
MEx	g 1,4-DCB	11	7	7	8	7	9	9	7	7	6	7
MRS	µg Cu eq	607	419	396	440	396	515	516	386	321	298	395
FRS	g oil eq	106	70	67	74	66	92	92	64	99	95	71

GW: global warming; FPMF: fine particulate matter formation; TA: terrestrial acidification; FWE: freshwater eutrophication; ME: marine eutrophication; MEx: marine ecotoxicity; MRS: mineral resource scarcity, FRS: fossil resource scarcity; PhEB: physical effects in biota

Interlaboratory collaborative life cycle assessment study in the food and packaging sector

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1. INTRODUCTION

Life cycle assessment (LCA) is based on a standardised (ISO 14040:2021 and ISO 14044:2021) and mathematical model, which helps LCA practitioners to collect data, assess impacts and interpret results. Today, the perception of the LCA is of an unreliable methodology because it is subject to much variability due to the many degrees of freedom within the system. These degrees of freedom are referred to variability factors and introduce elements that can lead to different LCA results based on assumptions, database and software choices, calculation methods, and above all arbitrary decisions made by the LCA practitioner (Scrucca et al., 2020). The result is that if different LCA practitioners analyse the same scenario, different and even conflicting results may be obtained. With this project, the preliminary objective of the work is to compare the performance of LCA practitioners and to assess how variability factors may influence the results from the environmental impact analysis. To achieve the objectives, a collaborative interlaboratory study in LCA was used, which is based on a statistical approach standardised at the ISO level (ISO 17043:2023 and ISO 13528:2022), by comparing different LCA Practitioners analysing the same scenario.

2. METHODS

Variability factors that may influence LCA results were identified through an in-depth study of the scientific literature and consultation with authoritative sources such as the ISO 14040 and ISO 14044 standards and the ILCD Handbook, identifying 52 potential variability factors. Following the ISO reference standards on the interlaboratory method (ISO 17043 and ISO 13528), analysis protocols were created to isolate the variability factors, the starting point for the development of procedures for carrying out LCA studies to maximise the homogeneity of the study. The analysis started from the study of 3 variability factors, out of the 52 identified, and the creation of 3 scenarios to be analysed (tests): (1) a case study on packaging to study the variability of the results deriving from the choice of software and database used, (2) a case study on apple dehydration to assess the variability of the results deriving from the country mix energy model used and (3) a case study on dry pasta production to assess the variability of the results deriving from the allocation method. Through the EPT (Effective Proficiency Team Platform), provider of the interlaboratory, the developed tests were made available internationally. Numerous LCA practitioners from all over the world joined the project free of charge and voluntarily, conducted tests and submitted their results. Each practitioner was provided with an automatically generated PIN code to access the EPT platform and publish their results. The PIN codes allowed full anonymity of the participants and later became the necessary tool for each practitioner to access the z-score-based evaluation of their performance.

3. RESULTS AND DISCUSSION

The collected results were analysed using two software packages in the programming languages R and Python following the relevant ISO standards (ISO 17043 and ISO 13528). It was thus possible to identify the state of the art with objective data, to represent the competence of the LCA professionals participating in the interlaboratory test using a z-score value, to determine the perfo of the results of the LCA studies in relation to the case studies and to experimentally quantify the measurement uncertainty.

4. CONCLUSIONS

In conclusion, it was possible to investigate the first three factors that determine the variability of LCA studies by validating the methodology developed, which will be replicated for the remaining 49 variability factors. The results allowed the LCA practitioners who participated in the study to visualise their positioning within the professional community of participating LCA practitioners. Future interlaboratory studies in LCA could be used to qualify and recognise the LCA practitioner profession internationally.

5. ACKNOWLEDGEMENTS

This project is also part of a PhD project funded by PON – National Operational Programme - Research and Innovation 2014-2020 – Action IV.5 - PhDs on green topics.

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Combined nutritional and environmental assessment of foods and diets (I)

06

REFRESH: a Validated Public Health Screener for Healthy Diets with Low Environmental Impact

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1. INTRODUCTION

Current dietary patterns are a major leading cause of morbidity and mortality worldwide [1], in addition to significantly contributing to natural resources scarcity, environmental degradation and biodiversity loss [2]. The general adoption of healthy diets with low environmental impact is timely [3].

Dietary screeners have been broadly used to assess briefly the adequacy of someone´s diet. However, no tool has been designed with the aim of screening the dietary healthiness and environmental sustainability at once. In this context, our research group has designed REFRESH (Rapid Evaluation FoR an Environmentally Sustainable and Healthy diet). It is composed by a short dietary questionnaire, as long as a scoring system to translate the dietary questionnaire answers into an index. The large-scale use of such tool would require a proper validation. Thus, the objective of this study is to present and validate REFRESH.

2. METHODS

2.1 REFRESH description

REFRESH is a 10-item dietary questionnaire to assess the habitual consumption of key food groups for a healthy and environmentally sustainable diet. Each item has two answer options, discriminating if the consumption of the assessed food group is in line with the recommendations for a healthy diet with low environmental impact according to reference entities in the nutrition field. Each of the 10 items of the questionnaire is scored 0 or 1 points, depending on the dichotomic answer. The total score is the sum of the points of each item. Thus, REFRESH score ranges from 0 to 10 points, with 0 points being the lowest score in terms of environmentally sustainable healthy diet and 10 points being the highest (best) score.

1.2 Study design

We performed an observational study to assess the reliability and validity of REFRESH. In total, 93 adults living in Spain took part on the study. The study lasted 8 days for each participant; in the first day, they answered a baseline questionnaire (which included the REFRESH questionnaire in addition to sociodemographic and lifestyle questions), and subsequently they registered their food consumption during 7 consecutive days by means of app-based food diaries (reference for comparison).

2.3. Statistical analysis

REFRESH´s internal consistency was evaluated by Kuder-Richardson Formula 20. The questionnaire´s validity was evaluated by the agreement among REFRESH and food diaries through Bald-Altman analysis. Linear regressions were fitted to assess the association of the scoring criteria with the consumption of specific food groups, nutrients, and environmental impact indicators. Nutritional composition was assessed using the software Nutritics®. Dietary environmental impact was assessed from cradle to fork, using Agribalyse as the main life cycle inventory library, and ReCiPe 2016 as the method of characterization.

3. RESULTS AND DISCUSSION

Our participants showed a mean REFRESH score of 7 points (range: 1-10). The screener presented a good internal consistency. Comparing REFRESH data to that of the food diaries, we found a percentage of agreement among 60% and 84% for each specific food item. We identified that participants tended to slightly overestimate their consumption of whole plant-based foods, while underestimate their consumption of animal-sourced and highly processed foods. Similar findings have been reported in the validation study of other dietary screeners [4].

The diet of those participants scoring higher included a larger proportion of whole plant-based foods. This pattern turned out in a higher intake of fibre, a lower intake of saturated fats, and a lower environmental impact (Table 1). These findings confirm the adequacy of the scoring criteria to screen healthy diets with low environmental impact.

4. CONCLUSIONS

REFRESH is a validated tool to screen healthy diets with low environmental impact, and could be used in large-scale interventions and clinical practice if we are to promote a transition towards healthy diets within planetary boundaries.

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Category	Items	Coef.	*p* value*
Food groups	Red and processed meat	-2.06	**0.000**
	Meat, fish and eggs	-1.10	**0.000**
	Dairy products	-0.31	0.105
	Beans	1.73	**0.000**
	Fruits and vegetables	0.57	**0.000**
	Nuts and seeds	0.88	**0.000**
	Ultraprocessed foods	-1.85	**0.000**
	Sodas	-1.47	**0.000**
	Whole grains	0.02	**0.000**
	Virgin olive oil	0.01	0.189
Nutrients	Energy (kilocalories)	5.13E-04	0.257
	Protein	-7.02E-03	0.251
	Free sugars	-7.22E-02	**0.002**
	Saturated fats	-8.64E-02	**0.002**
	Fibre	9.50E-02	**0.000**
	Sodium	-6.44E-04	**0.038**
	Calcium	1.11E-03	0.070
Environmental impact categories	Human health (end-point)	-1.54E+05	**0.003**
	Ecosystem (end-point)	-3.05E+07	**0.003**
	Resources (end-point)	-5.22E+00	**0.021**
	Global warming potential (mid-point)	-5.47E-01	**0.000**
	Land use (mid-point)	-3.89E-01	**0.013**
	Water consumption (mid-point)	2.88E+00	0.061

Table 1. Association between REFRESH scoring criteria and food groups, nutrients, and environmental indicators

Coef=coefficient of the linear regression. *p<0.05 denotes statistically significant association.

The Planet Health Conformity-Index: bridging the gap between nutritional and environmental sustainability in nLCAs

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1. INTRODUCTION

In order to enable consumers to make sustainable food purchases that equally account for health, the environment and planetary boundaries, we have developed the Planet Health Conformity Index (PHC) (Schade et al. 2023). Currently, it is impossible for consumers to identify the environmental and health benefits of food at the point of sale (Bunge et al. 2021), as existing labelling formats address either nutritional/health aspects (e.g. Nutri-Score) OR environmental aspects (e.g. Eco-Score, Climate-Score). Hence, if both mono-dimensional label types are shown together on one product, this would be disadvantageous from a communication perspective, as the label messages could be contradictory (e.g. a labelled product shows an A in the Nutri-Score, but only a D in the environmental label). This leads to the need for a new label metric that includes the multidimensionality of environment and health in one label. Consequently, this additional information would both satisfy an increasing request of consumers and facilitate the development of more sustainable food products (Green et al. 2023).

2. METHODS

The PHC includes 18 nutrients and five environmental impacts (GWP, cropland use, freshwater use, N & P application) contextualized in the concept of planetary boundaries (Willet et al. 2019). In its function, the PHC examines whether a food product can offer sufficient nutrient supply while simultaneously preserving the planetary boundaries (Table 1, Figures 1-2). Six different algorithm designs were tested comprising the choice of capping and weighting and applied to 142 food products in the German market (incl. imported foods). Further, the results of the PHC were compared to a mass-based and energy-based functional unit. This abstract presents only a selection of the most important results.

3. RESULTS AND DISCUSSION

The different modes of summing the PHC showed the varying impact of the algorithm design. Applying the arithmetic mean emphasizes single extreme values even when capping and weighting was applied. Specifically single-food products can hardly include all important nutrients which is why the median offers a fairer opportunity of summing. It was found that a considerable amount of food products was rated as preserving the planetary boundaries when a mass-based unit was applied. Including nutrients into the calculation altered the outcome significantly with many of these products actually exceeding the planetary boundaries when nutrients were accounted for in the analysis (Table 2).

Compared to other nFU-approaches the new PHC is equipped with the following innovative features: 1) The nutritional strengths and weaknesses of food products are highlighted from an environmental planetary boundary-based perspective. Thus, the new score breaks down the mass-based specifications of the Planetary Health Diet (PHD) into corresponding specifications on a nutrient level. Hereby, nutrients were selected with a high public health relevance. 2) Due to its two-factorial design (environmental impact divided by nutrient AND environmental PHD-based allowance divided by nutrient) and the division of these two factors by each other, all units are truncated. Consequently, the new score is applicable to a broad set of nutritional-environmental questions – on level of single products, composed recipes, whole dishes, whole diets and/or whole consumption patterns. 3) Due to it´s nutrient-based approach, the new score can be easily adapted to the nutritional needs of specific individuals or population groups to evaluate the ecological compatibility of foods, recipes, diets, etc. context-specifically.

4. CONCLUSIONS

Nutritional functional units need to be harmonized with nutritional recommendations, the dietary background and the health status of the target population in order to generate optimal results. Further, data quality needs to be monitored precisely as nFU usually demands the inclusion of several data sources. Traditional food LCAs need to start introducing nutrients as the basic function of food into their FU.

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Table 1 Nutrient related planetary boundaries for Global Warming Potential (GWP): g CO2e per nutrient (LB=lower bound, UB=upper bound)

Boundary transgression		<0,5			1			2			4			>4		
	Label	A	LB	UB	B	LB	UB	C	LB	UB	D	LB	UB	E	LB	UB
Energy	per 100kcal	38	36	41	76	72	82	152	143	164	304	286	329	304	286	329
Protein	per g	10	10	11	21	20	22	42	39	45	83	78	90	83	78	90
SFA	per g	35	33	38	71	67	76	142	133	153	283	266	306	283	266	306
MUFA+PUFA	per g	18	17	19	35	33	38	71	67	76	142	133	153	142	133	153
Sugar	per g	15	14	16	30	29	33	61	57	66	122	114	132	122	114	132
Fiber	per g	25	24	27	51	48	55	101	95	110	203	191	219	203	191	219
Vitamin B1	per mg	634	596	685	1268	1192	1370	2537	2385	2740	5074	4769	5479	5074	4769	5479
Vitamin B2	per mg	544	511	587	1087	1022	1174	2174	2044	2348	4349	4088	4697	4349	4088	4697
Vitamin B6	per mg	507	477	548	1015	954	1096	2029	1908	2192	4059	3815	4384	4059	3815	4384
Folate	per g	2.5	2.3	2.7	5.0	4.7	5.4	10.7	9.5	10.9	20.2	19.0	21.9	20.2	19.0	21.9
Vitamin B12	per µg	190	179	205	381	358	411	761	715	822	1522	1431	1644	1522	1431	1644
Vitamin C	per mg	7	7	7	14	13	15	28	26	30	55	52	60	55	52	60
Vitamin D	per µg	152	143	164	304	286	329	609	572	658	1218	1145	1315	1218	1145	1315
Vitamin E	per mg	54	51	59	109	102	117	217	204	235	435	409	470	435	409	470
NaCl	per g	203	191	219	406	382	438	812	763	877	1624	1526	1753	1624	1526	1753
Calcium	per mg	0,8	0,7	0,8	1,5	1,4	1,6	3,0	2,9	3,3	6,1	5,7	6,6	6,1	5,7	6,6
Magnesium	per mg	2,2	2,0	2,3	4,3	4,1	4,7	8,7	8,2	9,4	17,4	16,4	18,8	17,4	16,4	18,8
Iron	per mg	51	48	55	101	95	110	203	191	219	406	382	438	406	382	438
Zinc	per mg	76	72	82	152	143	164	304	286	329	609	572	658	609	572	658
Iodine	per µg	3,8	3,6	4,1	7,6	7,2	8,2	15,2	14,3	16,4	30,4	28,6	32,9	30,4	28,6	32,9

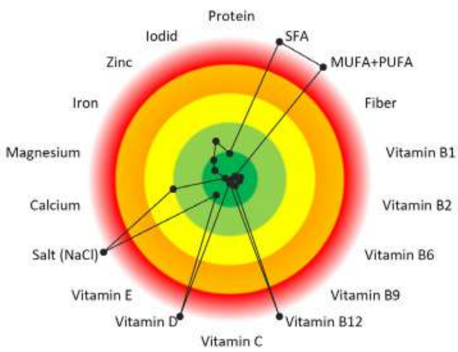

Figure 1 Single PHC Factors (GWP) per nutrient for Bananas from Ecuador

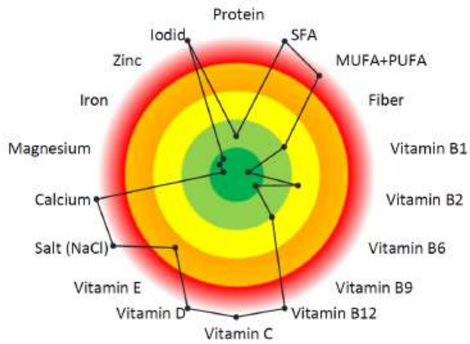

Figure 2 Single PHC Factors (GWP) per nutrient for Paddy Rice from Italy

Table 2 Food-specific Planetary Boundary Conformity Label (Mass- and energy-based) and PHC Scores for GWP (Selection from the 142 foods analysed)

Product	Prod. Country	PB conformity-label, mass-based, per 100g	PB conformity-label, energy-based, per 100 kcal	PHC Median uncapped	PHC Median capped at PB conformity factor 4 (D<E)	PHC Median capped at PB conformity factor 4 with nutritional weighting
Wheat	DE	A	A	A	A	A
Potatoes	DE	A	A	A	A	A
Paddy Rice	**IT**	C	B	D	D	D
Sugar, from sugarbeet	DE	A	A	E	E	D
Lettuce, open field	DE	A	C	A	A	A
Spinach, open field	DE	A	B	A	A	A
Onions, open field	DE	A	C	C	C	B
Tomato, unheated GH	NL	B	E	D	D	D
Oranges	ES	A	A	A	A	A
Bananas	**EC**	A	A	B	B	B
Apples	DE	A	A	C	C	C
Grapes	DE	A	A	B	B	A
Wine	DE	A	A	E	E	D
Beer	DE	A	A	C	C	C
Sunflower seed	HU	B	A	A	A	A
Sunflower seed Oil	NL	B	A	E	E	D
Palm Oil	ID	E	B	E	E	D
Almonds	USA	C	A	B	B	B
Walnuts	FR	C	A	A	A	A
Sesame seed	IN	C	A	A	A	A
Groundnuts	AR	E	C	C	C	C
Dates	TU	C	B	E	D	D
Meat, Chicken	DE	B	B	C	C	C
Meat, pig	DE	C	C	C	C	C
Meat, Cattle	DE	E	E	E	E	D
Eggs	DE	B	B	A	A	A
Milk	DE	C	D	D	D	D
Butter, Ghee	DE	E	D	E	E	D

Do Swiss food trends lead to healthier, more nutritious and environmentally friendly diets?

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1. INTRODUCTION

Production and consumption of food have a considerable environmental impact (Poore & Nemecek, 2018). In addition, dietary consumption influences the health and nutritional status but can change over time due to various socioeconomic factors. The aim of this study was to: 1) evaluate the nutritional, health and environmental (NHE) dimensions of 64 foods commonly consumed by the Swiss population; and 2) assess consumption trends in combination with the NHE dimensions from 1990 since 2017 at food and diet level.

2. METHODS

The nutritional dimension of sixty-four commonly consumed foods was analysed by the Nutrient Rich Food Index 10.3 (NRF10.3), based on the NRF9.3 developed by Fulgoni et al. (2009). To evaluate the health effects of dietary intake, the Health Nutritional Index (HENI) was used (Stylianou et al., 2021). The Swiss food composition database was used to obtain the nutritional composition of the selected foods. The environmental dimension of foods was assessed by LCA using the SALCA method v2.1 (Douziech et al., 2024), and seven impact categories were considered for evaluation: GWP (IPCC 100 years), water scarcity (AWARE), land use (agricultural), eutrophication freshwater, eutrophication marine and ecotoxicity freshwater. To evaluate consumption trends, we used disaggregated agent-based data on Swiss household purchases provided by Swiss Federal Statistical Office for the years 1990, 2000, 2010, 2017 for 6–12 thousand randomly selected participants of the survey (households of Switzerland) each year. The fraction of food wasted (avoidable and unavoidable, was estimated and subtracted (Beretta et al., 2017). Data analysis was performed at food and diet level. For the diet level analysis, a portion of out of home food intake was estimated (Beretta & Hellweg, 2019).

The decreased consumption of all meats except for poultry had a positive nutritional and health impact while decreasing the overall environmental impact due to meat consumption. The increased consumption of pulses increased the nutritional density and health of the Swiss population while having a low to moderate overall environmental impact. Nutritional and health dimensions behave differently for some products, highlighting the importance of reporting both dimensions. Figure 1 shows the NHE dimensions of four selected foods. At diet level, an increase in nutritional density and a decrease in health was observed (see Table 1). A significant different HENI value at year 2000, lead mainly by an increased consumption of nuts, fruits, vegetables and omega-3 fatty acids content of the diet was observed. The environmental dimension varies depending on the impact category considered and clear trends were more difficult to be determined. In general, ecotoxicity freshwater, climate change (GWP) and water scarcity increased, while eutrophication marine, land use agricultural, eutrophication freshwater and acidification terrestrial decreased (Table 1).

4. CONCLUSIONS

A better understanding of the dynamics of the nutritional, health and environmental dimensions as well as consumption trends of foods will help optimize dietary recommendations and identify synergies and trade-offs between dimensions. The next steps of this study are to analyse food groups at product and diet level based on dietary recommendations, and better align production and consumption recommendations with sustainable goals.

5. ACKNOWLEDGEMENTS

This work is supported by the project OptiSignFood, which received funding from the European Union's Horizon 2020 Framework programme under grant number 971242.

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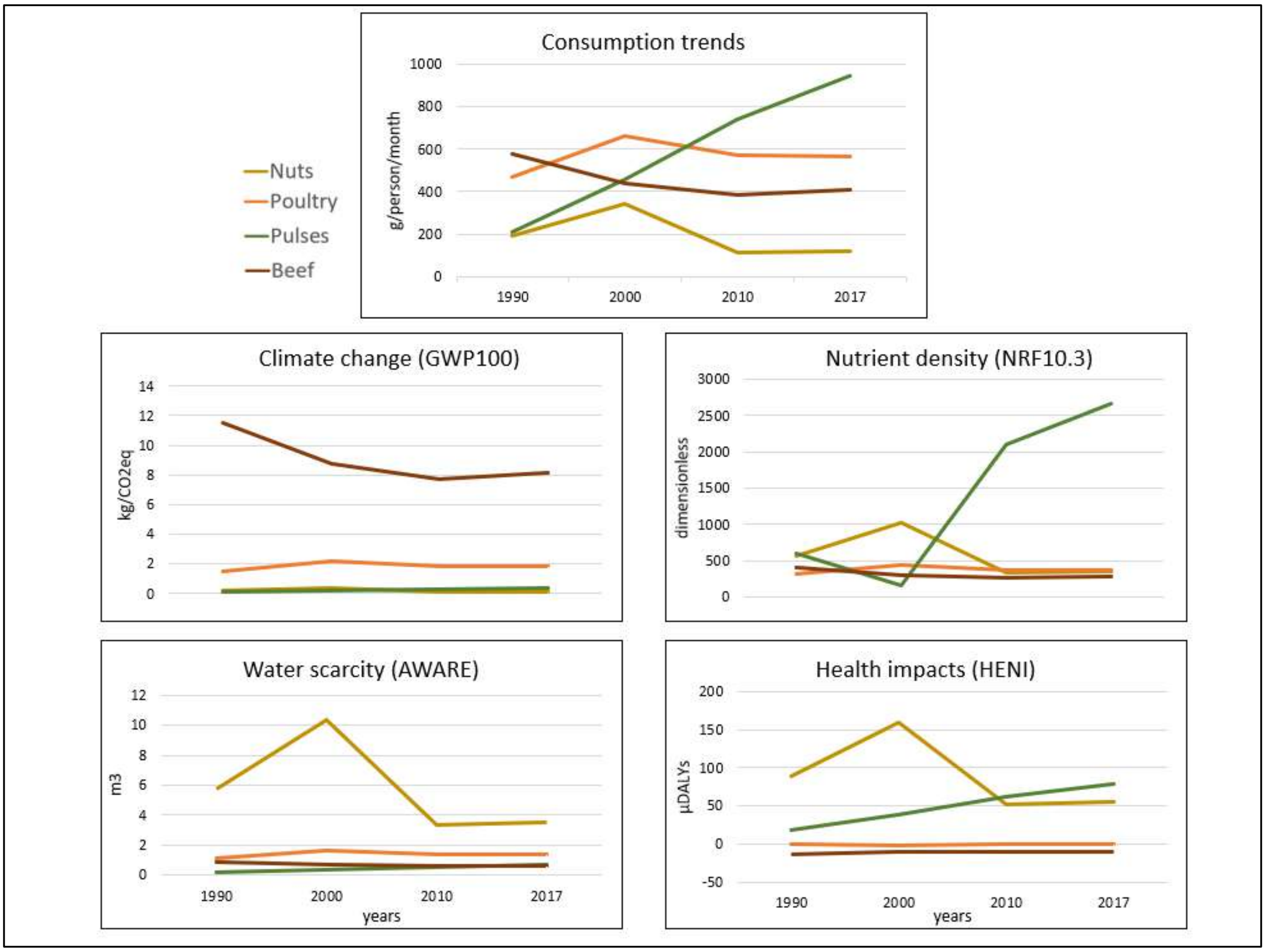

Figure 1. NHE dimensions of selected foods per consumption trends.

Footnote: NRF10.3: Nutrient Rich Food index 10.3; GWP100: Global warming potential 100 years; HENI: Healthy nutritional index; AWARE: available water remaining.

Table 1. *Trends in Nutritional, health and environmental (NHE) scores in 1990 – 2017 at diet level*

year	NR10.3	HENI	AWARE	LO	GWP	EM	EFW	AT	ECFW
1990	7.80	2.11	3.79	4.19	3.50	0.0046	0.0006	0.0370	3538.76
2000	8.20	14.19	4.93	4.56	3.52	0.0050	0.0007	0.0357	1762.69
2010	8.48	1.57	5.05	3.84	4.07	0.0043	0.0007	0.0374	5269.06
2017	8.54	3.25	4.58	3.90	3.94	0.0042	0.0006	0.0353	4487.39

Footnote : Red colour shows worst values; green colour shows better effect. Abbreviations: 1) Ecotoxicity.wP.-.USEtox.-.Freshwater (ECFW); 2) Acidification.-.Terrestrial (AT); 3) Eutrophication.-.Freshwater (EFW); Eutrophication.-.Marine (EM); 4) IPCC.2021.-.GWP100.(fossil.&.LULUC) (GWP); 5) Land.occupation.-.Agricultural (LO); 6) Water.scarcity.-.AWARE (AWARE); 7) Heath Nutritional Index (HENI); 8) Nutrient Rich Food Index 10.3 (NRF10.3).

Environmental and nutritional performance of meal trays served in public collective catering

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1. INTRODUCTION

Food transition is necessary to go towards healthy and sustainable diets. While diets are studied from environmental and nutritional points of view, analyses at the meal level are scarce. At the same time, public collective catering is spotlighted as a lever for food transition since it feeds a wide diversity of people, it is linked with agricultural production (directly or via intermediaries), and, in France, 20% of meals are eaten out of home. Hence, in this study, we aimed to quantify the environmental and nutritional qualities of meal trays served in a public restaurant to answer these questions: What's the link between the environmental and nutritional qualities of meals? Do these performances vary from season to season? Does the vegetarian offer reduce the environmental impacts of a meal? And does it offer good nutritional quality?

2. METHODS

This study was performed in partnership with a public restaurant at Paris-Saclay University. Data were collected during one week per season of 2023 (five days per week, one meal per day, i.e., 20 meals total). Data related to equipment in the kitchen were collected once at the beginning of the year. On each day of data collection, meal preparation was observed to collect recipes, composition, and nutritional values of products, cooking mode, and time. During the service, 70 vegetarian and 70 non-vegetarian consumer trays were pictured all service long, corresponding to 2,800 trays captured during the year.

Nutritional indicators were calculated from the nutritional values of products and eventually completed with the CIQUAL database when information was not available on the products.

Environmental indicators were assessed by LCA, considering a tray as the functional unit. System boundaries went from primary production to the tray. Collected data were completed with AGRIBALYSE 3.0 and Ecoinvent data. Impacts were computed with the EF3.0 method by using the Brightway2 framework.

Statistical analysis was performed with XLSTAT software.

3. RESULTS AND DISCUSSION

The presented results are about three seasons. The fourth season will be analyzed in the coming weeks, and the final results will be available for LCA Food 2024. However, no seasonal effect could be observed on the environmental and nutritional qualities of the trays for the studied seasons, suggesting that the inclusion of new results will probably not affect the other conclusions.

3.1 High environmental impact is correlated with high protein content

Principal component analysis (PCA) was performed on the 2,100 trays, including nutritional and environmental indicators (Figure 1). Environmental indicators were grouped, indicating a correlation between them. They were also grouped with protein content indicator, suggesting that the more the trays have a high environmental impact, the more they contain proteins. The other nutritional indicators were also grouped but separated from environmental indicators and protein content. This suggests no other correlation between environmental and nutritional indicators.

3.2 Vegetarian trays tend to have less environmental impacts

Different distributions could be observed between vegetarian and non-vegetarian meals (Figure 2). Vegetarian meals tended to generate less environmental impacts than non-vegetarian meals. At the same time, vegetarian meals tended to contain less protein and more fiber than non-vegetarian meals. However, these tendencies were not always verified, and many trays had similar environmental and nutritional qualities.

4. CONCLUSIONS

The environmental impacts of the trays were correlated to their protein content but not to other nutritional indicators. Consistently, vegetarian meals tended to generate less environmental impacts and to contain less protein and more fiber than non-vegetarian meals. No seasonal effect could be observed on the environmental and nutritional qualities of the trays. Such results provide information to support food transition in public collective catering.

5. ACKNOWLEDGEMENTS

This work was supported by the French National Research Agency through the ICAD project (grant number ANR-21-CE03-015-03). The authors also thank D. Forest, P. Arana-Agudelo, and N. Ly, as well as the restaurant's staff, for their assistance in data collection.

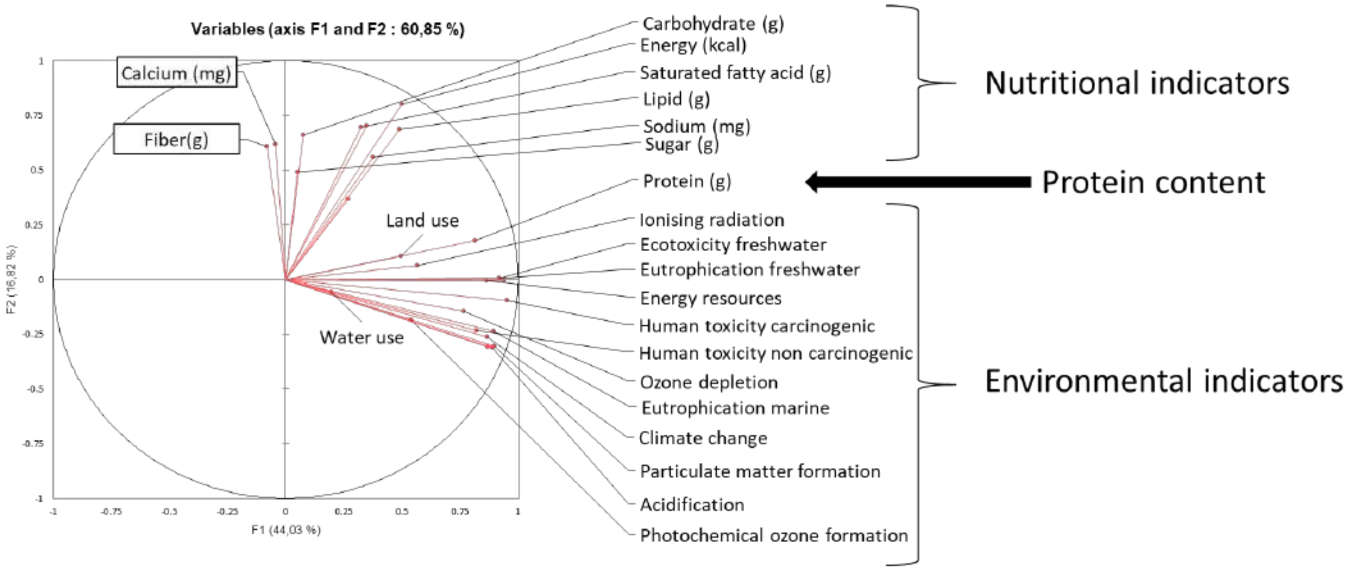

Figure 1. Principal Component Analysis of 2,100 trays by including both nutritional and environmental indicators: correlations between the indicators.

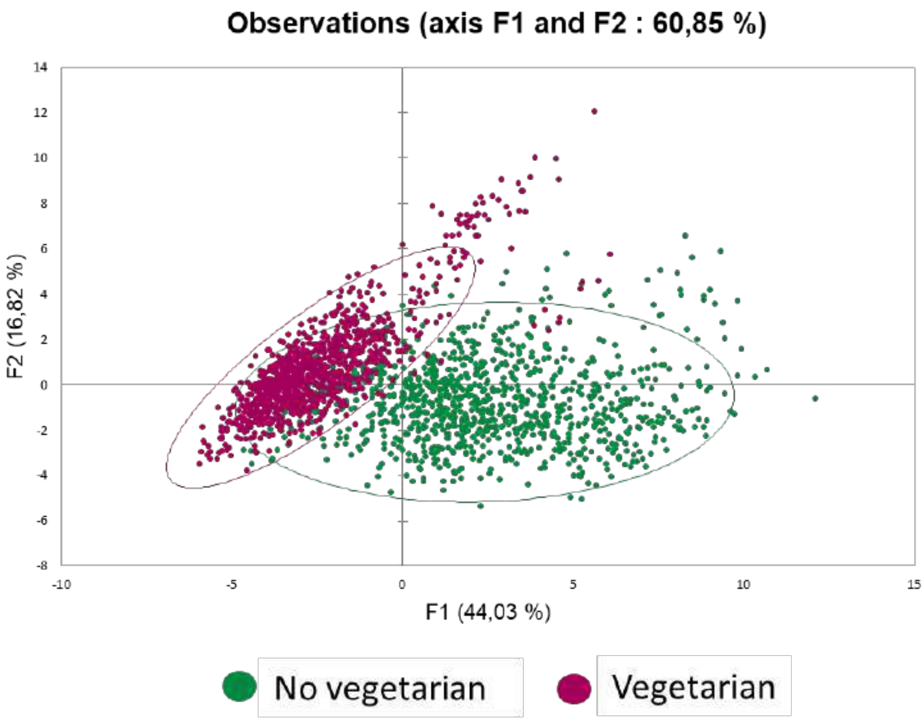

Figure 2. Principal Component Analysis of 2,100 trays by including nutritional and environmental indicators: positioning of the trays (no vegetarian trays in green, vegetarian trays in violet).

Nutrition-related health and environmental impacts of shifting to recommended diets in the US

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1. INTRODUCTION

There has been an increased focus recently on integrating sustainability into US nutrition guidance. Studies comparing the environmental impacts of the food patterns in the *Dietary Guidelines for Americans* (DGA) to current consumption[1] find wide impact variability. Despite this, attempts to integrate sustainability in the DGA have failed, with environmental burdens deemed out of scope by the government. Health outcomes, however, are undoubtedly in the DGA's scope. Studies have explored the adverse health outcomes that could be avoided by shifting to optimal consumption of certain food groups in the US[2,3], yet these consumption levels often do not align with the DGA. The goal of this study was to estimate both the nutrition-related health and environmental impacts of shifting to the DGA food patterns in the US.

2. METHODS

We implemented scenario-based simulation modeling where current and recommended dietary intakes were specified exogenously. Dietary intake for US adults was estimated using the National Health and Nutrition Examination Survey (2015–2018). Recommended food patterns were obtained from the DGA 2020-2025 report. Disease-specific health outcomes associated with intake of 18 food groups were calculated using Comparative Risk Assessment (CRA). CRA estimates the population-attributable fraction (PAF), which reflects the proportional reduction in cardiometabolic disease (CMD) deaths and cancer cases that would occur if the current intake reached the recommended level. PAF is then multiplied by CMD deaths and cancer cases to estimate the nutrition-related population level impacts on CMD mortality and cancer incidence. The model simulates net environmental impacts of dietary shifts using LCIA datasets from Heller and colleagues[4,5] as inputs, and a Monte Carlo approach with 1,000 runs.

3. RESULTS AND DISCUSSION

Shifting to each of the recommended patterns results in health benefits, with the greatest reduction in nutrition-related chronic disease outcomes found for the Healthy Vegetarian (VEG) pattern, followed by the Healthy Vegan (VEGN) pattern. Adopting the VEG pattern across the US adult population would result in 78,289 fewer cases of cancer and 295,960 fewer deaths from CMD annually (**Table 1**). At the same time, shifting to three of the four recommended patterns results in increases in water scarcity footprint (**Figure 1**), driven by increased fruit, nuts and seeds, and dairy intake. Adopting the Healthy-Mediterranean (MED) and Healthy-US Style (HUS) patterns also results in increased GWP, CED, and blue water consumption. By contrast, shifting to the VEG and VEGN patterns results in reduced GWP, CED, and blue water impacts, driven by reductions in red meat, poultry, seafood, and dairy (VEGN only).

4. CONCLUSIONS

Shifting to the VEG and VEGN patterns results in the greatest health and environmental benefits, despite a small increase in water scarcity for the VEG pattern. The DGA should focus on these patterns, with further research needed to develop additional healthy, low-impact, and culturally relevant options to meet the needs of the diverse US population.

5. ACKNOWLEDGEMENTS

This research was supported by the Interdisciplinary Research Innovation Fund (RAFINS) at the Friedman School of Nutrition Science and Policy at Tufts University.

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Table 1. Absolute change in nutrition-related and environmental impacts associated with a shift from current consumption to US dietary recommendations. *HUS: Healthy US-Style Pattern, MED: Healthy Mediterranean-Style Pattern, VEG: Healthy Vegetarian Pattern, VEGN: Healthy Vegan Pattern*.

	Dietary Pattern Median (95% UI)			
Outcome	**HUS**	**MED**	**VEG**	**VEGN**
GHGE (kg CO_2-eq capita^{-1} year^{-2})	65 (46, 85)	98 (78, 117)	-732 (-712, -751)	-1,083 (-1,062, -1,103)
CED (MJ capita^{-1} year^{-2})	1,888 (1,789, 1,982)	3,748 (3,658, 3,843)	-2,516 (-2,424, -2,622)	-4,370 (-4,273, -4,468)
Bluewater use (L capita^{-1} year^{-2})	12,239 (10,654, 13,861)	14,020 (12,413, 15,624)	-18,771 (-17,015, -20,324)	-41,001 (-39,421, -42,566)
Water scarcity (L-eq capita^{-1} year^{-2})	149,644 (140,706, 158,347)	193,193 (184,058, 202,270)	19,748 (10,505, 29,204)	-67,257 (57,950, -76,478)
CMD (deaths population^{-1} year^{-2})	193,108 (184,137, 201,964)	213,442 (204,184, 222,370)	295,960 (284,407, 306,901)	295,960 (284,407, 306,901)
Cancer (cases population^{-1} year^{-2})	54,619 (52,122, 57,370)	52,019 (49,387, 55,001)	78,289 (75,178, 81,390)	70,660 (67,557, 73,990)

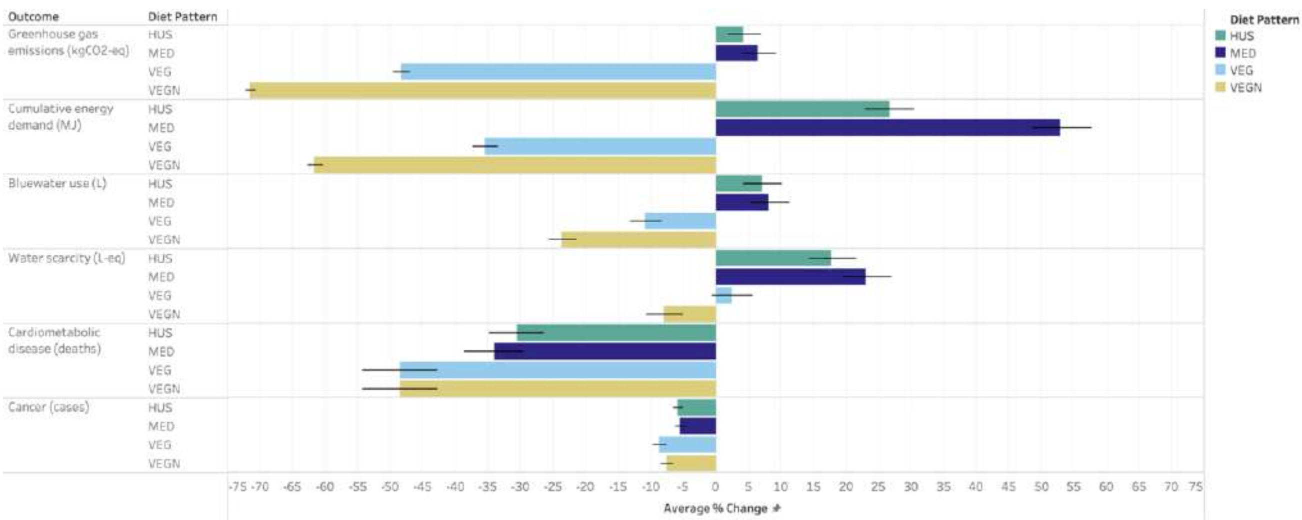

Figure 1. Percent change in nutrition-related and environmental impacts associated with a shift from current consumption to US dietary recommendations. *Error bars represent 95% uncertainty intervals. HUS: Healthy US-Style Pattern, MED: Healthy Mediterranean-Style Pattern, VEG: Healthy Vegetarian Pattern, VEGN: Healthy Vegan Pattern*.

Environmental and Health Impact Assessment of 6,000 Menu Items

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1. INTRODUCTION

Greenhouse gas (GHG) emissions from the current food system are reported to be unsustainable, accounting for 1/3 of the world's total emissions, with about 70% of the available fresh water being used for agriculture. There are many examples of environmental impact assessments related to food production and diet, and meat has a significant impact on the environment, but there are limited examples of comprehensive evaluations of the health effects of ingestion and health promotion effects. In this study, more than 6,000 food items were subjected to an integrated evaluation of environmental impacts from food production to the preparation stage and health impacts from the intake of nutrients contained in the food.

2. METHODS

Ingredient, preparation method, and nutrient information for 6455 recipes posted on the web were collected as data for the calculation. The functional unit in this study was the menu per meal, and the Inventory Database for Environmental Analysis (IDEA), a Japanese inventory database, was used for secondary data. The impact areas assessed were climate change, water consumption, and human health. Health impacts due to climate change and water consumption were calculated as disability-adjusted life years (DALYs) using LIME3 (Itsubo et al. 2017), while health impacts due to nutrient intake for salt intake were calculated following the methodology of Nakamura et al. (2022). Finally, Integrated DALYs were calculated by integrating health impacts from environmental impacts (Environmental DALYs) and health impacts from salt intake (Salt-intake DALYs).

3. RESULTS AND DISCUSSION

Figure 1 shows the results of the integrated health impact assessment by food group, and Table 1 shows a heat map of integrated health impacts by food group. The results show that grain menus have the highest GHG emissions, followed by meat menus, and even in terms of GHG emissions, the emissions of these food group menus are large, suggesting that methane emissions from rice paddies for grains and from ruminant burps for meat are the main factors. Although some foods on the meat menu have low GHG emissions, such as chicken, most of the meat menus have high loads, such as steaks and hamburgers. On the other hand, bean menus have about half the GHG emissions of meat menus, indicating the possibility of reducing GHG emissions as an alternative protein source. Water consumption was highest for the grains menu, which can be attributed to the use of irrigation water. Indirect water consumption is also higher for the meat menu, due to the large amount of grain

feed required to grow the livestock. The health impact of salt intake is greatest for grain menus, which are influenced by the greater use of high-salt seasonings such as pizza, pasta, ramen, and rice bowls.
Based on these results, we estimated the health impact reduction effect of protein source substitution and the use of low-sodium seasonings on a representative grain menu under the conditions shown in Table 1 and found that the combination of the two measures reduced health impact by about 30%, with a particularly high contribution from salt reduction (Figure 4). The results also suggest that the use of upland rice, which reduces methane emissions and water consumption is effective in further reducing health impacts.

4. CONCLUSIONS

In this study, the diet was comprehensively evaluated from an environmental and health perspective, considering the impact of nutrient intake on health. The results indicated that the more grains and meat the menu contained, the greater the integrated health impact due to methane emissions from the growing stage of the food, irrigation water, and seasoning use trends. It was also suggested that health impacts could be reduced by replacing protein sources with plant-based proteins and using reduced-salt seasonings. In the future, the number of recipes and target nutrients will be increased and menu combinations will be evaluated based on actual nutritional intake conditions.

5. ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to K. Nakamura for helpful discussions on data preparation and nutritional calculations.

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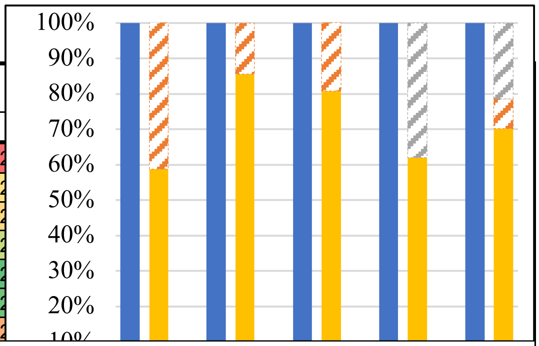
Table 1. Evaluation results by food group (average)

Per serving *the redder the worse	GHG emissions	Water consumption
Unit	kg-CO_2 eq	m3
Grains	4.3.E-01	8.6.E-02
Potatoes and starches	2.5.E-01	3.4.E-02
Beans	2.8.E-01	3.9.E-02
Vegetables	2.5.E-01	2.5.E-02
Fruits	2.0.E-01	1.7.E-02
Seafood	3.5.E-01	1.8.E-02
Meat	5.6.E-01	5.7.E-02



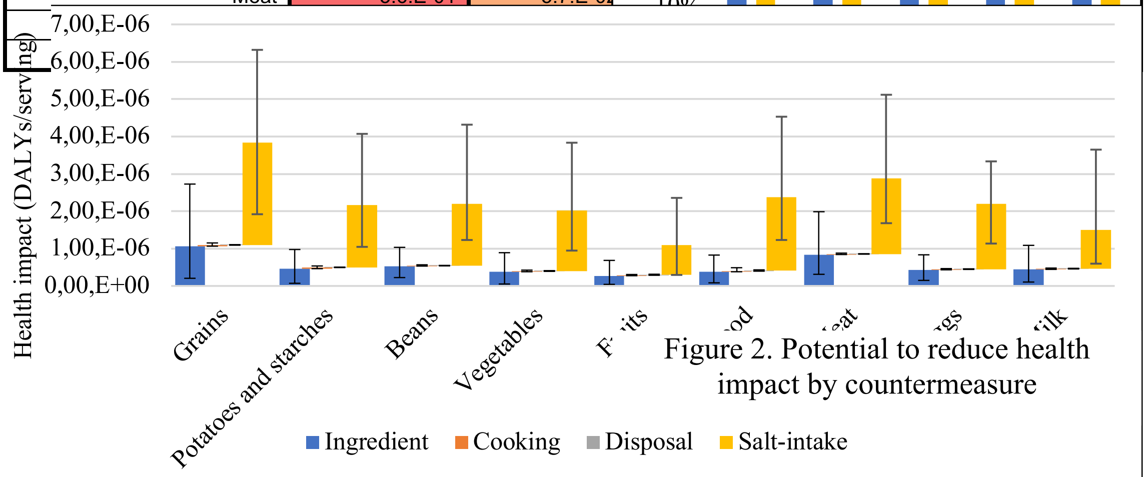


Figure 2. Potential to reduce health impact by countermeasure

Figure 1. Distribution of integrated health impacts by food groups

Table 2. Ingredients for typical menu by scenario

Garlic-flavored pork bowl for a serving				
	Baseline	Sustainable scenario	Alternative protein	Reduced-salt
Shoulder of pork	150g	-	-	-
Tofu	-	150g	150g	-
Small green onion	2g	2g	2g	2g
Soy sauce	18ml		-	-
Reduced-salt soy sauce	-	18ml	-	18ml
Rice	200g	200g	200g	200g
Garlic toast spread	12g	12g	12g	12g
Salt content	2.9g	1.8g	2.9g	1.8g

Combined nutritional and environmental assessment of foods and diets (II)

Changes in dietary-related greenhouse gas emissions through time in Peruvian cities

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1. INTRODUCTION

The food sector is an important contributor to global greenhouse gas (GHG) emissions, with countries in the Global South leading global contributions (Crippa et al., 2021). In this context, Peru is a country recognized for its biodiversity and gastronomy, which translate into variable GHG emissions due to the geographical variability and socio-economic gaps (Vázquez-Rowe et al., 2017). Despite these characteristics, Peru lacks historical data on GHG emissions from food consumption. In this sense, the study aims to carry out an analysis of the evolution of GHG emissions linked to dietary patterns in Peru in the period 2008-2022 based on apparent household purchases, considering spatial, temporal, and socio-economic variability.

2. METHODS

The estimation of GHG emissions embedded in the Peruvian diet was based on the National Household Survey (ENAHO, following the acronym in Spanish), and an array of emission factors (EFs) from recent scientific literature, as follows: i) per capita food consumption per city and poverty levels were gathered from ENAHO (INEI, 2023), with the total sample including data for 37,462 households, based on 92 main products consumed at home, and considering the period 2008-2022; ii) the calories and macronutrient contents in the main consumed foods were gathered from Peruvian tables of food composition (INS, 2017); and, iii) the EFs of each food product were obtained from scientific papers, prioritizing those that were carried out in the following order: Peru, Latin America, and global average. Each EF was standardized over the cradle-to-regional distribution center based on the systematic review by Clune et al., (2017), and considering the food loss and waste (FLW) ratios in production, storage, processing, and distribution phases (Gustavsson et al., 2011).

3. RESULTS AND DISCUSSION

The results reveal that in the last 15 years, Peru has experienced an increase in the annual per capita GHG emissions embedded in food consumption, from 952.8 $kgCO_2eq$ to 1030.6 $kgCO_2eq$, which can be related to an increase in caloric intake (from 2107 kcal/person/day to 2200 kcal/person/day). Furthermore, meats were the category with the highest environmental burden, contributing from 36% to 42% to the GHG emissions in the entire Peruvian diet. When this category is disaggregated, it can be noticed that emissions from beef show important decreasing trends (28%); however, this drop is slightly compensated with the increasing on emissions from chicken

(42%) and pork (9%). However, although on average an improvement in nutrition and decreasing consumption of red meat was detected, marked differences were identified between socioeconomic strata (Figure 1).

4. CONCLUSIONS

On average, the quality of the Peruvian diet has improved in the period 2008-2022 with a slight increase in GHG emissions and a decrease in the consumption of foods with high environmental burden. However, this improvement is not reflected in the lowest socioeconomic groups. Therefore, policies aimed at improving nutrition with lower environmental impacts are urgent.

5. ACKNOWLEDGEMENTS

The authors thank the *Dirección de Fomento de la Investigación* (DFI) at the *Pontificia Universidad Católica del Perú* for financial support through Project ID PI0769.

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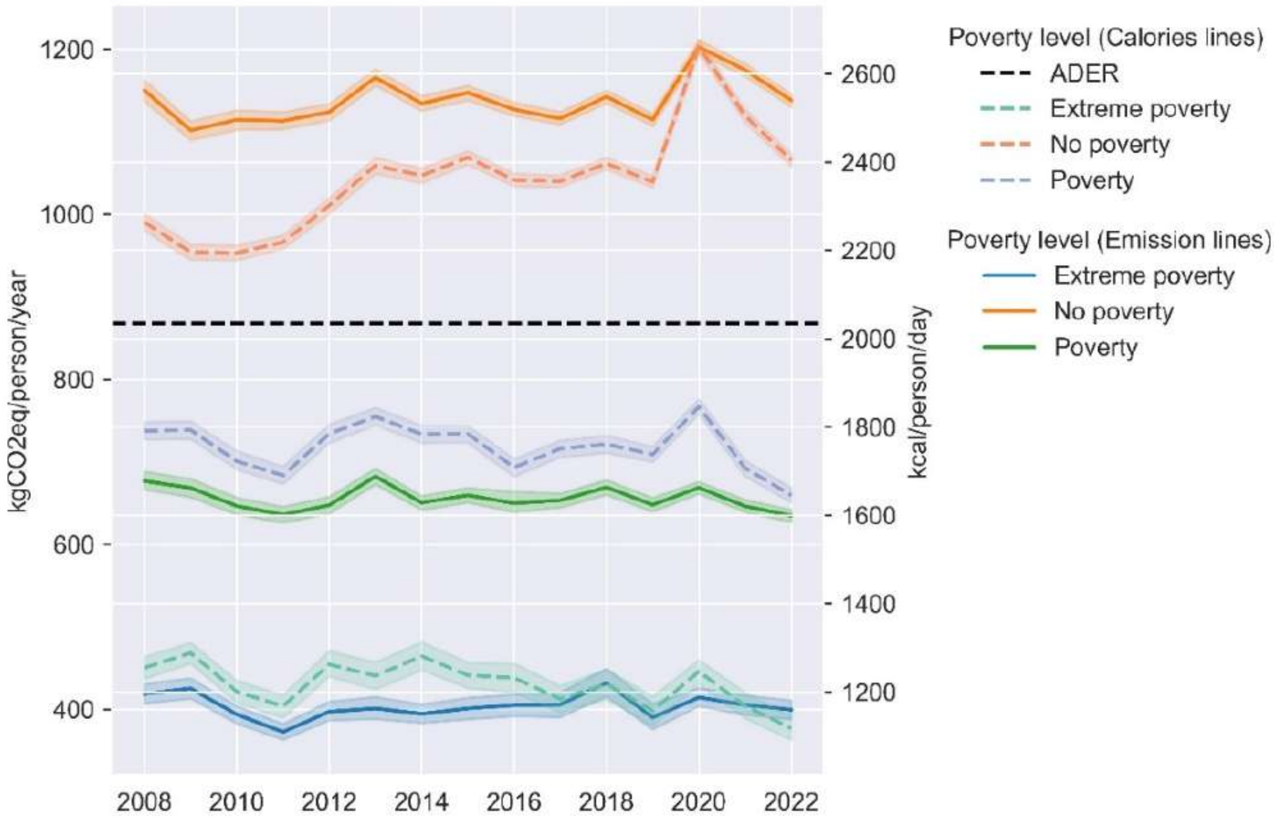

Figure 1. Evolution of GHG emissions embedded in per capita food consumption (principal Y axis) and calories intake (secondary Y axis) by poverty level during the period 2008-2021. Dotted lines in the secondary Y axis represent the reference values of Average Dietary Energy Requirement (ADER) (FAO 2023). The faded shadows of the lines represent the 95% confidence interval

Climate change impacts of dietary patterns of young adults in Canada

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1. INTRODUCTION

Activities within the food system, particularly at the agricultural stage, are one of the major contributors to global environmental change[1]. Food consumption choices are an important factor in determining which foods get produced, and consequently indirectly contribute to global environmental change. Thus, transitioning to sustainable and healthy diets could help avoid or mitigate a variety of environmental challenges as well as contribute to the health and well-being of society[2]. Furthermore, a particular focus on the eating behaviours of youth and young adults is required as they comprise a critical segment of the population and are in a transitional phase of acquiring dietary habits[3]. This study aimed to assess the environmental impacts of average food consumption among Canadian young adults (18-24 years) between 2004 to 2015, examining shifts in consumption patterns as a driver of environmental impacts.

2. METHODS

The average diets (i.e. type and amounts of food consumed) for 2004 and 2015 for the target population was sourced from the Canadian Community Health Survey (CCHS)-Nutrition from 2004 and 2015, based on food intake recall over a 24-h period. A total of 3022 and 1113 participants, aged 18 to 24 were included in the analysis from the 2004 and 2015 surveys. Foods were grouped into high-level food groups (HLFG) (e.g. Fruits, Vegetables) based on Canada's most recent food guide[4], and literature[5]. We chose 2500 calories as the functional unit to represent the average calorie consumption for one person over a day. Since there is under-reporting in intake recall surveys, the average intake of each food was adjusted proportionally to obtain 2500 calories. The environmental impacts for the average diet in each year was quantified using two life cycle inventories (LCI): (1) a Canadianized cradle-to-consumption gate LCI database previously used to determine GWP for two Ontario studies[5] and expanded to include other impact categories in openLCA using ecoinvent v3.8.; and (2) dataFIELD.[6]

3. RESULTS AND DISCUSSION

The GWP of average food intake was 5.92 and 5.71 kg CO_2eq per 2500 calories in 2004 and 2015, respectively, which is a very minor reduction (i.e., -4 % or -0.2 kg CO_2eq). For both years, the HLFG of 'Beef', 'Dairy and eggs', 'Vegetables', and 'Beverages' make up 76% and 71% of the overall GWP for 2004 and 2015, respectively. 'Beef' was by far the biggest contributor to GWP at 42% and 39% in 2004 and 2015, respectively. Major reductions in consumption of 'Beverages', 'Dairy and eggs' and 'Beef' resulted in 0.47 kg CO_2eq decrease in the overall GWP (Table 1). Although overall consumption of 'Vegetables' decreased, GWP increased by 0.03 kg CO_2eq due to the increased consumption of greenhouse vegetables (i.e. tomatoes and peppers (0.02 kg CO_2eq more GWP for each category)). There was increased consumption of 'Fruits', 'Baked goods', 'Grains', 'Poultry' and 'Fish and Shellfish'. Although, these HLFGs contributed to 15% and 18% of the total GWP in 2004 and 2015, respectively, only the latter two HLFGs contributed to an increase in the GWP of 0.14 kg CO_2eq. Overall, the contribution of animal-based proteins contributed to 69 and 68% of the GWP, in 2004 and 2015, while plant-based proteins, including pulses, nuts and seeds, contributed to less than 1% of the GWP in both years.

4. CONCLUSIONS

This study contributes to empirical knowledge linking human nutrition to planetary health. Although there have been small reductions in GWP in the average food consumption of young adults in Canada, the shift is not significant and requires substantial changes; particularly Canadian youth need to consume more plant-based proteins for both health and GWP reductions, and more vegetables with lower impact, emphasizing dark green and orange vegetables.

5. ACKNOWLEDGEMENTS

The authors acknowledge the Social Sciences and Humanities Research Council (SSHRC) for funding this research.

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Table 1 - GWP of HLFGs and differences in consumption and GWP between 2004 and 2015. Based on 2500 cal orie consumption for one person per day. Data is sorted based on changes in consumption (highest decrease (negative numbers) to highest increase (positive numbers))

HLFG	Change in Consumption (g)	GWP 2004 (kg CO_2eq)	GWP 2015 (kg CO_2eq)	Amount Difference in GWP (kg CO_2eq)	Percentage Difference in GWP	Percentage of total GWP in 2004	Percentage of total GWP in 2015
Foods with reduced consumption							
Beverages	-102.5	0.51	0.37	-0.14	32	9%	6%
Dairy and eggs	-37.4	0.94	0.91	-0.03	3	16%	16%
Beef	-8.5	2.51	2.21	-0.30	13	42%	39%
Sugar and sweets	-5.3	0.098	0.094	0.00	4	2%	2%
Spices and herbs	-0.9	0.002	0.002	0.00	22	0%	0%
Vegetables	-0.9	0.54	0.56	0.03	5	9%	10%
Cereals	-0.6	0.009	0.009	0.00	2	0%	0%
Sauces	-0.2	0.090	0.089	0.00	1	2%	2%
Foods with increased consumption							
Fats and oils	0.5	0.11	0.11	0.00	0	2%	2%
Miscellaneous	1.6	0.002	0.004	0.00	49	0%	0%
Nuts and seeds	2.7	0.021	0.032	0.01	43	0%	1%
Snacks	2.9	0.043	0.051	0.01	18	1%	1%
Pulses	3.2	0.003	0.005	0.00	66	0%	0%
Pork	3.3	0.17	0.20	0.02	12	3%	3%
Fish and shellfish	8.0	0.11	0.19	0.08	50	2%	3%
Poultry	10.7	0.36	0.43	0.06	16	6%	7%
Grains	11.1	0.16	0.17	0.01	9	3%	3%
Baked goods	15.3	0.14	0.17	0.02	14	2%	3%
Fruits	29.2	0.091	0.12	0.02	23	2%	2%

Environmental Impacts and Nutrition of Dietary Patterns: A Case Study of Canadian Provinces

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1. INTRODUCTION

To shift towards sustainable diets that have low impact and high nutrition, the environmental and nutritional aspects must be evaluated simultaneously. Life cycle assessment (LCA) has been previously applied to determine the environmental impacts considering nutritional aspects of various dietary patterns (DPs) (e.g. in Europe, USA), but they are limited in geographical scope. Only four LCA studies of DPs have been conducted in Canada[1], but this is the first to estimate the farm-to-fork environmental impacts of DPs considering nutritional aspects in 10 Canadian provinces, using three nutritional functional units. This research contributes to the growing body of knowledge of the environmental and nutritional aspects of regional DPs, providing insights on how to shift towards sustainable food consumption.

2. METHODS

We used LCA to quantify the farm-to-fork impact of the average DPs of 10 Canadian provinces using three nutritional functional units: (i) energy intake (2000 calories); and (ii) two dietary quality indices (DQI) the Nutrient Rich Foods 9.3 (NRF9.3) and the Canadian Healthy Eating Food Index-2019 (HEFI-2019). We identified average food consumption for each province from the Canadian 2015 Canadian Community Health Survey, which asked about 20,000 Canadians to recall the type and amount of food intake over a 24-h period. The provinces are Alberta (AB), Ontario (ON), British Columbia (BC), Prince Edward Island (PE), Quebec (QC), Newfoundland and Labrador (NL), New Brunswick (NB), Nova Scotia (NS), Manitoba (MB), and Saskatchewan (SK). To estimate environmental impacts, we used a Canadianized database with farm-to-fork environmental impacts, including food waste along food supply chain.

3. RESULTS AND DISCUSSION

We report only the global warming potential (GWP) impacts here. The average GWP for all provinces was 4.6 kg CO_2eq/2000 cal., with AB, BC, ON, QC, and SK having a GWP that was above average (

Figure 1), and much higher than what needs to be achieved to meet the climate change planetary boundary of 1.1 kg CO_2eq/2000 cal. The difference between the provinces with the lowest and highest GWP was 17% (4.3 and 5.0 kg CO_2eq for PE and SK, respectively). The rankings (Table 1) of highest to lowest GWP/2000 cal. were quite different compared to those using DQIs: i.e. BC has the seventh highest GWP/2000 cal., but the lowest GWP per DQI; NL ranks the second lowest in GWP/2000 cal. but ranks the second highest by GWP/DQI. In contrast, the rankings of lowest to highest GWP per DQI were the same for almost all regions regardless of whether using NRF9.3 or HEFI; there were only small differences in the rankings between the GWP/NRF and GWP/HEFI for: NB (2 vs 5), ON (4 vs 2), AB (5 vs 4). Although this highlights the importance of considering nutrition in evaluating impacts of DPs, it is not possible to determine what drives the relative GWP differences across provinces, i.e. if only the GWP/DQI is reported, it is unknown whether the high GWP per NRF9.3 for NL is due to a high GWP/ 2000 cal. or a low NRF9.3 score.

Figure 2 shows the GWP/2000 cal. vs DQI score, with the average of each variable (dotted lines), yielding four quadrants. The lower right quadrant represents low GWP and high DQI. No province falls within this quadrant. The average NRF9.3 is 3.88 (low of 3.50 in MB, high of 4.35 in BC) and no province achieves even 50% of the maximum NRF score. Provinces with above average GWP and DQI scores (QC, AB, ON, BC) need to reduce GWP while maintaining or improving DQI (Figure 2), while those with low GWP and low DQI (NL, PE, MB, NB, NS) need to prioritize increasing DQI while maintaining or decreasing GWP. Thus, reporting GWP based on DQIs is only a starting point for understanding sustainability of DPs, as they do not provide insights into what needs to change to achieve both low GWP and high DQIs.

4. CONCLUSIONS

LCA results of regions based on DQI functional units alone do not adequately provide insights into how to achieve low impact with high nutrition. It is important to include other approaches to inform policies and strategies for shifting towards healthy diets that meet 2050 climate targets.

5. ACKNOWLEDGEMENTS

The authors want to acknowledge the Social Sciences and Humanities Research Council (SSHRC) for funding this research.

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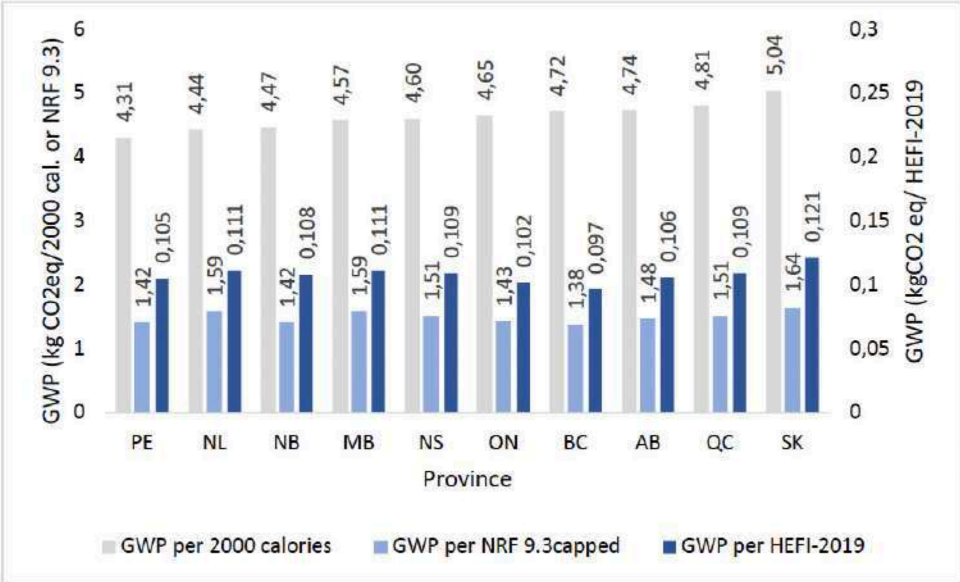

Figure 1. Global warming potential (GWP) of average daily dietary patterns per nutritional functional unit (FU) across ten Canadian provinces. Nutrient-based approaches are: (i) energy intake (2,000 calories); (ii) the NRF 9.3; and (iii) the 2019 Healthy Eating Food Index (HEFI-2019). The nutritional FU results are based on 2,000 calories.

Table 1. Ranking of lowest (1) to highest (10) GWP for different functional units based on 2000 calories.

PROVINCES	PER 2000 CAL	PER NRF 9.3	PER HEFI-2019
PE	1	3	3
NL	2	8	8
NB	3	2	5
MB	4	9	9
NS	5	7	7
ON	6	4	2
BC	7	1	1
AB	8	5	4
QC	9	6	6
SK	10	10	10

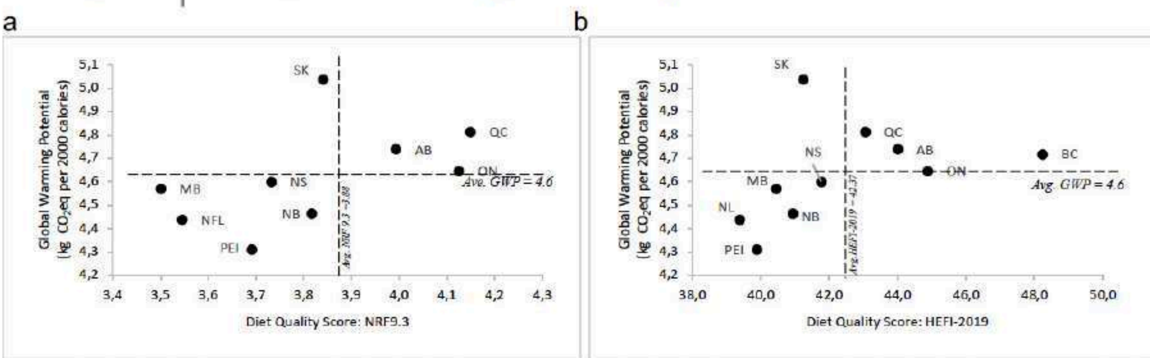

Figure 2. Association between daily global warming potential (GWP) of dietary patterns per 2,000 calories and their respective DQI scores for ten Canadian provinces. Due the different scales, Figure 2a presents the NRF 9.3 scores and Figure 2b presents the HEFI-2019. Dotted lines are the average results of GWP and DQI scores.

Nutritional life cycle assessment of Canadian grains, oilseeds and pulses

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Keywords: *nutritional LCA, functional unit, grains, oilseeds, pulses*

1. INTRODUCTION

For the world to eat a “healthy” diet, as per USDA guidelines, an additional gigahectare of land (about the size of Canada) is necessary [1]. However, agriculture already occupies 35-40% of terrestrial land [1], with little room for expansion and significant environmental impacts [2]. At the same time, poor dietary quality contributes to the paradoxical rising prevalence of both undernutrition and obesity (and related diseases) [3]. Given the increased demands of a growing population, coupled with the finite resources and assimilatory capacity of the environment for anthropogenic emissions [2], identifying viable strategies to maximize the nutritional and environmental efficiency of agri-food systems is imperative for a sustainable and healthy future. Therefore, the goals of this study were 1) to assess the nutritional quality of Canadian peas, lentils, beans, wheat flour and canola oil; and 2) to perform a life cycle assessment (LCA) of each food product with both a mass- and nutrition-based functional unit (FU). These results will ultimately be used to develop scenarios that optimize Canadian agricultural systems (i.e. allocation of land and agricultural biomass) for nutritional and environmental outcomes.

2. METHODS

Based on the attributes of nutritional quality indicators (NQIs) from the literature, described in [4], we calculated an NQI value for each food, as a ratio of beneficial to detrimental nutrients, using all nutrients reported in the Canadian Nutrient File, and those in the NRF9.3 [5]. The ratio of the amount of each nutrient per 100g of food to the relevant reference intake was calculated, for an average of adult males and females. Capping of nutrient intakes was performed for beneficial but not for detrimental nutrients. We then performed an LCA of each food product, sourcing data for the crop production stage from [6 and 7] for pulses, and [8] for wheat and canola. Wheat flour and canola processing impacts were assessed using Canadianized data from ecoinvent v.3.9.1. LCIA results were then reported per kg of food product, and per normalized NQI score (ratio of the highest NQI of all foods assessed to each food’s NQI).

3. RESULTS AND DISCUSSION

Lentils had the highest NQI of all the foods assessed, with an NQI of 899 (unitless ratio of beneficial to detrimental nutrients as a proportion of daily recommended intakes) (Table 1). Other pulses had NQIs ranging from 433 for faba beans to 757 for red kidney beans. Wheat flour had a somewhat lower NQI at 288, and canola oil was significantly lower with an NQI of 3. This is due to the higher levels of saturated fat, and low levels of vitamins and minerals, despite the beneficial omega 3 and 6 fatty acids, which were capped at 100% daily value. These results demonstrate the higher, and variable, nutrient contents of pulses. When using 1 kg of food product as the FU, canola oil had the highest impacts for the majority of impact categories, kidney beans had the highest impacts for terrestrial acidification, freshwater and terrestrial ecotoxicity, and particulate matter formation, and lentils had the highest land use (Figure 1). However, when using the NQI FU, canola oil had by far the highest impacts in all categories (up to 3 orders of magnitude), since its NQI was up to 300 times lower than the other foods.

4. CONCLUSIONS

The results of this study demonstrate the importance of choosing an appropriate FU for the goal and scope of the study. Since our goal is to optimize nutritional provisioning with minimal environmental impacts, nutrition is the key function of food products. The precise design of the NQI FU can have major impacts on the results [6], therefore it will be important to perform a sensitivity analysis around the choices made in this respect, such as the reference amounts for nutrient contents, the included nutrients, and the capping of beneficial nutrients.

5. ACKNOWLEDGEMENTS

Funding came from the Natural Sciences and Engineering Research Council of Canada.

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Table 1. NQIs for each food product assessed, with associated Health Canada food codes.

Food product	Health Canada Food Code	NQI (unitless)
Split peas	3395	585
Lentils	3393	899
Faba beans	3388	433
Navy beans	3384	655
Pinto beans	3270	460
Red kidney beans	Production weighted average of 3264 and 3382	757
Wheat flour	6642	288
Canola oil	451	3

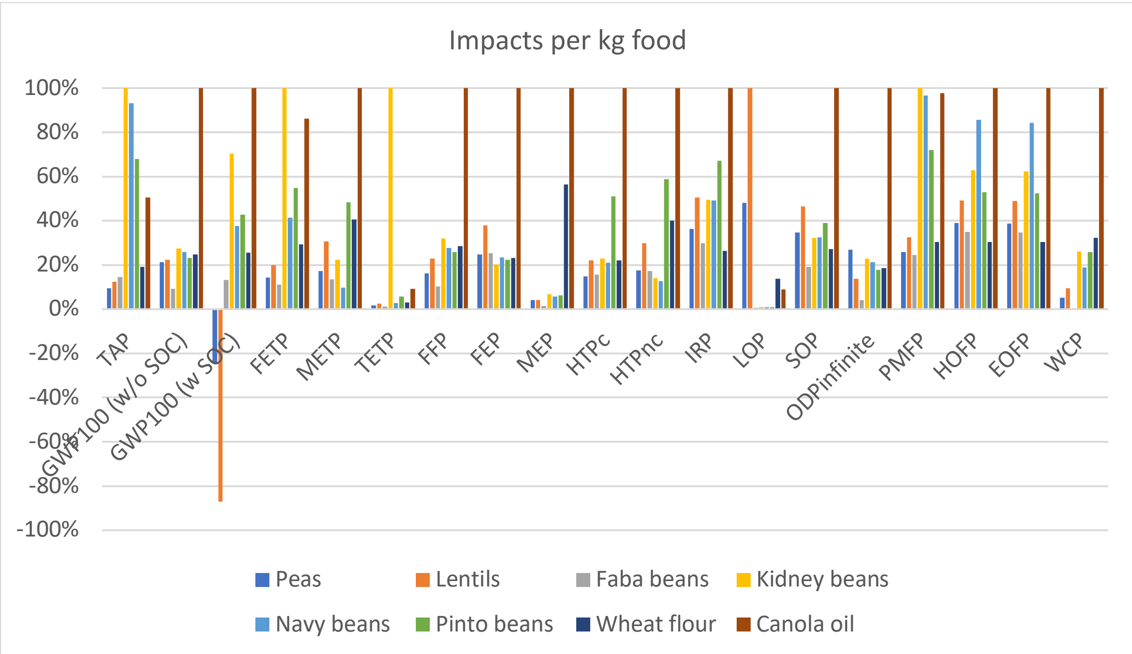

Figure 1. LCIA results for each food product using the FU of 1 kg, and the ReCiPe 2016 impact assessment suite: terrestrial acidification potential (TAP); global warming potential (GWP100) with and without soil organic carbon (SOC); freshwater ecotoxicity potential (FETP); marine ecotoxicity potential (METP); terrestrial ecotoxicity potential (TETP); energy resources: non-renewable, fossil - fossil fuel potential (FFP); freshwater eutrophication potential (FEP); marine eutrophication potential (MEP); human toxicity potential - carcinogenic (HTPc); human toxicity potential – non-carcinogenic (HTPnc); ionising radiation potential (IRP); agricultural land occupation (LOP); surplus ore potential (SOP); ozone depletion potential (ODPinfinite); particulate matter formation potential (PMFP); photochemical oxidant formation potential: humans (HOFP); photochemical oxidant formation potential: ecosystems (EOFP); water consumption potential (WCP).

Combined nutritional and environmental assessment of the Portuguese Dietary Pattern

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1. INTRODUCTION

Sustainable diets are crucial for human and planetary health (FAO & WHO, 2019). This research aims to assess the sustainability of Portuguese dietary patterns by calculating individuals' environmental and nutritional scores and describing the population food consumption within the two dimensions.

2. METHODS

Data from the 2015–2016 National Food, Nutrition, and Physical Activity Survey of Portugal was used to assess dietary patterns of Portuguese adults (18-64 years). Environmental and nutritional scores were created using indicators such as carbon footprint (CF), water footprint (WF), land use (LU), and Nutritional Rich Diet 9.3 score. CF and WF data were taken from the SU-EATABLE LIFE database (Petersson et al., 2021) and LU data from SHARP ID (Mertens et al., 2019). Environmental indicators were estimated by subtracting the individual's values to the median value of the Portuguese sample, and conversely, for nutritional indicator. The environmental score was obtained as a weighted mean of the three environmental indicators, considering a weighting proposal by the European Commission (European Commission et al., 2018). Individuals were classified into four sustainability quadrants using the population median scores as the cutoff point (above – better; below – worse).

3. RESULTS AND DISCUSSION

Two sustainability categories were identified and described: better environmental score & better nutritional score; and worse environmental score & worse nutritional score (Figure 1). The better sustainability group consumed significantly less cereals, derivatives, and tubers (-71g), dairy products (-33g), white meat (-21g), red meat (-116g), processed meat (-21g), oil and fat (-7g), cookies, cakes, and sweets (-54g), non-alcoholic drinks (-71g), and alcoholic drinks (-48g) compared to the worse sustainability group. Conversely, they consumed significantly more vegetables (+55g), fruits (+93g), and seafood (+19g). However, to better align with the planetary diet recommended by the EAT-LANCET Commission (Willet et al., 2019), the individuals behaving better on sustainability should increase their intake of vegetables, fruits, pulses, and nuts and seeds.

4. CONCLUSIONS

More sustainable diets are characterized by lower consumption of environmentally impactful foods (such as meat) and higher intake of vegetables, fruits, and seafood. However, there's a need to further align with planetary diet guidelines by increasing the consumption of vegetables, fruits, pulses, and nuts.

5. ACKNOWLEDGEMENTS

This work was supported by national funds through FCT/MCTES (PIDDAC): LEPABE, UIDB/00511/2020 (DOI: 10.54499/UIDB/00511/2020) and UIDP/00511/2020 (DOI: 10.54499/UIDP/00511/2020) and ALiCE, LA/P/0045/2020 (DOI: 10.54499/LA/P/0045/2020); by Sustainable Agrifood Production Research Centre/Inov4Agro–GreenUPorto, UIDB/05748/2020 (https://doi.org/10.54499/UIDB/05748/2020); and by NORTH 2020 to AgriFood XXI I&D&I project (NORTE01-0145-FEDER-000041). JMB was funded by an FCT, I.P., PhD Research Scholarship (2021.05216.BD).

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Food groups	Better environmental score, better nutritional score Median (Interquartile range) (values in grams)	Worse environmental score, worse nutritional score Median (Interquartile range) (values in grams)
Cereals, derivatives, and tubers	228.17 (134.78)	299.17 (202.81)
Vegetables	175.71 (126.43)	120.97 (114.99)
Fruits	202.48 (199.75)	109.24 (174.72)
Dairy products	216.87 (255.41)	249.77 (287.77)
White meat	28.40 (75.54)	49.22 (113.84)
Red meat	3.04 (43.35)	120.06 (138.51)
Processed meat	4.08 (15.49)	24.89 (40.00)
Seafood	54.98 (92.61)	35.85 (89.88)
Eggs	0.00 (27.15)	1.44 (29.13)
Pulses	0.00 (17.00)	0.00 (17.32)
Nuts and seeds	0.00 (1.00)	0.00 (0.00)
Oil and fat	14.97 (14.22)	22.13 (20.22)
Cookies, cakes, and sweets	30.96 (61.50)	84.60 (113.60)
Nonalcoholic drinks	111.00 (263.13)	182.16 (431.50)
Alcoholic drinks	3.69 (107.94)	51.58 (302.98)

Table 1. Dietary Consumption values across the Sustainability Categories

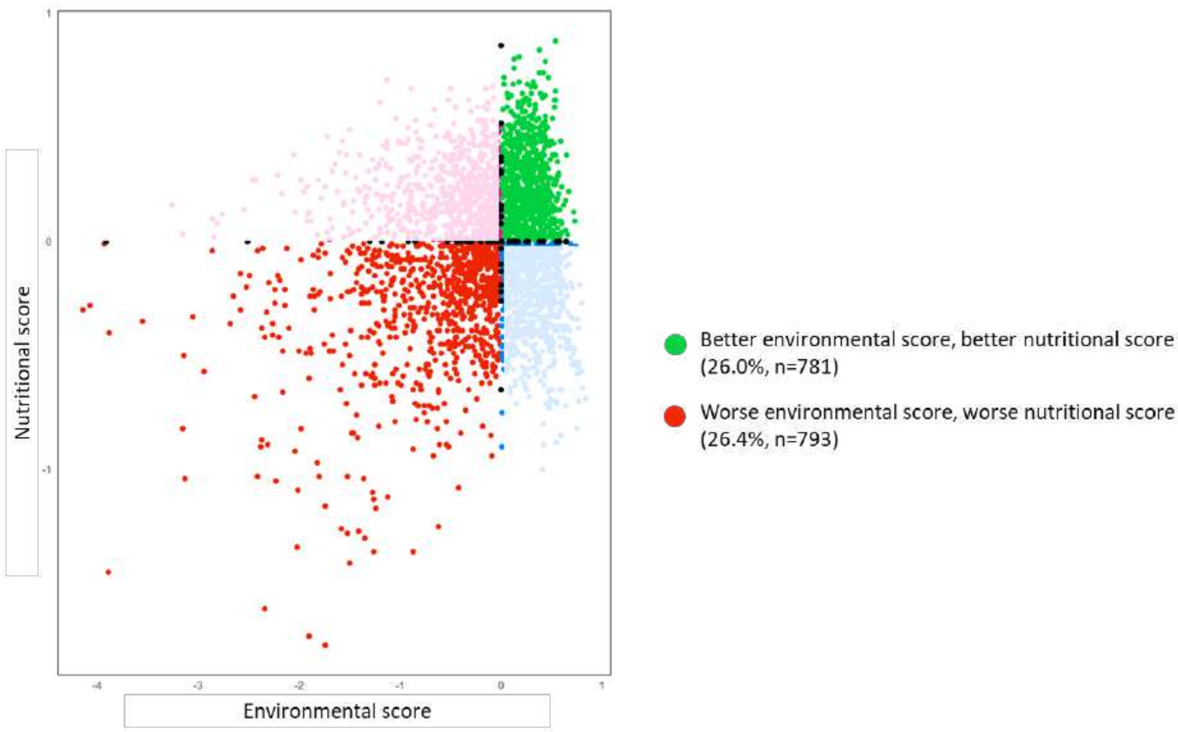

Figure 1. Distribution of the population within the environmental and nutritional score for the evaluated sustainability categories

Towards a combined environmental and nutritional Life Cycle Assessment of the four most caught fish by Belgian fisheries

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1. INTRODUCTION

Dietary guidelines advise to consume fish regularly as it is a high-quality protein source. Actually, the Flemish recommendation is to consume fish once a week, in an attempt to balance nutritional requirements and the potential depletion of fish stocks. In this study, we conduct a detailed LCA on Belgian fisheries using various nutritional functional units (nFUs): 100 grams of protein, 0.0013 mg MeHg, NRF9.3 (per 100 kcal) and several Nutrient Density Scores: NDS21, NDS23, NDS A, C and D (per 100 grams). Such scores create the opportunity to get a more complete picture of the nutritional composition, while considering its corresponding environmental, health and economic impact (Hallström et al., 2019; Bianchi et al., 2022). The aim is to evaluate which of the four most caught fish species by Belgian fishers offers the best combination of nutritional value and minimal environmental impact.

2. METHODS

The FU of the environmental LCA is, at first, one kg of the four most caught fish species by Belgian fishers arriving at the Belgian auction after their landing in a Spanish harbour in 2020. These species, in decreasing order were plaice, sole, skates (all types of lean fish) and cuttlefish. Next to fuel use, we include ship construction and maintenance within the system boundaries, as ship construction is frequently overlooked in seafood-related LCAs. Then, the different nFUs are considered, each with the corresponding amount of weight or kilocalories depending on the nFUs. We applied both mass and economic allocation, delivering complementary viewpoints. For the economic allocation, the market prices of 2020 were used, which were 2.21, 11.76, 1.75 and 2.94 €/kg for plaice, sole, skates and cuttlefish respectively. Price maxima and minima were considered from 1980 onwards. Sole and plaice were subdivided in size classes (1,2,3 and 4) since 1980 and 1990 respectively. The LCA was conducted using SimaPro 9.5.0.1, with EF3.1 V1.00/EF3.1 normalization and weighting set as impact assessment method and Agribalyse 3.1, USLCI, Ecoinvent 3.0, 3.6, 4.1 and LCA Food DK as databases. Significant impact categories were identified through singles scores to assess the environmental impact for the different FUs. Additionally, variability on three aspects over the years 1980 – 2020 is considered: (i) fuel use, (ii) quantity of ice, and (iii) price maxima and minima. For this study, a 95% confidence interval was utilized to address the variability surrounding fuel consumption. For ice replenishment, zero and four refills were regarded as extremes. The amount of ice generated on board varies due to some high-quality cooling facilities able to preserve ice for up to four days, while others require replenishment every one to two days. Maximum price fluctuations between 1980 and 2020 were also considered.

3. RESULTS AND DISCUSSION

3.1 LCA results for one kilogram of plaice, sole, skates and cuttlefish as FU

As expected, mass allocation on one kilogram of each species results in the same single score (Figure 1, left). With economic allocation, sole accounts for the majority of the environmental impact, due to high market price, followed by cuttlefish, plaice and skates (Figure 1, right).

3.2 Focus on LCA results for NDS23 specifically

Under mass allocation, superior nutritional performance determines the optimal fish choice and turns out to be skates followed by cuttlefish, sole and lastly plaice (Figure 2, green). Skate is also the preferred option under economic allocation, delivering the lowest environmental impact and the highest NDS23 value (Figure 2, blue).

4. CONCLUSIONS

Combining the nutritional aspects through the NDS23 indicator with the obtained results, both for mass and economic allocation, defines skates as the best choice. This is followed by cuttlefish, plaice and finally sole; in all these comparisons considering the variability in prices over 40 years, fuel use and ice making. Belgian fishers typically target sole and plaice, which are also the most highly valued by consumers, while skates and cuttlefish are caught more and more due to northward migration of fish. The results on skates offer an interesting perspective for future recommendations towards consumers.

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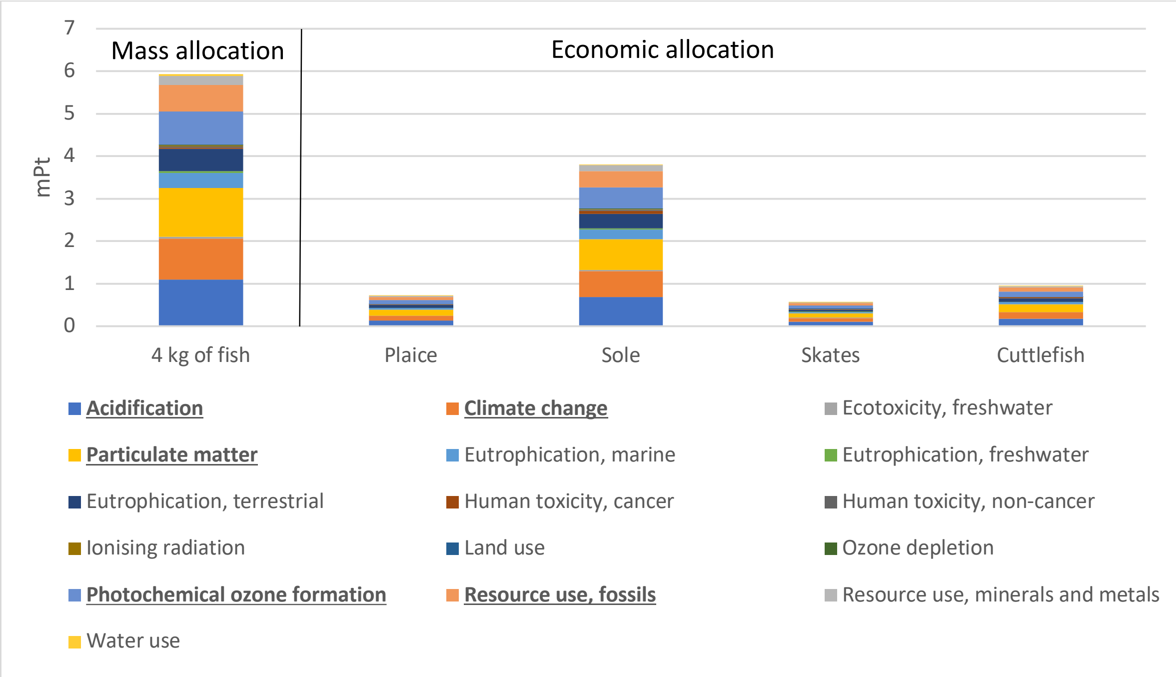

Figure 1. Single environmental impact scores for the four fish species while using mass and economic allocation. Mass allocation visualised for four kilograms of fish, with one kilogram of each fish species. Economic allocation visualised for one kilogram of each fish species. The significant impact categories are shown underlined and in bold.

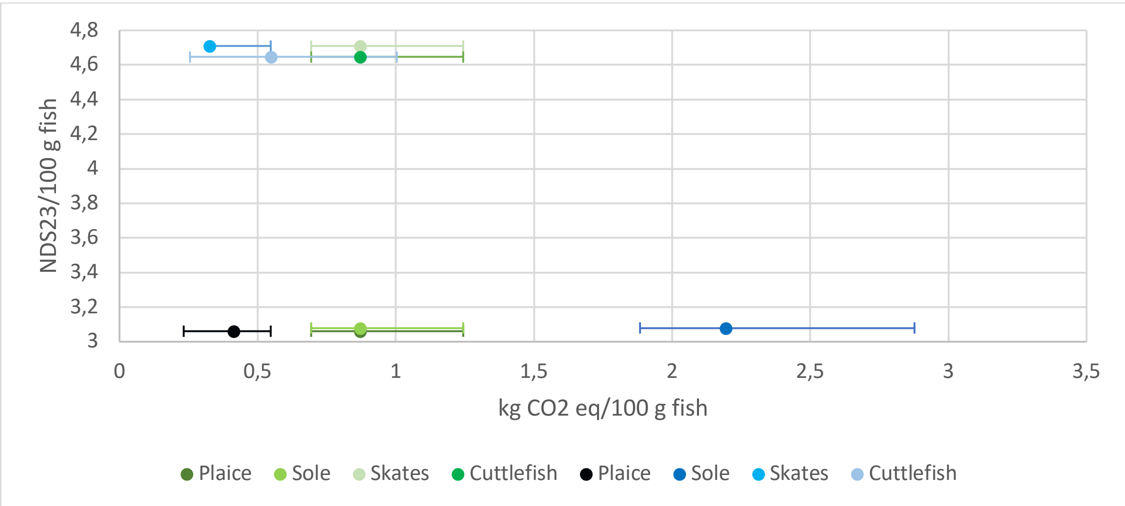

Figure 2. NDS23 combined with carbon footprint for the four fish species considering mass (green) and economic allocation (blue). The variability ranges are displayed as error bars. Note that skates do not have a left error bar in economic allocation, because the price range points in the opposite direction as fuel and ice making variability.

Combined nutritional and environmental assessment of foods and diets (III)

Calculating thresholds for differentiating different levels of climate friendliness for meals

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1. INTRODUCTION

Concerns over climate change imply that the global food system cannot be left out if the pledges made at national and global levels are to be met, since food systems are estimated to account between 26% and 31% of the total greenhouse gas emissions (See Figure 1), despite their decreasing share over the past two decades. However, translating global targets to levels at which individual meals are consistent with those targets is both necessary and fraught with methodological challenges.

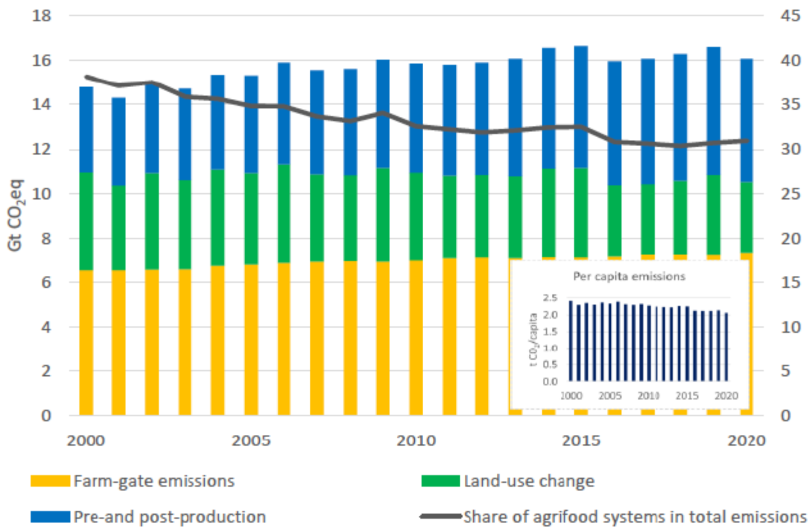

Figure 1. GHG emission totals and shares of the global food system (2000-2020)

In order to calculate several levels of climate-friendliness of different meals, we followed a methodology that is aligned with the targets adopted in the COP's Paris Agreement of 1.5°C and 2°C maximum temperature increases by 2100, among others.

2. METHODS

We have started with the carbon budgets that are aligned with the 1.5°C and 2°C climate targets, and defined four different thresholds that allow rating meals in five categories (Very Low, Low, Medium, High and Very High).

In order to define Thresholds 1 and 2, we first estimated the GHG emissions from the average European diet in 2015 using data from the FAO's Food Balance Sheets (FAO 2020) and emission factors from Klimato's database representing the necessary reduction in emissions to reach short- (2030) and long-term (2050) targets. Thresholds 3 and 4 were correlated with CFs per meal that reflect average CO_2e emissions per capita that correspond to an increase in global temperature of 2.5 °C and 3°C, respectively. The two thresholds were estimated using the Transient Climate Response to Cumulative Carbon Emissions (TCRE) metric, which directly relates global mean temperature increase to cumulative CO_2 emissions.

3. RESULTS AND DISCUSSION

The 4 thresholds calculated are 0.4, 0.9, 1.8 and 2.6 kg CO2-eq./meal, which allowed us to derive the meal rating system that is shown in Table 1.

Table 1. Klimato's rating system for individual meals

Meal categories	Kg CO2-eq.
Very low	<0.4
Low	0.4-0.9
Medium	0.9-1.8
High	1.8-2.6
Very high	>2.6

By including political targets in the calculation of thresholds, we offer a scientifically-based approach to aid decision-making in organisation and individual scopes. The thresholds calculated for differentiating categories represent a spectrum of low to high impact of meals on climate change. Even through these not tells us what a sustainable meal is, as value judgements need to be taken, it offers consumers and producers with an operational approach that aids decisions regarding procurement, as well as nudging consumers in a direction of a lower carbon footprint in their food consumption decisions.

4. CONCLUSIONS

By following scientific reasoning, we devised 4 thresholds for different levels in the carbon footprinting of meals, thereby allowing food services and consumers to make their own choices in order to fulfil their climate-change mitigation targets. This approach has its limitations and can be regarded as a first-step in a process of continuous improvement.

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Methodological considerations for quantifying the effect of nutritional compositions and product formulation in environmental life cycle assessments of food items

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1. INTRODUCTION

Measuring environmental impacts of foods against their nutritional value is becoming more commonplace as consumers demand foods that are healthy for both the planet and themselves. One method to quantify this is nutritional-LCA. For this to be fully operationalized, advancements in methods for both nutrient algorithms (i.e., measuring the nutrient content of foods) and their use as the functional unit is needed. Accordingly, we developed a framework to explicate methodological choice and provide a starting point for best-practices in developing nutrient indices that can be used alone or as the functional unit in LCA. We also discuss this framework as it relates to novel or formulated foods for which product or nutritional compositions are often altered. Changes in food composition can occur during product development such as when foods are fortified, combined to meet amino acid requirements in one product (e.g., pea and rice plant-based burger patties), or when poorly processed/formulated, the outcome of which is often referred to as 'ultra-processed.' Overall, nutritional-LCA has many applications, and further developing the method is needed to unlock its full potential, for instance, for use in specific cases such as product formulation.

2. METHODS

We first illustrate the influence of method choice on nutrient index scores. For this, we determined multiple 'points of differentiation,' based on a literature review, that could influence scores (Figure 1). We then tested the effect of each 'point', while holding all others constant, through a series of nutrient profiling systems. Following this, we assess how these nutrient indices used as the functional unit affect environmental scores (i.e., GHG emissions, water use, land use, eutrophication, and acidification). We tested the significance of our findings using spearman rank correlations for the former part and Wilcoxon signed rank tests for the latter. Lastly, we discuss the importance of such methods for novel or formulated foods.

3. RESULTS AND DISCUSSION

For nutrient scores, the ‘points’ of energy standardization, disqualifying nutrients, capping, and dietary specificities had the strongest effects. Additionally, food groups were affected differently depending on the ‘point’ applied. For formulated products, the latter three ‘points’ are particularly important. For instance, capping greatly affects the scores of fortified foods, which poses questions such as how to measure foods that are fortified but also high in disqualifying nutrients (e.g., added sugar). When considering nutritionally-invested environmental impacts (i.e., impacts measured with a nutrient-based functional unit), the effect of the ‘points’ was confounded with the environmental impact of the foods. For instance, foods that had extremely high (e.g., GHG emissions of beef) or low (e.g., GHG emissions of brassicas) environmental footprints were less affected by the choice of nutrient metric (Figure 2). For foods with similar environmental impacts, the choice of nutrient metric greatly affected sustainability rankings. This is particularly important for novel foods that have different formulations due to fortification (e.g., almond beverages). Overall, statistically significant differences were found across most methodological ‘points,’ indicating their importance and the need to assess them further within the context of combined sustainability analyses.

4. CONCLUSIONS

New products arrive on the market every day to address the demand for more environmentally-friendly or healthy food items. Combined analyses are needed to understand tradeoffs and promote synergies across these dimensions, when possible. For instance, extra processing steps to create a more nutritious product may lead to higher environmental impacts and foods with low environmental footprints may be formulated in suboptimal ways (i.e., high in disqualifying nutrients and lacking in needed ones). Nutritional-LCA is one method to address this, and the proposed framework provides guidance on how to advance this discussion. Nevertheless, gaps persist, such as quantifying the effect of ‘ultra-processed’ foods or the use of disqualifying nutrients in the functional unit.

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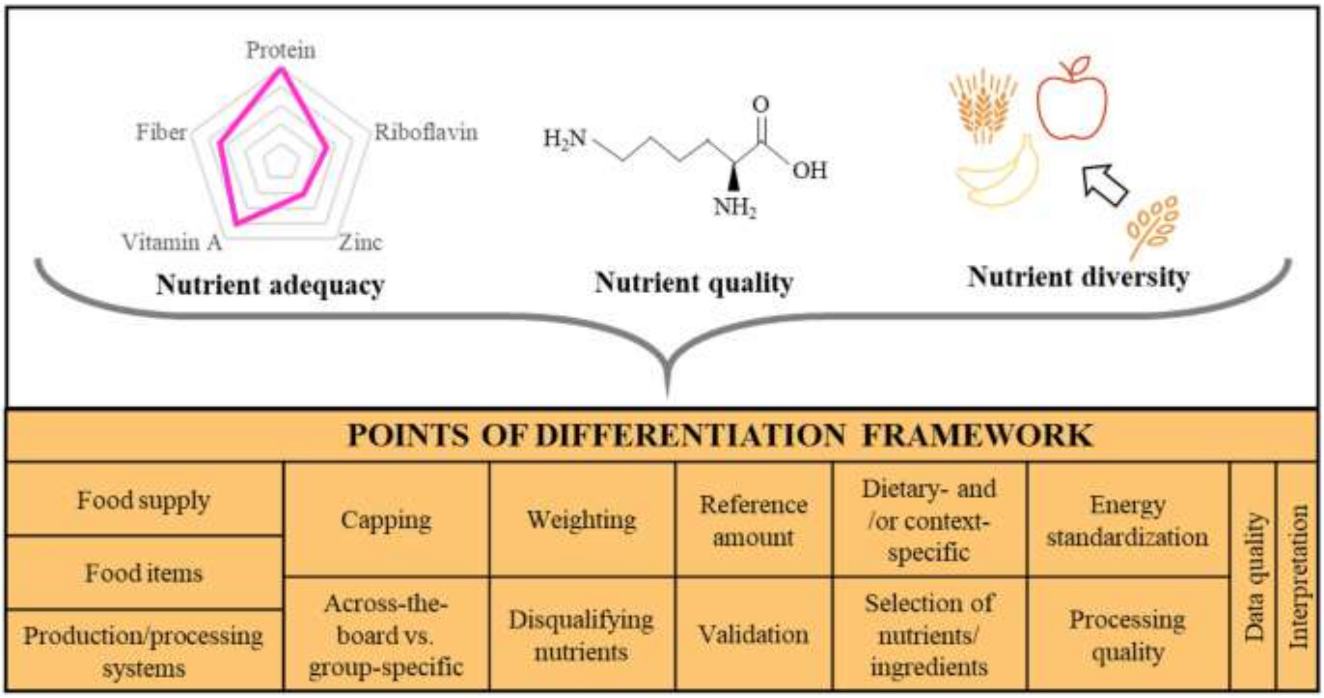

Figure 1: Points of differentiation framework. This framework lists the various 'points' identified as having an important effect on nutrient index scores. The application of each point is discussed with reference to the type of nutrient metric (i.e., nutrient adequacy, quality, and diversity) as well as food level (i.e., food supply, items, production/processing systems). (Green et al. 2023) The picture representing nutrient quality is the chemical symbol for the amino acid Lysine.

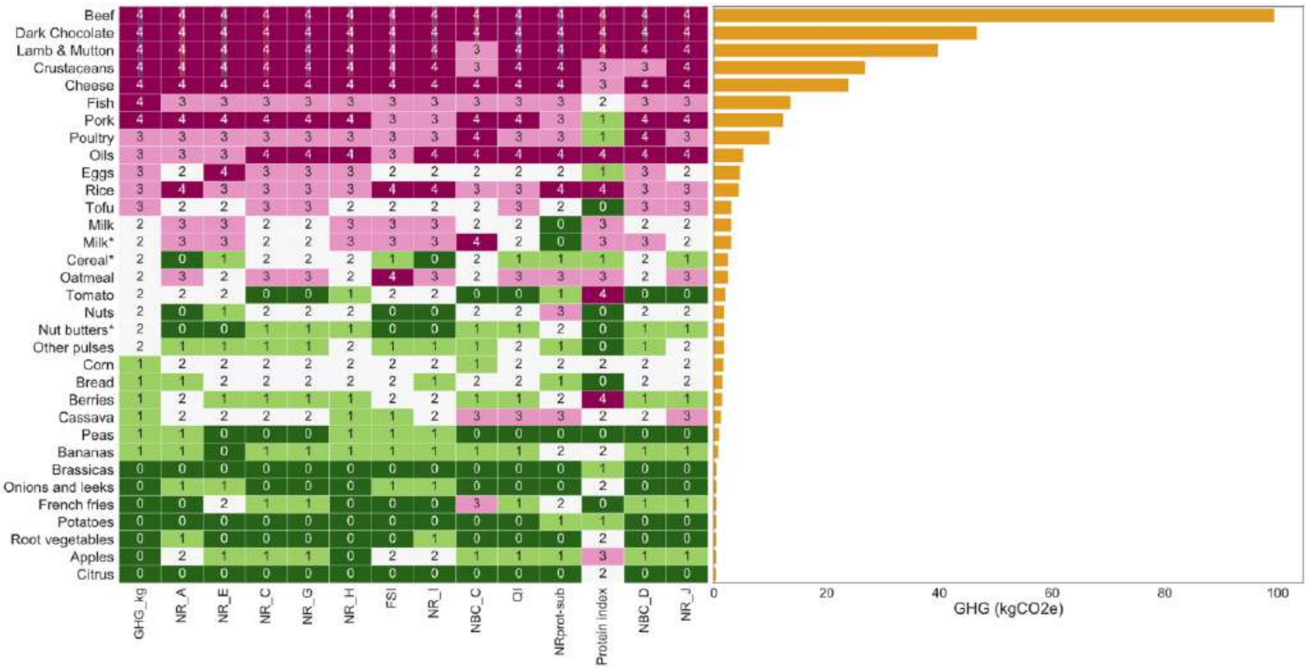

Figure 2:
Nutritionally-invested GHG emissions under different functional units. Each functional unit tests a different 'point of differentiation.' Functional units are shown on the left side of the x-axis. The bars on the right indicate GHG emissions under a functional unit of 1 kg. Values range from 0 (low emissions) to 4 (high emissions). Asterisks refer to fortified foods. (Green et al. 2023)

Multi-criteria decision analysis (MCDA) as a context-adaptable weighting method for Life Cycle Assessment impact categories in sustainable nutrition science

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1. INTRODUCTION

– To evaluate sustainability of foods against health, several criteria can be considered through Life Cycle Assessment (LCA), for example greenhouse gas emissions, land or water use, and acidification or eutrophication. No commonly agreed weighing methodology has been established in sustainable nutrition science to aggregate these (potentially conflicting) environmental impact categories (EICs) into one single index. These weighing schemes inherently involve subjective value choices depending on policy, cultural, ideological, and ethical considerations[1]. The European Commission suggested one approach[1], which, however, may not capture data structure and specific context of a food system. Such generic weights help identifying sustainable diets overall, yet may not generate realistic dietary patterns for the distinct contributions of food groups. Food groups require tailored weighing schemes since both the magnitude (impact) and variance (improvement potential) of EICs between groups are incomparable, as reflected for example in the comparison between greenhouse gas emissions and water consumption for different food groups (figure 1). Use of default weights precludes accurate environmental assessment of relevant alternative food options in a dietary context.

Alternatively, multicriteria decision analysis (MCDA) involves a range of methods aiding decision making in problems with conflicting criteria considering data structure and context[2], offering potential for balancing LCA impact categories[3]. In food science MCDA has not yet been applied to capture the complexity of dietary patterns, including grouped food alternatives, diverse contexts, and political, cultural, ideological, and ethical considerations. The aim of this methodological study is to develop a universal model using MCDA in assigning environmental value to relevant interchangeable food items with potential synergies and trade-offs among LCA impact categories. This model may be adapted to diverse dietary contexts and food systems with impact choices that depend on policy, culture and other value systems.

2. METHODOLOGY

– The application of MCDA to LCA of foods consists of three main stages: (i) selection of relevant interchangeable food items and EICs to consider; (ii) normalization environmental impact of food items per EIC; and (iii) weighting of the relative importance of each EIC in the overall environmental impact score per set of food alternatives.

For selection of foods and EICs, we use Dutch LCA data for 2131 food items. Blonk Consultants (Gouda, the Netherlands) delivered life cycle inventories for 242 food items (71% of foods consumed in the Dutch context) considering the six EICs in figure 2. The Dutch National Institute for Public Health and the Environment performed the life cycle impact assessment using ReCiPe-2016 and SimaPro software (version 8.52)[4] and thereupon established extrapolations.

We classify interchangeable foods into food groups. Linear partial value functions normalize data per EIC between worst and best food option (the swing) of food groups, scaled from 0 to 1 respectively[2]. Additive value functions with tailored weights combine partial values of each EIC per food item into a normalized weighted score per food item (figure 2). A swing weighting method defines weights per food group, considering data structure and context (i.e. the Dutch food system)[2]. We evaluate subjectivity in the method through comparing different EIC preferences (e.g. distance to target, expert opinion, panel approach). Moreover, we perform stochastic multi-criteria acceptability analysis testing uncertainty in determined value profiles[5].

3. CONCLUSION

– MCDA is a promising method for weighing LCA impact categories and determine overall environmental sustainability of interchangeable foods while considering contextual factors related to production and consumption in a (localized) food system. The environmental value profiles of Dutch foods allow accurate evaluation of more sustainable and healthy diets.

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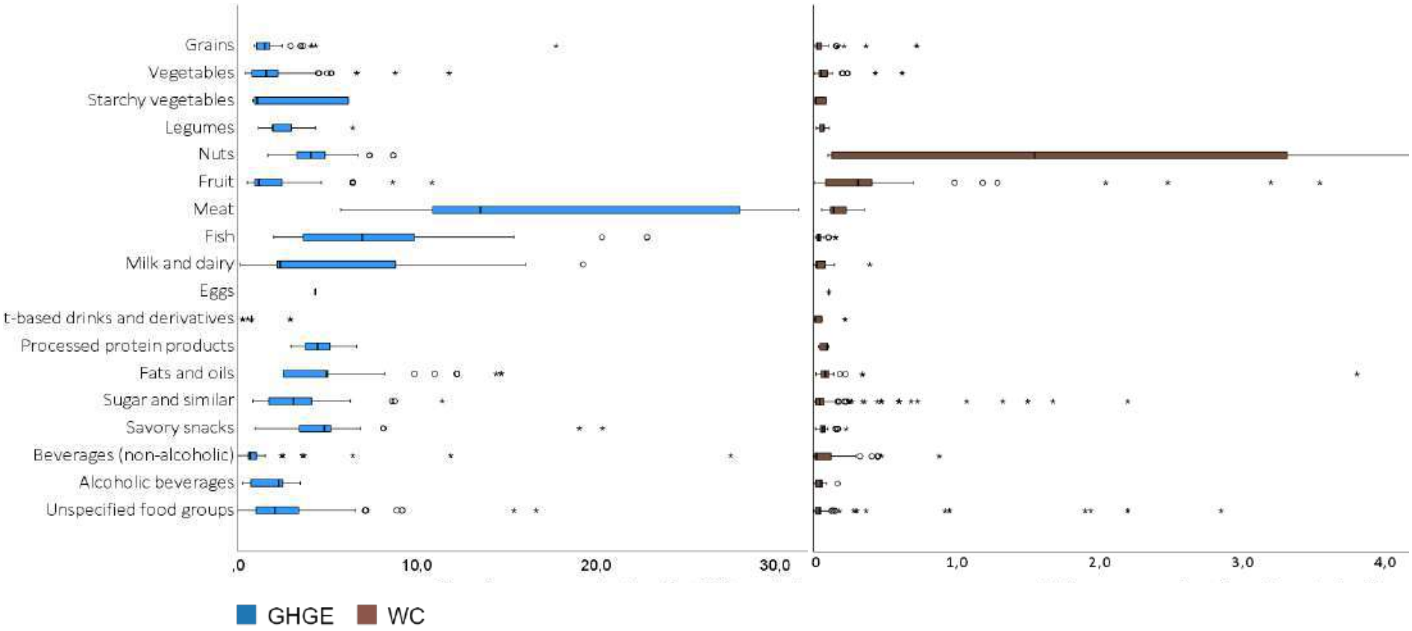

Figure 1
Boxplots of kg-equivalent environmental impact of (Dutch) food groups, displaying the relevance of data structure in weighing environmental impact categories (EICs): food groups have different magnitudes and variance per EIC constructing the overall environmental impact.

GHGE = greenhouse gas emission (kg CO2); WC = water consumption (m3)

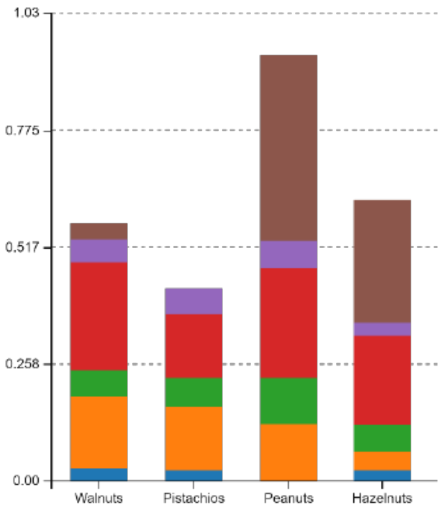

Figure 2
Example of Dutch MCDA value profiles of a selection of nut types, determined using ranking elicitation of environmental impact categories (EICs) based on the swing (worst to best option) of this food group (ranking used: WC > FWE > LU > TA > MWE > GHGE). The colored bars show how the normalized partial values of EICs per food item (0 to 1, where higher partial value equals lower relative impact) contribute the overall value (0 to 1), after weighing (where WC received the highest weight and sum of weights equals 1).
Created using an in-house developed online tool for MCDA (mcda.drugis.org).

GHGE LU TA FWE MWE WC

GHGE = greenhouse gas emission; LU = land use; TA = terrestrial acidification; FWE = freshwater eutrophication; MWE = marine water eutrophication; WC = water consumption

Mitigating environmental impacts through more sustainable diets: Consequential life cycle assessment of various regional diet shift scenarios

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1. INTRODUCTION

While food systems are responsible for diverse burdens, they are also key for transitioning to more sustainable systems. Shifting to a plant-based diet is proposed as one of the most efficient ways to mitigate these burdens. Yet, market effects on the supply side are rarely considered in environmental assessments. In previous research, we combined economic modelling and consequential LCA to simulate a drastic diet shift following the EAT-Lancet recommendations for red meat and legumes (Willet et al., 2019) in the EU (Guillaume et al., 2024). Due to international demand, we predicted it would have only minor effects on EU red meat production and environmental impact reductions. A simultaneous diet change outside the EU or even globally could be necessary to achieve substantial environmental benefits. Therefore, this research evaluates the environmental consequences of this diet shift in diverse regions in 2030. In addition to the scenario of EU diet shift, three scenarios are assessed. Because in this former scenario (Guillaume et al., 2024), the majority of red meat is predicted to be exported to China, an adoption of these recommendations by both the EU and China is evaluated. Building on the EAT report (EAT, 2020), we then assess a diet change by 40% of the population eating the most red meat and finally by the whole world.

2. METHODS

To identify the market effects following the diet shift, we first used the global agro-economic model CAPRI which simulates ex-ante scenarios. The resulting global production was used as inputs for a consequential Life Cycle Assessment (LCA) to assess environmental consequences. We used the Environmental Footprint 3.0 impact assessment method with OpenLCA.

3. RESULTS AND DISCUSSION

3.1 Market effects

A diet shift in the EU alone reduces the consumption and production of red meat in the EU by 73% and 22% respectively (Table 1), explained by additional exports to non-EU countries leading to a 2% increase in consumption and a 4% decrease in production in these countries. Shifting diets at the global level, consumption and production of red meat in the EU are reduced by 68% and 48%, respectively, and by 42% and 45% in non-EU countries, respectively.

3.2 Environmental consequences

Adopting a more sustainable diet both in the EU and China already brings higher environmental benefits compared to the EU alone (Figure 1). Interestingly, these benefits are quite close in the case of a diet shift by 40% of the population or the whole population, suggesting that a diet shift in the regions far from the EAT-Lancet recommendations on red meat can already bring significant advancements. Globally, when the diet is adopted by everyone, 1.5 Gt of CO_2 eq (-21.9% compared to actual agricultural emissions) and 170.2 million ha (Table 2) are saved. Furthermore, the results bring additional information forward on local environmental impacts in the different regions: while aquatic eutrophication increases in Africa due to the additional legume production, we see a major decrease in local pollution such as acidification in Asia.

4. CONCLUSIONS

Compared with a unilateral diet shift, significant local environmental benefits, mostly related to regional specificities, could already be achieved when 40% of the people with the largest red meat consumption shift their diet. Up to 21.9% of agricultural GHG emissions could be avoided globally. In the future, a consequential LCA of a policy adoption on the supply side, such as higher subsidies for legumes or export quotas, will be compared to the current results.

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Table 1. Relative changes in legume and red meat consumption and production for the different scenarios in EU (left columns) and non-EU (right columns) regions compared to business-as-usual (2030); bold numbers are explained further in section 3.1 in relation to the dealignment between consumption and production changes

EU=diet shift in the EU; EU&CHN=diet shift in the EU and China; 40%= diet shift in 40% of the population eating the most red meat; Global= world diet shift

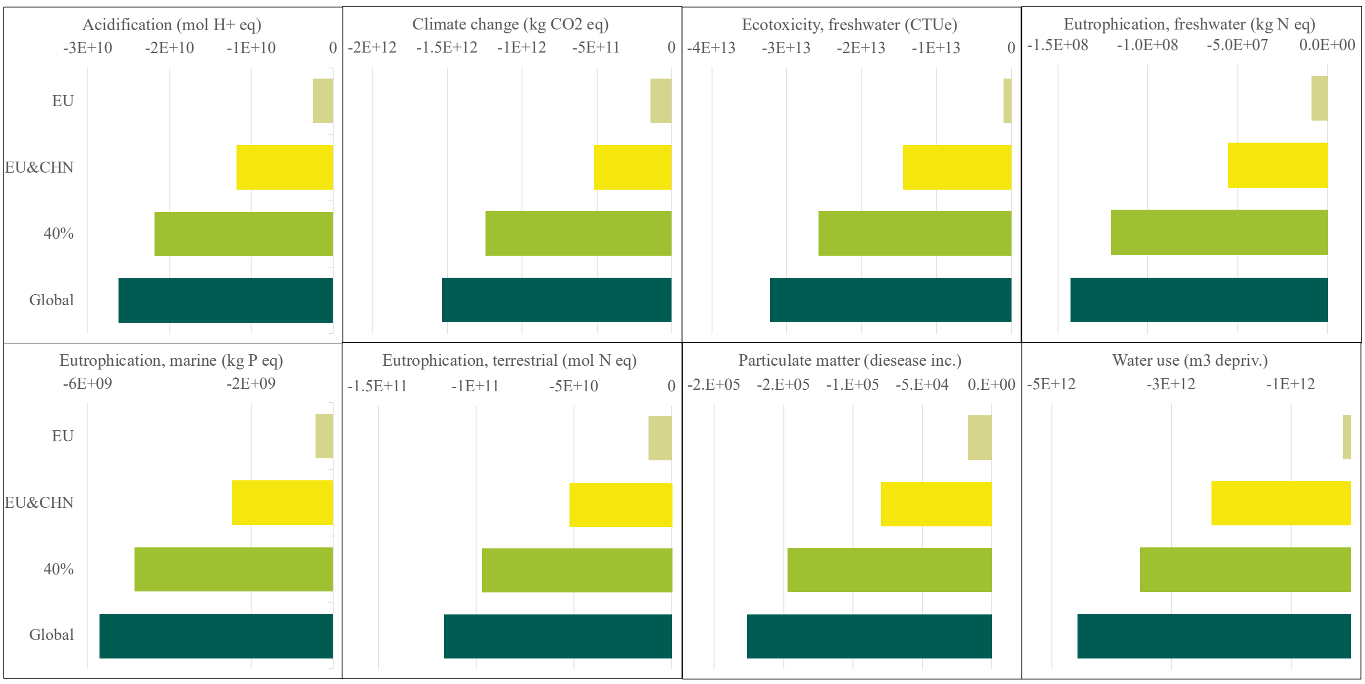
Figure 1. Absolute changes compared to business-as-usual (2030) for the selected LCA impact categories for the different regional scenarios of shifting diets; the larger the bar, the higher the environmental benefit

Region		EU				non-EU			
Scenario		EU	EU&CHN	40%	Global	EU	EU&CHN	40%	Global
Legume	Consumption	1205%	1357%	1638%	1484%	-1%	83%	174%	298%
	Production	51%	75%	148%	242%	0%	1078%	2675%	4951%
Red meat	Consumption	**-73%**	-74%	-70%	**-68%**	**2%**	-15%	-36%	**-42%**
	Production	**-22%**	-33%	-46%	**-48%**	**-4%**	-19%	-38%	**-45%**

Table 2. Absolute changes in agricultural areas for the different region

al scenarios of shifting diets compared to business-as-usual 2030; a negative number means land freed up

Scenario	EU	EU&CHN	40%	Global
Agricultural land used (million ha)	-7.1	-68.7	-143	-170.2



Life cycle environmental consequences of a more cycling-oriented mobility including additional calorie intakes and regional diet evolutions

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1. INTRODUCTION

Transportation is a major contributor to climate change [1], and the deployment of active mobility – e.g., cycling, walking – seems a promising lever to mitigate climate change (CC) [2]. But switching to active modes requires to produce more food to supply additional calorie intakes (ACI) for travelers, and ACI's environmental consequences have been overlooked in life cycle assessment (LCA). Unexpected burden-shiftings could occur, due to switching from petroleum-based to food-based mobility, depending on: the penetration of active modes; the physical condition of travelers switching to active modes combined to the duration of the trips, as the quantity and type of macronutrient consumed depends on the maximum amount of oxygen the body can use during exercise ("VO_{2max}") [3], itself depending on the Lipoxmax, i.e. the intensity of exercise that elicits a maximal oxidation of lipids [4]; the additional food introduced in the diet to supply the ACI [5], [6]; the supply chain of this food [7], [8], [9]. As cycling is an affordable and accessible active mode, with similar speeds compared to competitive modes in urbanized areas, we will assess the environmental impacts of global future mobility under different cycling penetration scenarios, including ACI and changing regional diets.

2. METHODS

The method is based on a three-step assessment: (1) developing scenarios of global future transportation demands including cycling, (2) conducting the LCA of transportation modes (cycling and other land-based modes), (3) assessing the environmental impacts of the scenarios.

2.1 Scenarios of global future transportation demands including cycling

Scenarios of future cycling penetration in land-based transportation at the global scale are estimated depending on the area of pertinence of the mode. Thus, based on existing scenarios of transportation demand [10], modal shares are calculated, as well as modal shifts to cycling.

2.2 LCA of transportation modes

We first develop regional archetypes of conventional modes (e.g., public transportation, cars), to conduct prospective LCAs (pLCAs) with a prospective inventory background modelled with *premise* [11]. Then, we conduct the pLCA of different cycling practices: we develop archetypes of bikes (electric or mechanical, mass and material of the frame, lifetime mileage), bike usage (electricity or not, nutrients consumed), and model typical dietary patterns (e.g., western, vegetarian, vegan, or Asian diets), to calculate the life cycle impacts of different cycling practices in different regions of the world over time.

2.3 Calculating and analysing global environmental impacts

Using the characterization method IMPACT World+ [12], we calculate the life cycle environmental impacts of the different scenarios of land-based transportation demand defined in section 2.1 using the inventories from section 2.2. We consider midpoint (e.g., CC, land occupation and transformation (LULUC), water scarcity, eutrophication) and endpoint indicators (human health, ecosystems). We analyse the most contributing midpoint categories to the endpoint damages to identify hotspots in the different scenarios. We thus zoom on the impacts due to cycling, and especially the ACI, to estimate the environmental effects of a more cycling-oriented mobility related to its additional food demand.

3. RESULTS AND DISCUSSION

Our preliminary results show that cycling can have a similar carbon footprint to using an electric car depending on the electricity mix and size of the car, with a meat-based diet, and can generate burden-shiftings on LULUC, and eutrophication. Future results presented at the conference will scale up the impacts for global mobility scenarios, to specifically draw conclusions on the significance of the environmental impacts due to the ACI to sustain more cycling. Limits of the study include the use of simplified archetypes for diets and transportation modes, static modelling of agricultural systems to produce food, limited inventories to regionalize dietary patterns, and the well-known disputable data quality of LULUC inventories.

4. CONCLUSIONS

The novelty of this study especially stands in including fine modelling of ACI in the LCA of cycling and unveiling potential counter-intuitive results of some cycling practices more impacting than using cars. At the global scale, the analysis of burden-shifting and potential stakes on LULUC under different futures will aim at supporting decision-makers, especially on the attribution of land for different sectors.

5. ACKNOWLEDGEMENTS

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A Protein Quality Adjusted nutritional-LCA of Soy-Based Meat and Dairy Alternatives: Understanding the Environmental and Nutritional Implications of Food Processing

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1. INTRODUCTION

Efforts to address sustainability, food security, and health concerns have led to the rise of plant-based alternatives in high income markets. Plant-derived proteins generally have imbalanced essential amino acid compositions and lower digestibility than animal-derived proteins, yielding lower protein quality for human nutrition (Herreman et al., 2020). In this nutritional LCA (n-LCA), possible trade-offs between nutrient quantity and quality, and environmental impacts when replacing meat and milk products are explored. A novel *in vitro* protein digestibility protocol enables faster evaluation of food matrices for their protein quality (Sousa et al., 2023). By integrating a quality corrected (qc) -protein content, we offer a more holistic evaluation of processing plant proteins into meat and dairy substitutes.

2. METHODS

As nutrient delivery is a key function of food, the comparison between the products under investigation is based on the protein quality and nutritional density. We compare novel plant-based meat analogues (PBMA), a soy drink, and tofu to animal-derived products (milk and meat from dairy cows and broilers). The (potential) qc-prot in 100 g of food is determined by multiplying the protein amount in 100 g by the *in vitro* Digestible Indispensable Amino Acid Score (DIAAS). Representative data in the SALCA database (Nemecek et al., 2023) serves as the foundation for the Swiss agricultural production of animals and soybeans. The processing steps, including protein separation, were taken from Ecoinvent v3.9.1 and AGRIBALYSE life cycle inventory (LCI) database. Background inventories were adjusted to the geographical location when needed. Economic allocation was applied consistently for multi-output inventories in all processes. A “cradle-to-gate” system boundary is set for calculating the environmental impacts, whereas the nutritional values are measured “ready-to-eat”.

3. RESULTS AND DISCUSSION

The animal-derived products under investigation showed DIAAS values greater than 100 and can therefore be considered an “excellent” quality protein source for growing children. The same is true for the age group “older child, adolescent, adult” (not shown here). As the plant-based substitutes are only of “good” protein quality (<75 DIAAS > 99), adjusting the nutritional functional unit (nFU) from 100 g protein to 100 g qc-protein resulted in elevated environmental impacts (Figure 1). In the latter case, broiler meat becomes competitive with PBMA and tofu. Utilising soybeans from Brazil rather than Switzerland for the plant-based substitutes reinforced this trend (scenario analysis, not shown). Beef and milk cannot compete with plant-based substitutes. However, both show a high nutrient density. Given a fixed qc-prot content, only broiler meat requires 6 % less food intake compared to meat from cows (Table 1). Almost double the food intake for soy drink (+80%) and more than the double for tofu and PBMA (+136% and +119%, respectively), is needed to achieve the same qc-protein as the reference. This increased food intake results in more calories and higher sodium levels across all plant-based substitutes. Sodium intake can have detrimental effects on health and should be minimized. The increased calorie intake can lead to excess weight which raises the risk for non-communicable diseases. On the other hand, all plant-based substitutes were high in fibres and in case of minerals, the investigated PBMA was high in calcium and is enriched for iron but bioavailability, for humans from these sources, needs further investigations.

4. CONCLUSIONS

Processed plant proteins showed lower environmental impacts than beef and milk thoroughly. They are good sources of fibre, calcium, and iron (if enriched), but the consumption of similar protein contents results in a higher intake of calories and sodium compared to their animal counterpart. Total caloric intake and nutrient bioavailability from processed plant protein sources need to be carefully assessed in the overall diet.

5. ACKNOWLEDGEMENTS

This work is supported by the project OptiSignFood, which received funding from the European Union’s Horizon 2020 Framework programme under grant number 971242.

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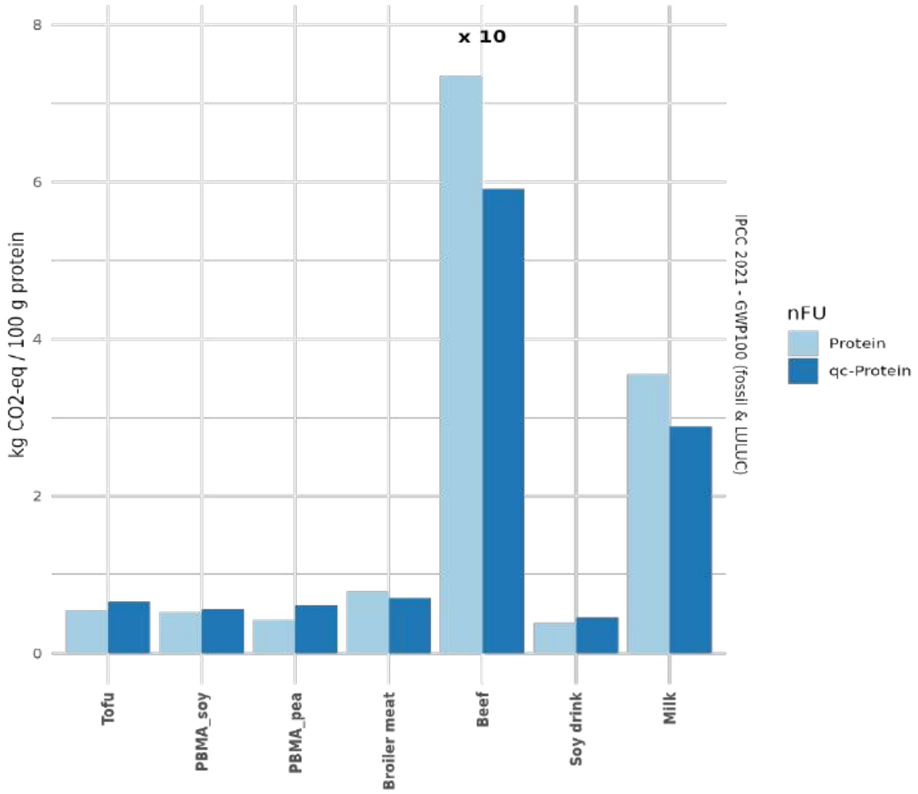
Table 1. Given the same nFU (qc-protein), percentage difference for food intake and nutrient values is shown compared to meat and milk from dairy cows. Excess energy and sodium are detrimental to health and should be minimized (red, if greater than reference), whereas nutrients below qc-protein should be maximized (green, if greater than reference)

	Tofu	PBMA	Broiler meat	Beef burger patty	Soy drink	Cow dairy, 3.5% fat
Food intake	+136 %	+119 %	-6 %	Reference for Meat	+80 %	Reference for Dairy
Energy	+15 %	+49 %	-47 %		+85 %	
Sodium	+4 %	+85 %	-83 %		+80 %	
qc-Protein	0	0	0		0	
Fibre	n.a.*	n.a.	0		n.a.	
Calcium	+813 %	+ ~10^3 %	+25 %		-88 %	
Iron	+65 %	+471 %	-59 %		n.a.	
Zinc	-54 %	-71 %	-80 %		+35 %	
Cobalamin	n.a.	n.a.	-88 %		n.a.	

* n.a. = not available; not detected in reference (green) or in alternative (red)

Figure 1. Correcting for protein quality (dark blue) increases the global warming potential (GWP) of all plant-based alternatives per 100 g protein when compared to animal-derived products. Broiler meat becomes



competitive with PBMAs and tofu in GWP and land use (not illustrated here), but this is not true for beef and milk

Greenhouse gas accounting and reporting

Integrating land use and land-use change greenhouse house gas emissions into the French life cycle inventory database Agribalyse

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1. INTRODUCTION

Land use and land-use change (LULUC) account for a large proportion of greenhouse gas (GHG) emissions from agriculture. The Product Environmental Footprint (PEF) guidelines (European Commission, 2021) recommend integrating direct land-use change (dLUC) following the PAS 2050 standard (BSI, 2012), based on the IPCC stock-difference approach. PAS 2050 (i) estimates dLUC over a 20-year inventory period based on national crop-area statistics (when the previous land-use category is unknown), (ii) estimates steady-state stocks of carbon (C) in soil and biomass under current and previous land-use categories based on IPCC default factors, and (iii) linearly amortises the stock difference over a 20-year period. However, this method has several limitations. Over the past two decades, major efforts have been made to improve LULUC accounting in LCA. Based on this work, we developed a method to integrate GHG emissions of LULUC into the French life cycle inventory database Agribalyse.

2. METHODS

Spatially explicit conversion matrixes for 2000-2020 were used for 94 departments of metropolitan France. dLUC was assessed for 16 land-use categories (including hedgerows). Steady-state C stocks in soil and biomass (including dead organic matter) were estimated for each land-use category in each department, based on national measurement networks. We determined land management change (LMC) using national surveys of farming practices. Default IPCC factors were used to estimate effects of LMC on soil organic carbon (SOC). The difference in C stock was annualised using a 20-year amortisation period. We determined N_2O emissions due to SOC losses according to IPCC (2019). This yielded estimated GHG emissions per land-use category for each department (i.e., shared-responsibility approach at the local scale). Emissions were aggregated at the national scale for each crop by weighting the emissions of the corresponding land-use category by crop production in the departments. We compared three LULUC assessment methods: (i) *PAS 2050*, the weighted average according to PAS 2050 applied using the LUC Impact Tool 2023, (ii) *AGBc*, the current Agribalyse method based on a French literature review of SOC-stock trends, and (iii) *AGBp*, the proposed Agribalyse method described here.

3. RESULTS AND DISCUSSION

PAS 2050 estimated no LULUC GHG emissions for crops whose area decreased (e.g. silage maize, Fig. 1). Furthermore, for annual crops whose area increased (e.g. soya bean, Fig. 1), only dLUC from perennial crops was considered. Our model showed dLUC from perennial crops but also from grassland and forests. *AGBc* had a shared-responsibility approach at the national scale, resulting in the same emissions for all crops of the same land-use category (*e.g.* silage maize and soya bean, Fig. 1). In *AGBp*, however, crop emissions were driven by the emissions of the main producing departments, introducing variability at the national scale. Considering SOC storage due to LMC and establishment of permanent grassland strongly influenced the predictions. Finally, changes in hedgerow area contributed greatly to the LULUC GHG emissions for all land-use categories (data not shown).

4. CONCLUSIONS

As recommended by the IPCC (2019), we used spatially explicit land conversion data with regionalised organic C stocks, based on national measurement networks. We calculated reference values for five agricultural land-use categories in 94 departments of metropolitan France and mean national results for 90 crops. We recommend that future LCA studies include SOC storage and GHG emissions due to hedgerow losses.

5. ACKNOWLEDGEMENTS

The authors thank the French Agency for Ecological Transition (ADEME) for funding and Mérieux NutriSciences for providing the LUC Impact Tool data.

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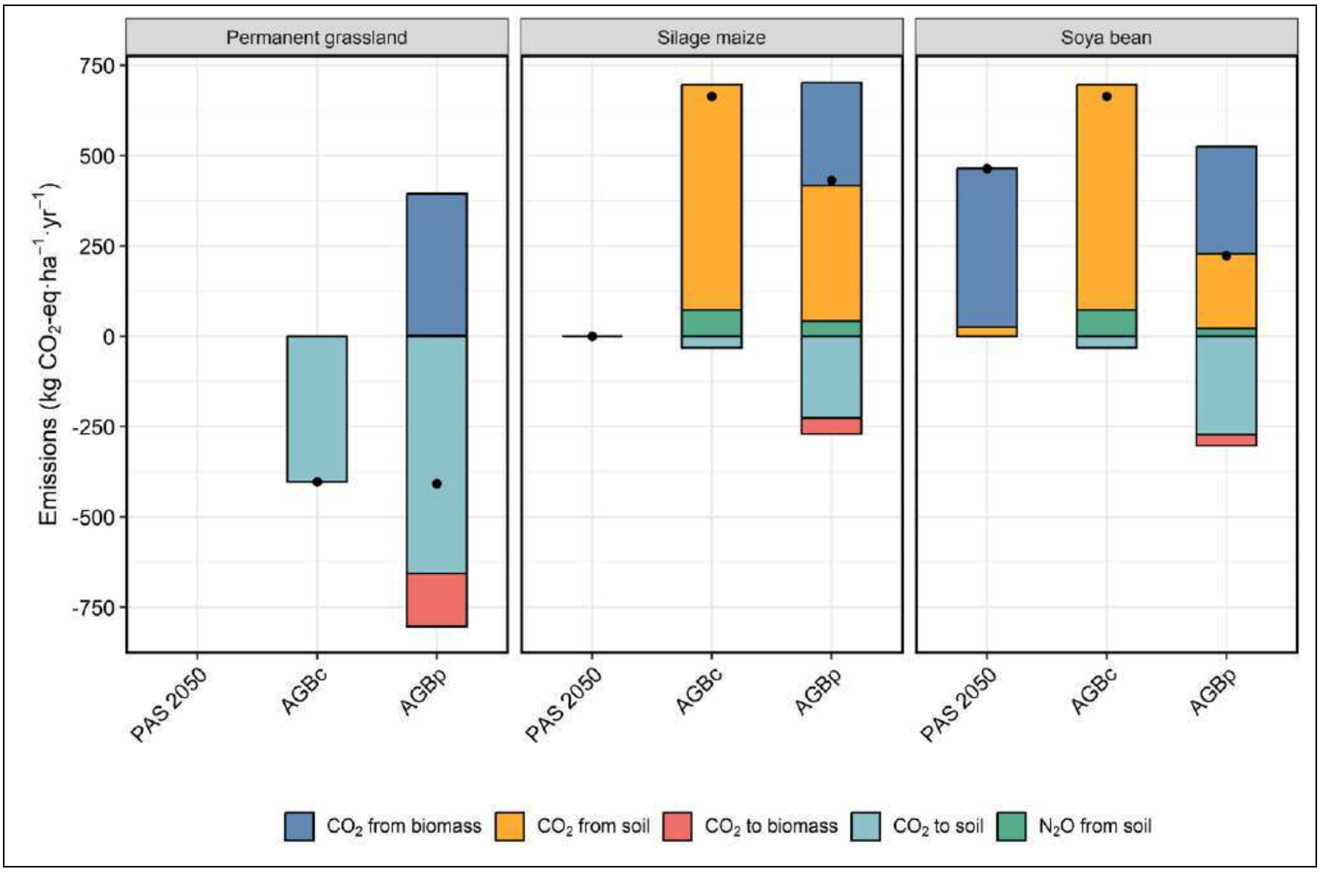

Fig. 1. Greenhouse gas emissions of LULUC of three crops at the national scale estimated according to three methods: *PAS 2050*, the application of the PAS 2050 method; *AGBc*, the current Agribalyse method; and *AGBp*, the proposed Agribalyse method.

Methodological development to include the effect of land management changes in GWP of field crops

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1. INTRODUCTION

Land use and land use change greenhouse gas (GHG_{LULUC}) emission and removal inclusion in life cycle assessment (LCA) is limited due to undeveloped methods as well as data gaps. Typically, LULUC effects are included in LCA in cases when a direct land use change (LUC) has occurred during the past 20 years (BSI 2011). However, also the effects of land management changes (LMC) in cases where land category remains the same should be accounted for (ISO 2018, European Commission 2021). Previously, the IPCC default Tier I method has been used for LMCs in LCA. Nevertheless, more site-specific methods would enhance a more accurate representation of land management history as well as local climate and soil conditions. For example, in Finland, agricultural soils have high organic matter content and thus, a tendency to lose carbon. These regional limitations should be accounted for, and therefore, this study aims to specify the LMC-related GHG_{LULUC} estimates for agricultural mineral soils in Finland.

2. METHODS

To evaluate the effect of different LMCs on GHG_{LULUC}, we developed a method including changes in living biomass, dead organic matter, and SOC, with a specific focus on SOC in mineral soils. Employing a Tier II approach, the method allocates the total carbon stock changes from one steady state to another over a fixed-term responsibility window of 20 years or 100 years post-LMC. The method is built on a multi-model approach using several soil C models. Although still under development, a preliminary version of the method was applied to continuous barley (*Hordeum vulgare* L.) grain cultivation in Finland, considering two LMCs: i) red clover (*Trifolium pratense* L.) as a cover crop for barley, and ii) manure application of 30 Mg of slurry/ha/year. The soil C model used in the preliminary version was Yasso07. It was assumed that there were no LUCs in the past 20 years and the shares of organic soil in the production chain were set as i) 0%, ii) 10%, and iii) 20% of agricultural land. The GHG_{LULUC} was included in the global warming potential (GWP) of 1 kg barley grain (cradle-to-farm gate). The fossil GHG emissions were acquired from the Agri-footprint database, and organic soil GHG emissions were calculated using IPCC emission factors.

3. RESULTS AND DISCUSSION

The inclusion of LMC impact in the GWP of barley compensated for the GWP fossil, but the magnitude of compensation was lower when a responsibility window of 100 years was applied compared with 20 years (Fig. 1). In total, the annual SOC stock increase was approximately 1400 kg C/ha with 20-year responsibility window and 300 kg C/ha with 100-year responsibility window, assuming that the LMCs continued constantly. Nevertheless, the permanency of LMCs is a controversial concept in agricultural management where management decisions are made annually adapting to the prevailing socio-economic and environmental conditions. Hence, the requirement of covering full long-term SOC impacts within a 20-year responsibility window may be problematic. An increase in the percentage of organic soils in the production chain diluted the effect of SOC stock increase in mineral soils. For example, with 20% of organic soils in the barley production chain, the organic soil GHG emissions were equal or up to 4 times higher compared with SOC stock increase in mineral soil.

4. CONCLUSIONS

The findings highlight the importance of including changes in all land-related carbon stocks in LCA, thus, not only focusing on potential SOC stock increase on mineral soils. Including SOC stock increase could mitigate the GWP of barley, but the magnitude depends on the responsibility window length and organic soil share. Especially the problems related to optimal fixed responsibility window length for agricultural LCA require further attention.

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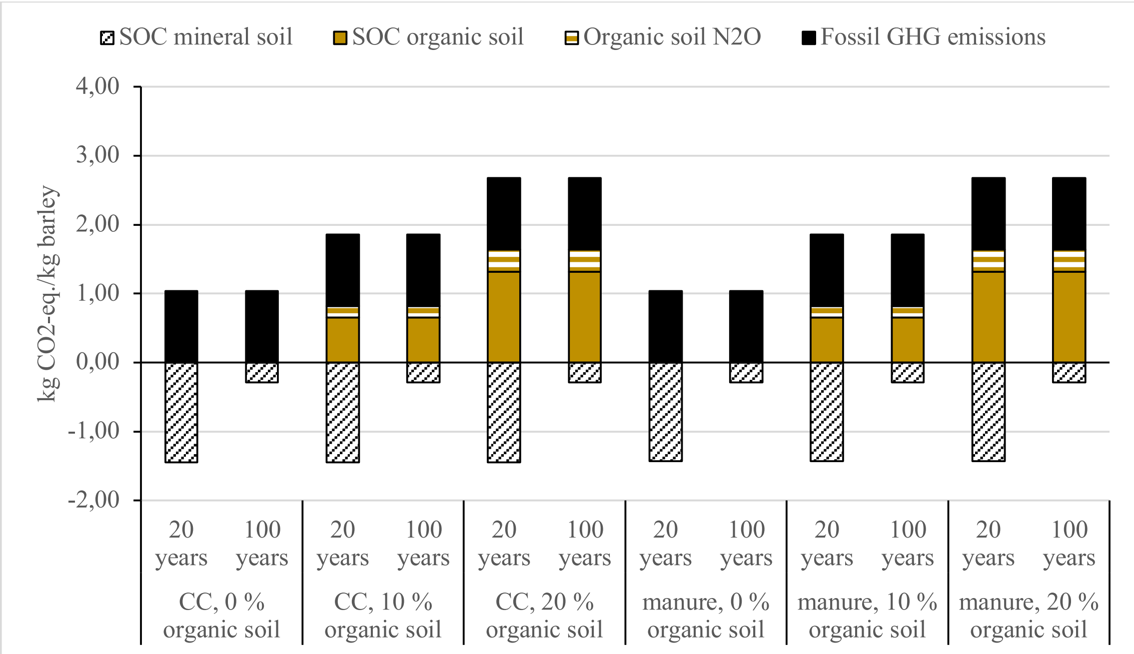

Figure 1. Global warming potential of 1 kg barley (cradle-to-farm gate) with two land management changes: i) CC = start of cover cropping, and ii) manure = start of cattle manure application. Organic soil share within the barley production chain: 0%, 10% and 20% of agricultural land. The responsibility windows for SOC stock changes on mineral soils: 20 and 100 years.

Quantifying land conversion carbon emissions in the absence of traceability

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1. INTRODUCTION

The complexity of the livestock and pet food value chain poses unique challenges to accurately assessing a product's carbon footprint. For pet food, manufacturers must identify the origins of the animal by-products, where the animals were raised, what they ate and where the feed ingredients came from. While information about the origin of the by-products is often within reach of manufacturers via their suppliers, the origins of the feed ingredients, such as soy and corn, are likely more obscure. However, without this information, one of the most important drivers of environmental impacts of such embedded commodities — land conversion — cannot be properly assessed. There are no off-the-shelf solutions for this challenge. Supply chains modelled in existing LCI databases are typically too coarse to accurately capture the origin of embedded commodities, such as feed, down to the subnational level. We present a refined approach to unraveling the complexity of embedded soy's climate impacts by combining trade statistics and subnational, high-resolution data on land conversion, highlighting the implications for chicken used as pet food, and by extension, pet food and livestock in general.

2. METHODS

We must answer two questions at the highest possible resolution to accurately assess the land conversion impacts of embedded soy: 1) Where is the soybean produced? (i.e., in which subnational regions?) and 2) What is the land conversion footprint of the soy for each region?

Using a matrix-based international trading model, we work backwards, tracing the origins of the soy feed consumed in slaughterhouses in Europe, focusing particularly on major soybean exporting countries with a high risk of land conversion (e.g., South America). We then use subnational trade data from Trase (trase.earth) to locate the jurisdictions that directly supplied Europe with soy within each producing country (Trase 2022). Because each European country sources from a different set of jurisdictions, each has a unique land use change (LUC) footprint. We create an explicit record for every country which directly imports soybean from a major soybean exporter in our trade matrix (e.g., "BR_NL" if the Netherlands is directly importing from Brazil and "BR_DE" if Germany is directly importing from Brazil) to track the unique LUC footprints across countries that export a large proportion of the soybean imported. We then combine this information to the impact factors of Orbae (Reinhard et al. 2024) which calculates the greenhouse gas (GHG) emissions from land conversion in each subnational boundary by combining data on agricultural crops and land conversion derived from satellite imagery (30 m resolution).

3. RESULTS AND DISCUSSION

With the improved granularity of Orbae, we found that LUC emissions for soy vary widely within producing countries. In Brazil, footprints range from 100 to 18,000 kg CO_2e per metric ton of soy depending on the municipality (Figure 1). Replacing the coarse default assumptions with the refined factors from Orbae resulted in a 35% decrease in the chicken's overall carbon footprint. We also found that non-forest land conversion makes up a third of the climate impacts of the soy value chain and observed how the unique sourcing patterns of soy imported to different European countries result in unique carbon footprints. (Figure 2).

4. CONCLUSIONS

Our embedded commodity approach for soy offers a blueprint for other commodities used in animal feed with high-risk of land conversion (e.g., corn, rice, palm), and paves the way for integration of other regionalized data, such as land occupation, biodiversity loss and water stress. Our approach can be used for corporate GHG accounting, developing more accurate carbon reduction roadmaps and performing deforestation exposure assessments even in the absence of perfect traceability information.

5. ACKNOWLEDGEMENTS

Orbae by AdAstra is a start-up innovation project supported by Innosuisse, the Swiss Innovation Agency.

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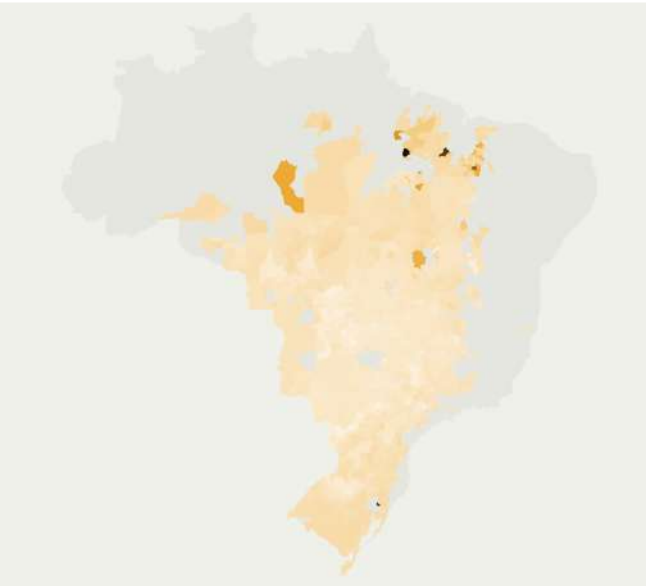

Figure 1. The carbon footprint of soy in Brazil varies by municipality, ranging anywhere from 100 to 18,000 kg CO_2e per metric ton of soy.

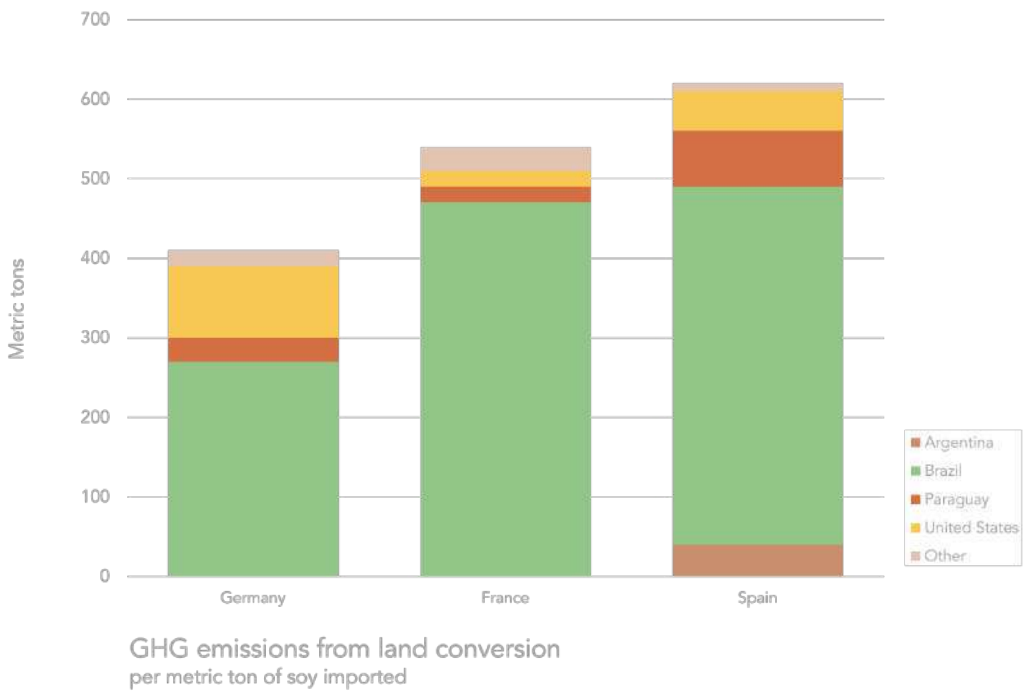

Figure 2. Unique LUC GHG emissions for soybean imported to different European countries.

Radiative forcing footprints for the Australian red meat industry

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1. INTRODUCTION

According to the IPCC, "Stabilizing the climate will require strong, rapid, and sustained reductions in greenhouse gas emissions, and reaching net zero CO_2 emissions." (IPCC, 2021) This requirement to achieve net zero CO_2 emissions stems from the long-term impacts of these emissions, potentially lasting for millennia. The IPCC also notes that, "Limiting other greenhouse gases and air pollutants, especially methane, could have benefits both for health and the climate." (IPCC, 2021) In comparison, biogenic methane emissions have a relatively short atmospheric lifetime, in the order of 12 years, meaning that a more-or-less steady emissions profile over time can be consistent with climate stabilization. These differences complicate the development of multi-gas climate action strategies and reporting. Climate metrics can be used to establish an equivalence between different types of GHG emissions, with results typically reported as CO_2-equivalent emissions. However, it is well known that there is no absolute equivalence. Each climate metric uses a different basis for comparison. While the 100-year global warming potential (GWP100) is commonly used in LCA studies, typically without justification or consideration of its limitations, it is important to underscore that this metric does not have any special significance (Myhre et al., 2013). This article explores the use of an alternative approach to impact assessment, the radiative forcing (RF) footprint, using red meat production in Australia as a case study.

2. METHODS

Disaggregated timeseries of GHG emissions (CO_2, N_2O, CH_4), covering cattle production (including feedlot finishing), sheep meat production, goat production, and domestic processing were compiled for the years 1990 to 2020 as described in Ridoutt (2024). These data were extrapolated to 2030 under a business-as-usual scenario (including an increase in production of cattle and sheep of 13% and 18%) and under a scenario including various additional GHG mitigation and vegetation management actions. RF footprints were quantified following Ridoutt (2021) and Ridoutt et al. (2022) using equations and parameters reported in Myhre et al. (2013).

3. RESULTS AND DISCUSSION

The RF footprint reports present radiative forcing from current year emissions together with radiative forcing from historical emissions remaining in the atmosphere. As such, it presents what might be described as a radiative forcing balance sheet. It enables examination of the trajectory of RF and can inform climate action designed to stabilise total RF (a requirement for climate stabilization) or management toward an RF target. For the Australian red meat industry, the RF footprint plateaued around 2015 and is projected to remain more-or-less level under a business-as-usual scenario (Figure 1). This demonstrates no incremental contribution to climate change since around 2015. Under a scenario that includes additional GHG mitigation and vegetation management, the RF footprint is projected to decrease from 7.07 mW/m^2 in 2020 to 6.81 mW/m^2 in 2030 (Figure 2), comparable to a net negative CO_2 emission.

4. CONCLUSIONS

According to ISO 14044:2006 Subclause 4.4.2.2.1, the selection of characterization models *shall* be justified. This is rarely the case when GWP100 is used. RF footprints are an alternative, that can be applied at organisational or product levels. Importantly, they avoid the arbitrary choice of a time horizon that can greatly influence study results and conclusions. RF footprints offer transparent information that can be used to align with climate stabilisation goals.

5. ACKNOWLEDGEMENTS

This abstract is based on a research publication currently in review. The study was funded, in part, by Meat & Livestock Australia (www.mla.com.au), grant number B.CCH.2301, and in part by the Commonwealth Scientific and Industrial Research Organisation, Australia.

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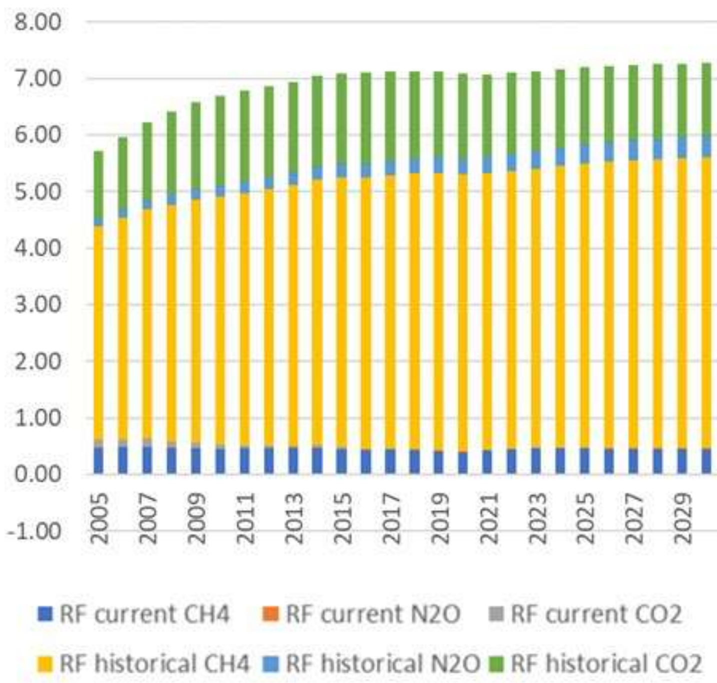

Figure 1. Australian red meat industry radiative forcing (RF) footprint (mW/m^2) under a business-as-usual scenario. Historical data 2005 to 2020. Projected data from 2021.

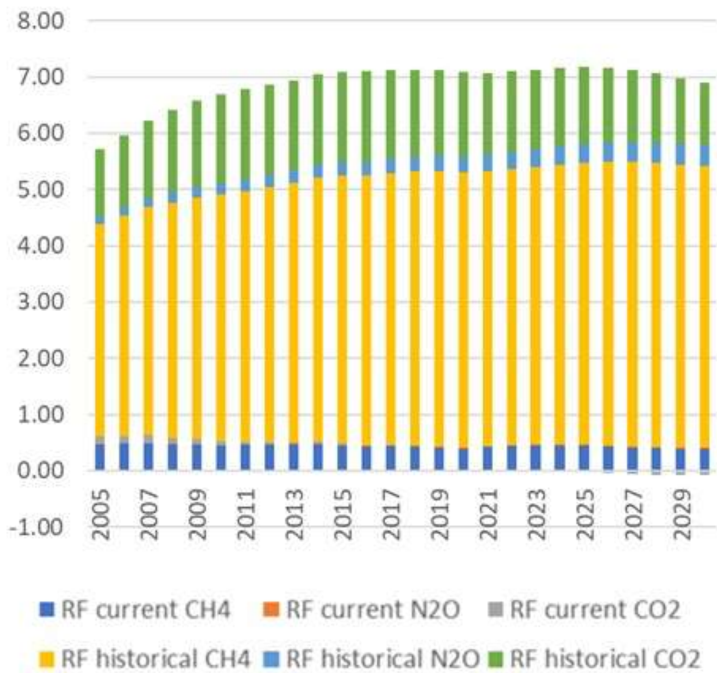

Figure 2. Australian red meat industry radiative forcing (RF) footprint (mW/m^2) with adoption of additional GHG mitigation and sequestration actions. Historical data 2005 to 2020. Projected data from 2021.

Application of environmentally extended input-output data to estimate greenhouse gas emissions attributable to packaged foods and beverages in Australia

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1. INTRODUCTION

Estimation of greenhouse gas emissions (GHGe) from packaged foods have to-date focused on process-based life cycle assessments (LCA) (1). However, LCAs require visibility of each process and ingredient, are prone to truncation error, and are resource intensive and therefore available for a small fraction of food products marketed in a country (2). Environmentally extended input-output (EEIO) analysis is a method of attributing an environmental impact to each economic activity by combining knowledge of financial flows, as detailed in national input-output tables, with their associated environmental impact (2).

2. METHODS

We used EEIO data to estimate GHGe for Australian packaged foods and beverages. GHGe intensity, expressed as kilograms of carbon dioxide equivalents (kg CO2eq) per Australian dollar, were sourced from EEIO data (3), 2019 price-adjusted. Corresponding median prices per kg of product were obtained from 2019 NielsenIQ Homescan data and used to convert GHGe per dollar to GHGe per kilogram. We applied the EEIO-derived GHGe intensities per kilogram to a 2019 Australian packaged food database, FoodSwitch, and reported median and interquartile range (IQR) overall and for major food categories. We compared the findings to those derived using prior LCAs from Poore and Nemecek (4) and FoodSwitch (5).

3. RESULTS

EEIO-derived intensities were estimated for 23,550 packaged food products, and the median overall GHGe based on EEIO data was 6.87 kg CO2eq / kg (IQR 4.20 to 10.5) (Figure 1). LCA-derived estimates were comparatively lower, showing a median overall GHGe of 2.42 kg CO2eq / kg (IQR 1.41 to 5.00) using Poore and Nemecek data and 2.35 kg CO2eq / kg (IQR 1.24 to 4.53) using FoodSwitch. There was good alignment in the ordering of GHGe intensities for food categories using the EEIO- and LCA-derived data, however, there were large differences in median GHGe for individual food categories between the two approaches.

4. DISCUSSION

Whilst the approaches were well aligned in the ranking of most to least emitting food categories, the EEIO-derived estimates were often several times higher than LCA-derived ones. Three main steps were undertaken to align the approaches that were further explored as potential contributors to the differences. First, matching broad input-output industry sectors with finer categorisations of packaged foods was challenging but, even when closely matched, showed higher estimations of GHGe in the EEIO-based approach compared to LCA. Second, the inflation of prices to 2019 dollars, which was found to be unlikely as an explanation for the large differences based on sensitivity analyses without inflation. Third, the conversion of GHGe per dollar to GHGe per kilogram, which was done using nationally representative price data. Here, an explanation may lie in the average price per sector calculated from purchases in 2019 due to seasonal differences in prices, overestimating GHGe per kilogram. To improve estimates of GHGe for packaged foods, a hybrid approach involving the LCA approach and utilising EEIO data for better coverage may provide more accurate and locally tailored estimates.

5. CONCLUSIONS

EEIO-based methods have some appeal for estimating GHGe intensities for packaged foods, but more work is needed to understand how robust GHGe estimates can be obtained from EEIO-derived data. A hybrid LCA approach may provide more accurate and locally tailored estimates.

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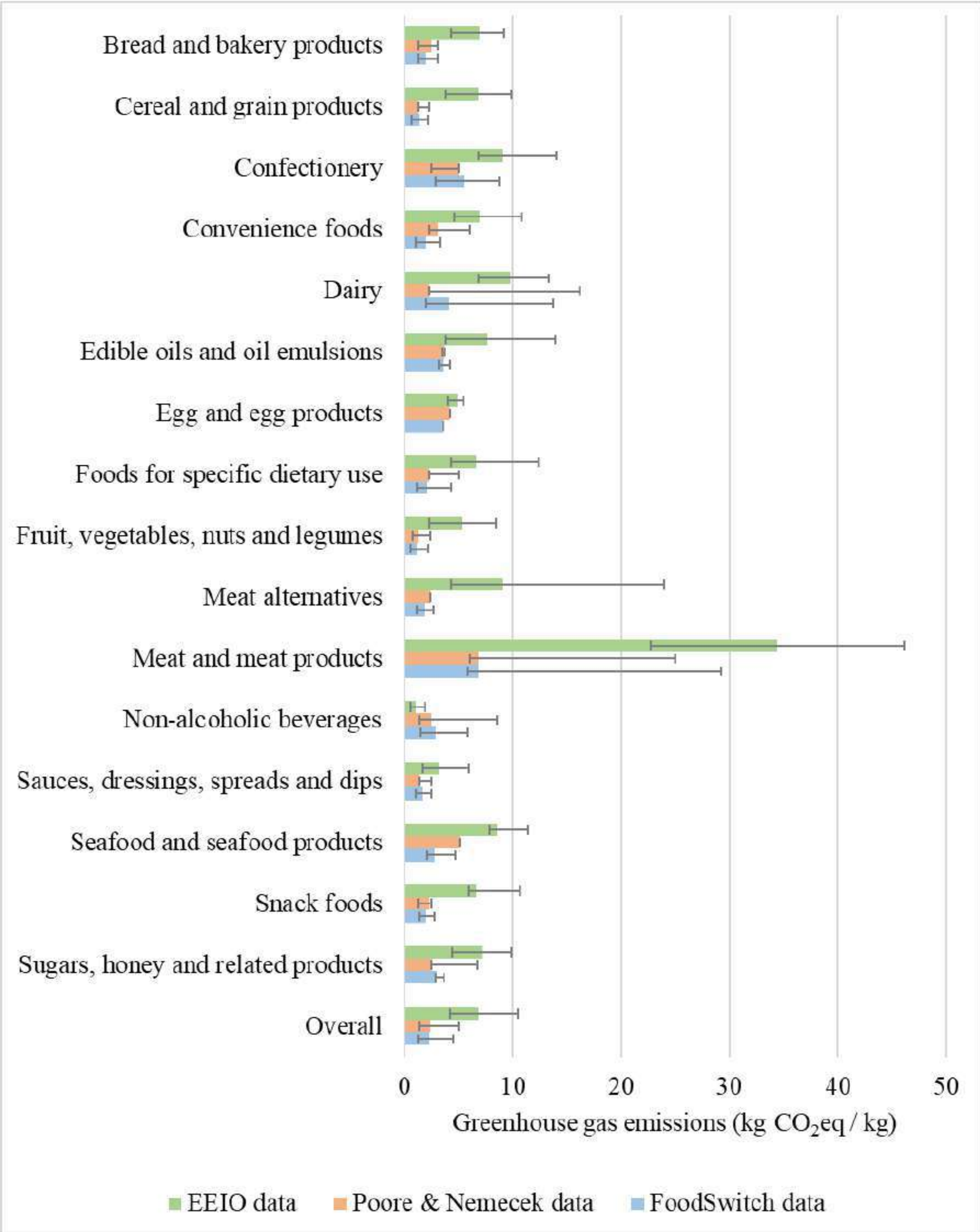

Figure 1. Overall and category-specific median and interquartile range greenhouse gas emissions for packaged foods in 2019 grouped by 16 major food categories and estimated using environmentally extended input output data, Poore and Nemecek data (4) and FoodSwitch data (5). kg CO2eq = kilograms of carbon dioxide equivalents; EEIO = environmentally extended input output.

Carbon footprint of low-input livestock systems: accounting for natural baseline emissions within the ecosphere

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1. INTRODUCTION

LCA approaches dealing with services provided by nature usually establish the system boundaries in the frontier between ecosphere and technosphere. Accordingly, wild herbivores are considered natural biotic resources entering the system as elementary flows from the ecosphere. Their emissions are characterized as natural GHG fluxes and not included in the impact assessment of the derived products (Fiala et al. 2020). However, these boundaries can be difficult to define, especially in pastoral systems with a strong link to natural ecosystems. Extensive pasture lands have been pointed out as resources extracted by humans from nature, at the same level as wood harvested from primary forests, or seafood from ocean waters. The aim of this work is to propose a framework for livestock systems that allows the separation of emissions between ecosphere and technosphere, by using a baseline that accounts for natural wildlife emissions. To illustrate its application, we explore the GHGs of two low-input pastoral systems linked to natural grasslands in 1) Tanzania and 2) Spain.

2. METHODS

In Tanzania, we analysed the Loliondo Game Controlled Area (GCA), a savanna ecosystem being used by Maasai pastoralists with cattle, sheep, and goats, and negligible external inputs. Details described in Manzano et al (2023). In Spain, we studied low-input transhumant systems of sheep grazing semi-natural grasslands (details in Pardo et al 2023). Livestock GHG emissions were modelled according to herd structure and IPCC guidelines. Off-farm emissions from any external feeds or fuels were accounted for based on existing LCA databases.

In the proposed framework, wild herbivores are considered part of natural systems, whose emissions occur in the ecosphere (Fig. 1). Intensive livestock based on crop products is considered a human-made system, with its emissions occurring in the technosphere. When pastoral systems are based on the use of natural grasslands, thus occupying the ecological niche of wild herbivores, a fraction of their emissions can be considered as produced in the ecosphere. As a proxy to establish that amount, we use the so-called natural "baseline" GHGs emitted from wild herbivores in an equivalent natural grassland ecosystem. To do so, we estimated the GHG emissions from nature reserves of Tanzania (Serengeti-Mara) and Spain (Cabañeros) based on (1) IPCC guidelines and (2) allometric regression equations, and we subtracted them from grazing livestock systems in the same area.

3. RESULTS AND DISCUSSION

Herbivores density estimated in the Serengeti-Mara was higher than in Loliondo GCA (14.3 vs 12.8 Mg/km^2), while both adjacent areas showed similar GHG emissions, comparing wildlife to pastoralism (76.2 vs 76.5Mg CO_2-eq km^{-2}). Such similarity highlights that the emissions from these pastoral systems can be attributed to the ecosphere, and therefore the outputs produced would result in a negligible carbon footprint (kg CO_2eq/kg meat or milk) (Fig 2). In Spain, low-input transhumant systems presented higher stocking density than adjacent wildlife area (4.8 vs 5.8Mg/km^2), indicating some influence of technosphere (Pardo et al 2023). When considering natural baseline emissions attributed to ecosphere, the carbon footprint of lamb meat was reduced by almost 30%, reaching values below those reported for intensive lamb production systems in Spain (Pardo et al 2023).

4. CONCLUSIONS

Considering natural baseline emissions in grazing systems could have important implications in the analysis of global food systems. Under this new GHG accounting perspective, low-input grazing-based ruminant systems would be a good option when aiming at climate neutrality.

5. ACKNOWLEDGEMENTS

Financial support provided by Spanish Government María de Maeztu excellence accreditation 2023-2026 (Ref. CEX2021-001201-M, funded by MCIN/AEI/10.13039/501100011033); Basque Government BERC 2022-2024 program; and CircAgric-GHG project (MCIN/AEI/10.13039/501100011033) and European Union NextGenerationEU/PRTR (ref. num: PCI2021-122048-2A).

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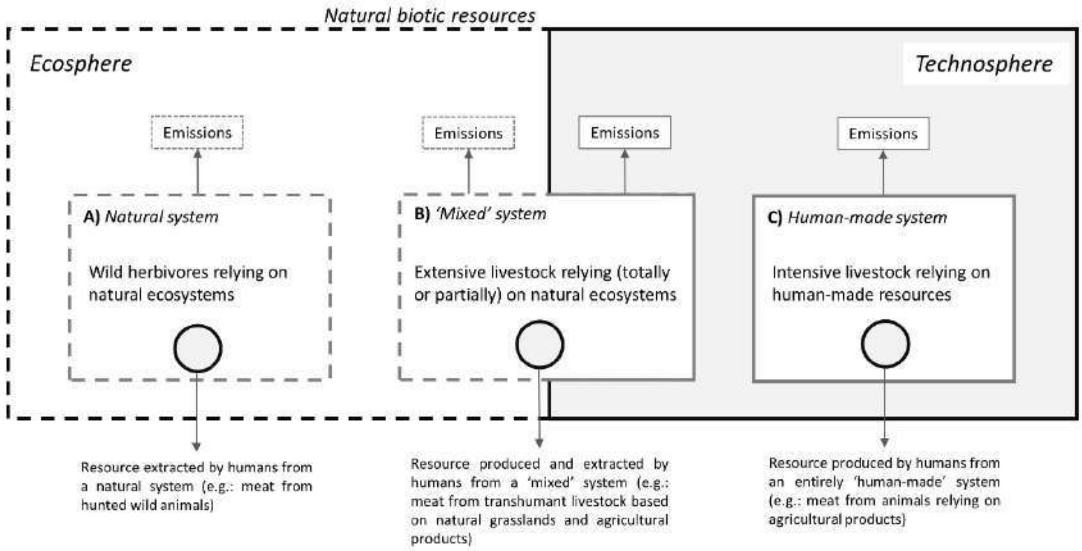

Figure 1. System boundaries between ecosphere and technosphere for different systems producing biotic resources. In natural systems (A), resources are produced in natural environment, and emissions are considered within the ecosphere. Mixed systems (B) involve human intervention but resource production relies totally or partially on natural environment. Entirely human-made systems (C) are based only on resources produced through human intervention (i.e., within technosphere).

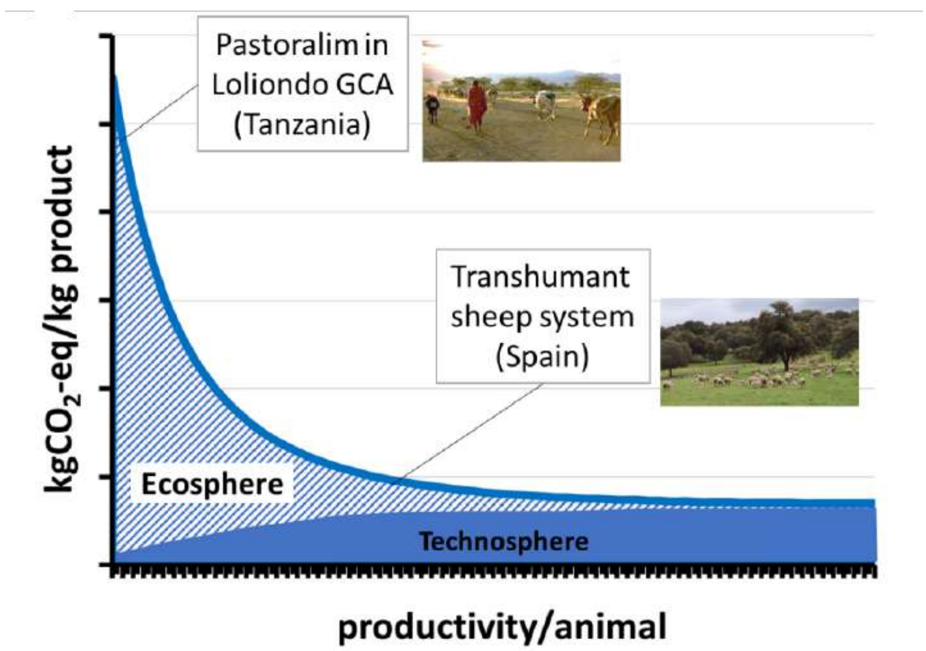

Figure 2. Profile of GHG emissions within Ecosphere and Technosphere for the two low-input pastoral systems analyzed.

Life cycle sustainability assessment of food systems

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Integrated sustainability assessment of insect-fed chicken: Integrated Sustainability Index

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1. INTRODUCTION

Overall sustainability is typically assessed through a combination of life cycle assessment (LCA) for environmental sustainability, life cycle costing (LCC) for economic sustainability and social LCA (SLCA) for social sustainability. Combining these into a single, integrated sustainability index is a challenge. To assess the overall sustainability of broiler rearing in a way that includes different scenarios and all three sustainability pillars, a matrix was developed, allowing the normalization of different results and their combination into a single index.

2. METHODS

The method for the overall sustainability assessment was based on the method of SLCA, which was expanded and adjusted. For the SLCA, the starting relevant themes/categories, as well as the evaluation system were adopted from Pelletier, N. (2018). The evaluation system was expanded into a 5-point grading system, grading the company actions from 5 – Not assessed (risk too high/unreliable sources) to 1 – committed. This grading system was applied to each of the categories in each of the scenarios, allowing the calculation of an average social sustainability grade for each of the scenarios (Table 1). A similar logic was applied to the integrated sustainability assessment: the single score results of LCA, as well as the production prices of the modelled chicken meat scenarios, were normalized the 5-point grading system. The normalization was done proportionally and was dependent on the range of the results of LCA and LCC. Once all three sustainability assessments could provide a 5-to-1 grade to each of the modeled scenarios, an average grade could be calculated, and the most sustainable scenario could be identified. The condition for the application of this methodology is the use of the same system boundaries and the same functional unit in all three sustainability assessments.

3. RESULTS AND DISCUSSION

The adapted methodology allowed the calculation of an integrated sustainability index, which is simplified but allows an overall sustainability overview, comparison and is understandable to the general public. The results allowed to identify the system relying on automation without the application of insects as more sustainable, followed by automated with insects, manual control and manual with insects (Table 2).

It should be noted that having in mind the limitations of this index, it must be used with caution. Firstly, it allows comparison between different scenarios within the same sustainability assessment, but not between different assessments (unless they are intentionally conducted so that they are comparable). A major danger of misinterpretation also lies in "compensating" for the cracks in one of the sustainability pillars with good results in another. Good results in, say, economic sustainability, must not justify the lack of commitment to environmental or social sustainability. For this reason, a threshold in each of the sustainability pillars below which the scenario is deemed unsustainable must be established and respected.

4. CONCLUSIONS

A matrix for calculation of a single, integrated sustainability index was developed and allowed a quick and simple comparison of overall sustainability of different modelled scenarios. While the index has proven to be useful and understandable to the wide audience, it has its limitations and must therefore be used with caution.

5. ACKNOWLEDGEMENTS

The study has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 101102316 (ADVAGROMED).

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	Insect farm		Chicken farm			
	Predominantly manual	Automated	Predominantly manual		Automated	
			Insects included	Control	Insects included	Control
Health and Safety	3	2	3	2.5	2.5	2
Fair wage potential	2.42	2	2.42	2.42	2	2
Freedom of Association and Collective Bargaining	Small, likely family farm, and therefore not relevant					
Child Labour						
Working Hours	3	1	3	3	2	2
Equal opportunities/Discrimination	3	2	3	3	2	2
Forced Labour	3	1	No difference introduced by insects expected			
Social Benefits/Social Security	3	3				
Overall	2.90	1.83	2.85	2.73	2.13	2

Table 1: Social Assessment Matrix

	Chicken meat production							
	Predominantly manual				Automated			
	Insects included		Control		Insects included		Control	
	Males	Females	Males	Females	Males	Females	Males	Females
LCA	4.23	4.65	4.27	5.00	4.23	4.65	4.27	5.00
LCC	3.85	5.00	3.63	4.58	3.85	5.00	3.63	4.58
SLCA	2.85	2.85	2.73	2.73	2.13	2.13	2.00	2.00
Sum	10.94	12.51	10.63	12.30	10.21	11.78	9.90	11.58
Overall index	3.65	4.17	3.54	4.10	3.40	3.93	3.30	3.86
	3.91		3.82		3.66		3.58	

Table 2: Integrated sustainability assessment matrix

Sustainability performance of innovative ruminant systems in Europe

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1. INTRODUCTION

European livestock systems are facing a set of sustainability challenges encompassing environmental (e.g., greenhouse gas emissions, biodiversity decline), economic (e.g., value creation, profitability), and social issues (e.g., labour conditions, animal welfare). To understand how livestock systems in Europe can become more sustainable, the Horizon 2020 PATHWAYS project works with groups of European livestock farmers, organised around sustainable innovation practices. To assess their performance and identify benefits and trade-offs of those practices, we performed environmental (E) and social (S) LCAs and economic analysis.

2. METHODS

Sustainability data was collected from four ruminant farms (beef and dairy) in the UK, Sweden, Romania and Germany, with an adapted version of the Public Goods Tool (PG tool) (Paraskevopoulou et al., 2020) and interviews with farmers. The E-LCA used the FarmLCA tool (Schader et al., 2014), that includes biodiversity and soil carbon impacts, following a systematic method review. The analysis adopted a cradle to farmgate boundary and included the functional units 1 kg liveweight of finished beef, 1 kg of energy corrected milk, hectare of land utilised, and unit of currency of livestock output. The S-LCA followed a reference scale approach and included five impact categories of the UN Environment Programme Guidelines for S-LCA (UNEP, 2020). The economic analysis included ten indicators, based on reporting variables in FADN standard results (EC, 2022).

3. RESULTS AND DISCUSSION

We present preliminary results of the UK beef system, those of the other systems will follow. E-LCA results show a relatively low carbon footprint per kilogram liveweight, compared to a recent UK estimate (McAuliffe et al., 2023). The biodiversity impact was positive, due to a lack of external feed reliance (Figure 1). S-LCA results are mixed, e.g., the beef system scores below a generally acceptable level for half of the assessed impact categories (Table 1). Economically, the beef system performed better than the average specialist UK cattle farm in FADN (Table 2).

4. CONCLUSIONS

It was shown that use of the FarmLCA tool, together with S-LCA and economic analysis, building on data from the Public Goods Tool allows for a holistic sustainability assessment of innovative livestock farms. The sustainability assessment of the UK case shows benefits, such as carbon footprint per kg liveweight, a low biodiversity impact, local employment, fair competition, and beneficial economics but also trade-offs.

5. ACKNOWLEDGEMENTS

We would like to thank all farmers, and I. Jamieson, D. Hahn, J. Thompson, S. Mignon and L. Baumgart for collecting data. This research has been funded by the EU's Horizon 2020 Research and Innovation Programme under grant agreement No 101000395.

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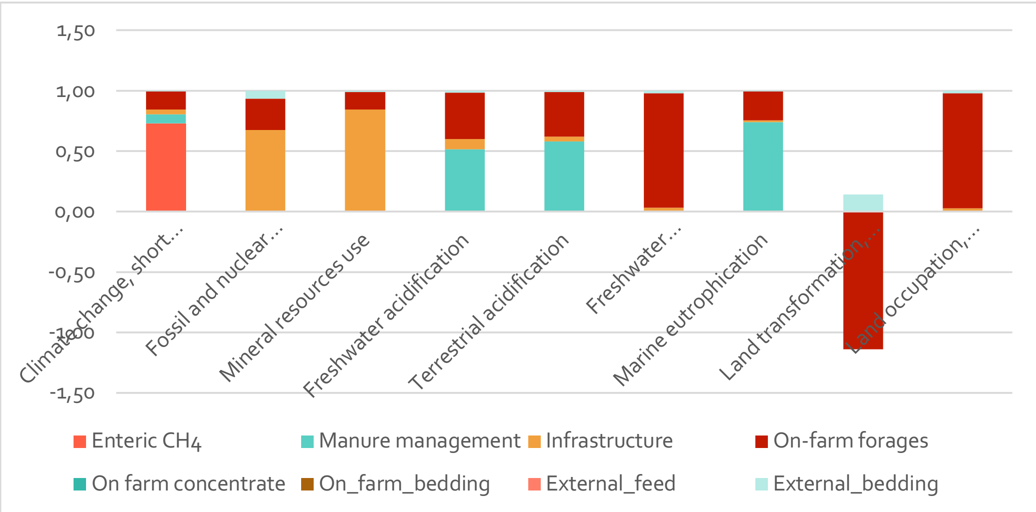
Table 1. Social performance of UK beef system

Impact subcategory	Performance indicator	Score UK beef	Reference scale score
Operational Health and Safety	Number of work accidents	0.3	-2
	Presence of a formal policy concerning health and safety	7 yes	
Safe and Healthy Living Conditions	Complaints with regards to safe and healthy living conditions	Yes	-1
	Presence of flood defence measures	Average	
	Presence of emission minimization measures	Maintain good litter quality (dry and friable) by circulation air and standard climate control	
Local employment	Percentage of workers belonging to local communities	80-100%	2
	Presence of a policy with regards to local hiring preferences	Yes	
Fair competition	Presence of an anti-competitive behaviour policy	Yes	2
	Presence of a fair price and fair trade policy for small scale entrepreneurs	Yes	

UK



UK

Figure 1. Contribution analysis for impact categories of beef system

Table 2: Economic performance of beef and FADN average (farm type specialist cattle)

Impact category	Profitability		Value creation			Amount jobs		Quality jobs	Competi-tiveness	Markup
Indicator	FNI[a]	FNI / FWU[b]	FNVA[c]	FNVA / FWU	FNW[d]	AWU[e]	FWU	Deprecia-tion/AWU	Receipts / costs	Markup
	k€ / year	k€ / year / FWU	k€ / year	k€ / year / FWU	k€ / year	AWU	FWU	k€ / AWU	-	%
Farms	165	132[f]	251	201[f]	2,925	3.41	1.20[f]	7	1.63	-6.1%
FADN	6	5	13	11	1,275	1.37	1.16	14	1.04	-17.9%

[a] FNI = Farm Net Income; [b] FWU = Family Working Unit; c FNVA = Farm Net Value Added; [d] FNW = Farm Net Worth; [e] AWU = Annual Working Unit; [f] Excluding two farms that had a low amount of own labour (40 and 80 hours per year). Including these two farms, the means would be: FWU = 1.08, Farm Net Income/FWU = €2,212,689 / year, Farm net value added/FWU = €2,861,886 / year.

DEXi a framework to integrate LCA in sustainability assessment. Application to animal production system

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1. INTRODUCTION

Growing awareness of global challenges and increasing pressures on the farming sector emphasize the need for sustainable production. Designing or comparing farming systems across the sustainability dimensions (environmental, social and economic) is a considerable challenge, notably due to the heterogeneity of production conditions. Multicriteria decision analysis, like the DEXi method (Bohannec, 2020), helps in evaluating overall sustainability by combining environmental, social, and economic dimensions. DEXi simplifies complex issues, changing both quantitative and qualitative data into comparable qualitative scores, and being adapted to depict farm heterogeneity; its participative approach facilitate trade-offs awareness. We applied DEXi at the European scale for ex-post evaluation of sustainability of dairy farms with a focus on GHG mitigation (DEXiDairy, Wilfart et al, 2023) and on IMTA systems for an ex-ante evaluation, focusing on energy dependence (DEXiAqua, Le Féon et al., 2021).

2. METHODS

To develop the assessment models, the first step was to define the general objective of the assessment and constituted expert groups assigned to each pillar of sustainability. The second step consisted in defining the indicator library. For each sustainability pillar, attributes were organized in principles, criteria, and indicators (Fig. 1) and structured in a tree to establish dependencies. For DEXiDairy model, environmental attributes relied on LCA or LCI indicators, except for biodiversity. DEXiAqua used LCA, Emergy accounting and additional indicators for environmental attributes. In DEXiDairy, Economic attributes were based on the EU Farm Accountancy Data Network (FADN) and the social ones on the Maslow's concept of needs. DEXiAqua involved partly life-cycle costing (LCC) and social LCA, as well as additional technical indicators for several attributes. The third steps is to calculate each indicator. The last step is to define the aggregation rules using utility functions. DEXi framework represents attribute values discretely with qualitative statements like "low, medium, high". Qualitative scales and utility functions were defined for each attribute level to allow aggregation to the next level. Lastly, a list of data requirements based on selected indicators was provided to guide data collection in case study farms (Baillet et al, 2021, Le Feon, 2021).

3. RESULTS AND DISCUSSION

The DEXi framework was employed to design assessment trees across three sustainability dimensions. In DEXiDairy, the model included 40 indicators, with 22, 12, and 6 in the environmental, economic, and social dimensions, respectively. DEXiAqua had 69 indicators, with 27, 22, and 20 indicators in its environmental, social, and economic branches. The final users of DEXi trees can be researchers, policymakers, and agricultural advisors, notably to provide an ex post assessment prior to the implementation of innovative technics or as ex-ante assessment to analyze development scenario as we used for DEXiAqua. The aggregation process to upper levels in both cases relies on the assembled expert panel. This approach has the advantage of emphasizing stakeholder priorities while employing quantitative metrics like LCA and FADN. Notably, this is valuable as there is often a lack of reference values to standardize these quantitative metrics.

4. CONCLUSIONS

The DEXi Framework serves as a valuable tool for integrating LCA impact categories into a comprehensive sustainability assessment. It extends its utility by integrating LCA, LCC, and SLCA in a more informative manner, involving skateholders. This multi-criteria sustainability assessment framework provides a robust foundation for comparing agricultural system performances through the sustainability perspective. Additionally, it simplifies the message, making it accessible for less expert users seeking an indication of their system's sustainability, while keeping the details of attributes to highlight the key benefits and hot spots..

5. ACKNOWLEDGEMENTS

We thank the partners of the European SIMTAP project who helped develop DEXiAqua and the partners of the European Milkey project who helped develop DEXiDairy.

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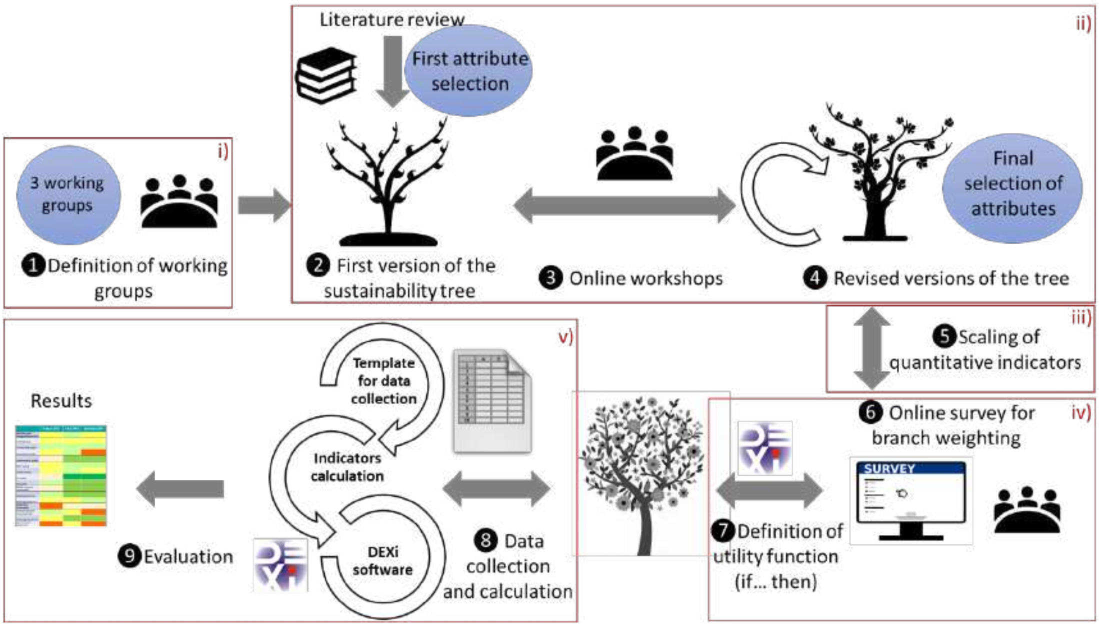

Figure 1. Description of Framework to design a DEXi model: (1) to (9) refer to the different steps to follow, while the boxes and numbers in red correspond to the conceptual framework proposed by Craheix et al. (2015) and adapted by Le Feon et al. (2021) et Wilfart et al (2023)

LCA to feed multi-criteria sustainability assessment of intermediate food value chains

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1. INTRODUCTION

The European agri-food system heavily relies on globalisation, large-scale production, and the involvement of major retailers with “long” value chains (VC). While offering advantages like mass production and lower prices, this leads to economic, social, environmental, and health issues; i.e., uneven distribution of value, pressure on farmers, a decline in rural employment, poverty in rural areas, environmental degradation, increased risk of contamination, and nutrient deterioration in food products due to long supply chains.

On the other hand, "re-localization" or "short" VCs have emerged in the EU, supported by rural development policies. These chains prioritize cooperation, local development, and close relations between producers, processors, and consumers. Despite offering benefits like fair prices and social cohesion, they face challenges such as limited product range and volume. Small farmers also encounter issues with marketing, workforce, consumer accessibility, environmental optimisation, and policy barriers. Potentially, the concept of "intermediate" VCs forms blends aspects of short and long chains, promoting proximity and high-quality products while handling larger volumes.

But are these types of VCs performing better in every sustainability aspect? Which aspects are more key to enhancing sustainability in the coming decades and which ones are of less priority? To answer these questions, we studied five case studies of European dairy and vegetable value chains. In all these, there is a short or long VC already in place, an innovation is also piloted and tested to take these cases closer to an intermediate VC. Using life cycle assessment (LCA) in a multi-criteria decision analysis (MCDA) theme, we assess the sustainability of these current and innovative VCs to shed light on similarities and differences.

2. METHODS

In the European research project, FAIRCHAIN, LCA was practised for all five cases (e.g., in Le Féon et al., (2023), Le Féon et al., (2023b) and (LE FEON et al., 2023)) to assess the environmental impacts of the innovative VCs in comparison with the baseline scenarios, i.e, the current VCs with no innovations. Then we used these LCA results to feed an MCDA method that we developed to assess the overall sustainability performance of these innovative VCs. Since the cases varied, different sets of sustainability indicators were required to address all key aspects, encompassing environmental, social, and economic considerations. We identified these for all cases, suggesting common LCA environmental impact categories were insufficient as they fail to consider e.g., biodiversity loss potential or animal welfare. We thus made new environmental impact categories for different cases. A food FVC includes all stakeholders involved in the production and value-adding activities to produce a certain food product (Rad and Sonesson, 2024). We, therefore, assigned weights for all these indicators on a case-by-case basis and in a participatory approach, engaging people from the research and practice side of the innovations. Similarly, we assigned sustainability scores to indicators in both baseline and innovative value chains. Finally, we fed all these to an MCDA-based method, called DEXi, to assess the sustainability of the cases in all scenarios.

3. RESULTS AND DISCUSSION

This is an ongoing project, and the results are not final yet. However, the tentative results show that the innovation in all cases performs comparatively better than the baseline in general, although it performs worse in some indicators, most dominantly water use, energy use, and toxicity. Moreover, the inadequacy of standard LCA environmental impact categories is evident as in some cases biodiversity loss potential and animal welfare proved more important and gained higher weights than other impact categories such as global warming potential and water use.

4. CONCLUSIONS

Considering all aspects of a system or value chain gives insights into the whole sustainability spectrum and is a way forward to use LCA results meaningfully to improve sustainability. Moreover, it is crucial to consider the environmental impact categories e.g., biodiversity loss potential, that are not normally included in LCA studies but can play a key role in the sustainability of an innovative VC. MCDA proved reliable and accessible to handle the objective conflicts among indicators.

5. ACKNOWLEDGEMENTS

This study is a part of the project FAIRCHAIN which is funded by the EU H2020 programme grant agreement 101000723. www.fairchain-h2020.eu

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A practitioner-driven methodological framework to assess the environmental, social and economic sustainability of regional food products

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1. INTRODUCTION

Consumers are increasingly turning towards more sustainable products and tend to associate regional production with greater sustainability. However, existing studies of regional food products rarely include all three dimensions of sustainability and tend to adopt qualitative methods [1]. The one-year DurAOP project aimed at developing a methodological framework to assess the sustainability of Protected Designation of Origin (PDO) labelled products, in close collaboration with PDO producer associations of Swiss cheese, bakery and *charcuterie* product varieties. The PDO certification ensures production within a geographical area, while preserving regional cultural aspects. Therefore, the project particularly focused on incorporating environmental as well as quantifiable social and economic sustainability issues into a holistic framework.

2. METHODS

The methodological framework was developed iteratively and collaboratively before testing its applicability on five PDO products. We first met with the project partners to better understand the product value chains and their expectations for the assessment framework. In parallel, we identified existing social and quantitative indicators in the literature. The selected indicators had to be relevant, practical and scientifically robust. Second, for each product we defined in collaboration with the project partners a reference scenario describing the most common production "types", and alternative scenarios, which, either, represented other types of actors or explored measures to improve one or several sustainability areas. Third, we collected data using tailored questionnaires and on-site interviews with producers identified by our partners. Data quality was verified through follow-up calls and cross-validation with experts and literature. Finally, to facilitate the interpretation of hotspot and trade-off analyses, we developed product-specific sustainability checklists that highlighted potential action levers for each partner.

3. RESULTS AND DISCUSSION

The methodological framework was successfully applied to five PDO products using primary data from 17 different producers, complemented with generic data. Seven environmental impact categories, six economic and seven social indicators were quantified from the agricultural production to the point of sale (Table 1). The environmental impact assessment followed the Swiss Agricultural Life Cycle Assessment (SALCA) methodology [2], whereas the social and economic impact assessments relied on simpler indicators, yet specific to actors along the value chain. Existing social LCA indicators and databases could indeed not reflect regional issues of a country like Switzerland, while typical life cycle costing (LCC) indicators lacked the granularity needed for the project. Finally, the framework accounted for the characteristics of specific types of products, while allowing a generalisation over a broad range of products. A key challenge was the vast data collection required to cover an extensive set of sustainability issues. This can partly be mitigated through streamlined data collection. However, building trust among producers is paramount to ensure their participation and a successful assessment.

4. CONCLUSIONS

The methodological framework developed within the DurAOP project proved useful to quantify the sustainability of three PDO product types, at product, organisational, and value-chain levels. The project highlighted the importance of frequent discussions to facilitate knowledge transfer from academia to practitioners. Clearly defining the goal and scope at the onset of the project, as well as timing partners' inputs were crucial to guarantee the work's scientific robustness.

5. ACKNOWLEDGEMENTS

This research was conducted in collaboration with : Association Suisse des produits AOP[1]/IGP[2], Interprofession du Gruyère AOP, Interprofession du Vacherin Fribourgeois AOP, Interprofession de la Cuchaule AOP, Interprofession de la Charcuterie AOP. The project was co-funded by the producer associations and the Canton de Fribourg's Economic Development Agency (PromFr).

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[1] *Appellation d'origine protégée* (PDO, in English) ; [2] *Indication géographique protégée* (Protected geographical indication)

[2] Nemecek, T., Roesch, A., Bystricky, M., Jeanneret, P., Lansche, J., Stüssi, M., & Gaillard, G. (2023). Swiss Agricultural Life Cycle Assessment: A method to assess the emissions and environmental impacts of agricultural systems and products. The International Journal of Life Cycle Assessment, 1-23.

Dimension	Indicators	Assessment level
Environmental	Climate change, biodiversity loss due to land use, water scarcity, non-renewable resource use, freshwater eutrophication, terrestrial acidification, freshwater ecotoxicity	Product
Economic	Profitability: return on capital; income per family work unit (only for agricultural production); gross operating margin Liquidity: Cash flow ratio; Dynamic gearing ratio Stability: Capitalisation ratio, Equity-to-fixed assets ratio	Organisational
Social	Working conditions: Workload, Potential labour deficit	Agricultural production, Processing stages
	Animal welfare: Level of adequacy with animal welfare housing criteria	Agricultural production stage
	Governance : Bargaining power, Food-miles	Value chain
	Cultural Heritage : Potential labour deficit	Agricultural production, Processing stages
	Contribution to the regional economy	Region

Environmental and Social Life Cycle Assessment of drinking water

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1. INTRODUCTION

Barcelona is characterized by a high consumption of bottled water (around 60 %) (Bartoll-Roca et al., 2021). The consumption of bottled water is responsible for the generation of a large amount of plastic waste, which is increasing exponentially on a global scale. Plastics production processes are responsible for non-renewable resources depletion and for the emissions of harmful pollutants (e.g. greenhouse gases, particulate matter) into the environment. Recently, the percentage of population that use domestic equipment for tap water treatment, such as reverse osmosis and activated carbon filter, is also increasing. In this context, the aim of this study was to compare the environmental, and social impacts associated with different drinking water choices in Barcelona (Catalonia, Spain), including tap water, bottled mineral water and tap water treated with domestic equipment (activated carbon filter and reverse osmosis system). To do this, the Environmental and Social Life Cycle Assessment tools (ELCA and SLCA, respectively) have been used.

2. METHODS

Barcelona has 3 water supply areas: 1) Llobregat area (around 16% of the water supply) receives water from the drinking water treatment plants located in Abrera, Sant Joan Despí, and the desalination plant; 2) Llobregat and Ter area (around 77% of the water supply) receives water from the three drinking water treatment plants in Llobregat and Ter basins, and the desalination plant; and 3) Ter area (around 7% of the water supply) receives water from the Cardedeu drinking water treatment plant. A cradle to gate environmental and social LCA (ISO, 2006, UNEP/SETAC, 2020) were carried out to assess the environmental and social impacts of different drinking water alternatives. The scenarios considered were: i) tap water, ii) tap water treated with domestic activated carbon filter, iii) tap water treated with domestic reverse osmosis, iv) bottled mineral water (PET bottle). The functional unit used was 1 L of water. For the ELCA, system boundaries accounted for input and output flows of material (mainly chemicals and materials for packaging) and energy resources (electricity). With regards to the SLCA, the following stakeholders were considered: workers, consumers, local community, value chain actors and society. Performance Reference Points were used to evaluate positive or negative social impacts (-2: no compliance with legal standards and worse performance; +2 ideal compliance and best performance).

3. RESULTS AND DISCUSSION

From an environmental point of view, results showed that the environmental impact of bottled mineral water were from 60 up to 4000 times higher than the other alternatives, depending on the impact categories and the water supply areas (Figure 1). It was mainly due to energy consumption, packaging and transportation associated with bottled water consumption. Moreover, the environmental impact of tap water treated with domestic equipment is from 2 to 10 times higher than tap water. With regards to social aspects, results showed that tap water had better social performance than bottled mineral water (Figure 2). However, domestic devices use does not improve the social performance of tap water.

4. CONCLUSIONS

The consumption of tap water is the most environmentally friendly alternative with the best social performance. The environmental impact of tap water treated with domestic devices is slightly higher that tap water, however, its social benefits are low. Bottled water, despite presenting a good social performance, is the alternative with the highest environmental impacts due to packaging and transportation.

5. ACKNOWLEDGEMENTS

This study has been funded by the Barcelona City Council and La Caixa Foundation (project BWater - 22S07285-001) in the frame of the Barcelona Science Plan 2020-2023.

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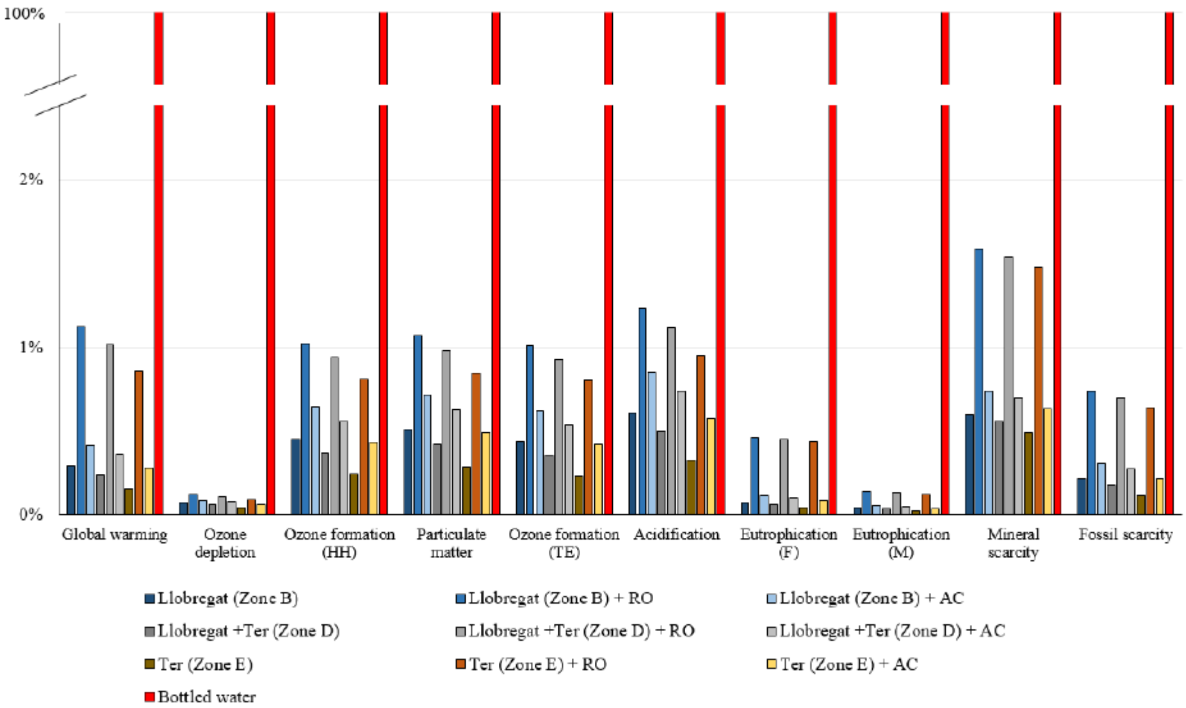

Figure 1. Environmental impacts of the different scenarios considered (FU: 1 L of water). Note: HH: Human Health; TE: Terrestrial Ecosystems; F: Freshwater; M: Marine; RO: reverse osmosis; AC: activated carbon

Stakeholder	Impact category	Impact subcategory	Indicator	TAP WATER		BOTTLED WATER	ACTIVATED CARBON DEVICE	REVERSE[3] OSMOSIS DEVICE
				Treatment	Distribution			
Workers	Health & Safety	-	Health & Safety performance	2	2	1	1	0
	Working conditions	Fair salary	Lowest salary compared to the living wage	-1	1	1	-2	-2
		Flexibility	Work-family balance	2	2	2	1	0
	Human Rights	Inclusion	Equal opportunities	1	2	1	-2	-1
		Gender equality	Women in managerial positions	0	1	1	-2	-2
		Gender discrimination	Gender wage gap	2	-1	-1	-2	-2
Consumers	Health & Safety	-	Product quality	2	2	2	0	2
		-	Health risk (trihalomethanes and nitrates)	0	0	1	0	1
	Human Rights	Water quality	Drinking water quality parameters	2	2	2	2	2
		Acceptance	Acceptance level	1	1	2	1	2
		Affordability	Drinking water cost compared to household income	2	2	2	2	2
	Governance	End-of-life responsibility	Waste hierarchy alignment	2	2	0	1	0
		Transparency	Presence of sustainability reports	2	2	1	-1	-2
Local Community	Governance	Access to material resources	Certified environmental management systems	2	1	-1	1	0
	Socio-economic repercussions	Local employment	Workforce hired locally	NA	NA	NA	NA	NA
		Local suppliers	Proportion of spending on locally based suppliers	2	1	NA	NA	NA
Value Chain Actors	Governance	Social Responsibility policies	Certifications and/or codes of conduct	1	2	1	1	-1
		Social Responsibility promotion	Audited suppliers	NA	2	NA	NA	NA
Society	Socio-economic repercussions	Technological development	Partnerships in research and development	2	2	-2	0	-2
		Education	Collaboration with educational centres	1	2	1	-2	-2
		Poverty alleviation	Formalized commitment to reduce poverty	-2	2	-1	0	-2

Table 1. Social impacts of the different scenarios considered.

Integration of agroecology and soil health in LCA

Enhancing Life Cycle Assessment Methods for Agroecological Systems: Insights from a UK Case Study

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1. INTRODUCTION

Life Cycle Assessment (LCA) methods are being increasingly used to assess the environmental impacts of agroecological production systems. As an alternative, impacts can be assessed at a farm level using holistic sustainability assessment tools. The purpose of this study was to evaluate whether an integrated approach combining a “detailed and narrow” LCA with a “broad and shallow” sustainability assessment could ensure that socioeconomic and ecosystem service evaluations are considered within LCAs of innovative and mainstream agroecological systems.

2. METHODS

An innovative case study farm (CSF) was compared with mainstream organic farming systems (MFS) using LCA and a farm-level sustainability assessment. The CSF is one of the UK’s original Community Supported Agriculture (CSA) projects (Ravenscroft et al., 2012) and combines a diversity of enterprises within an innovative governance structure. The MFS data was obtained from organic farms within the UK Farm Business Survey, farm management handbooks and through expert consultation (Smith et al., 2018). The functional units (FU) were 1 kg of bone-free meat, 1 kg of fresh tomatoes and 1 kg of fresh unwashed carrots purchased by the consumer. System boundaries were cradle-to-farm gate. In addition, whole farm sustainability assessments were carried out of for both the CSF and for 18 comparative MFS using the Public Goods Tool (PGT, Paraskevopoulou et al. 2020). Results from the LCAs and PGT evaluations were compared to reveal synergies and trade-offs.

3. RESULTS AND DISCUSSION

The climate impact of beef modelled to the farm gate was 20.67 kg CO2e kg LW-1 from the CSF compared to 14.56 kg CO2e kg LW-1 within the MFS (Table 1). Emissions for both systems were dominated by CH_4 from enteric fermentation. Methane and nitrous oxide emissions from cattle rearing and crop production were higher at the CSF but emissions from farm machinery operations were lower than within the MFS. Tomatoes and carrots from the CSF had a lower climate impact per kilogram (0.039 kg CO_2e kg^{-1} for carrots, less than half that of the comparative process; and 0.102 kg CO_2e kg^{-1} for tomatoes compared to 0.142 kg CO_2e kg^{-1} for the MFS). The main processes contributing to these differences were fuel combustion in farm machinery, lime application and diesel and electricity production. Per hectare, tomatoes had a slightly higher GWP than within MFS. Water consumption per kg of beef and carrots at the CSF was half that of the comparative system whilst water consumption was much higher than the MFS for tomatoes.

PGT assessment results for the CSF (Figure 1) show that the farm scored highly on the 'agricultural systems diversity', 'social capital', 'agri-environmental management', 'landscape and heritage' and 'farm business resilience' categories, when compared with the MSF. Lower scores for the CSF were found for the 'energy and carbon', 'water management' and 'animal health and welfare' categories, and MFS scores were more evenly distributed. The PGT assessment results broadly tie in with the main hotspots and areas for improvement that the LCA identified (e.g. water consumption and GHG emissions). However, depending on the output, LCA results tend to focus on negative externalities, rather than including positive impacts captured within the PGT e.g. regarding system diversity and social wellbeing (van der Werf et al., 2020). LCAs also generally exclude the semi-natural 'unproductive' parts of a farm such as hedgerows which are important for biodiversity aspects which are included in the 'landscape and heritage features' spur in the PGT.

4. CONCLUSION

Results from the CSF analysis highlight the link between environmental impacts and production efficiency with lower climate impacts strongly associated with higher outputs. This is less apparent when impacts are scaled to an area based functional unit. The PGT assessments provided context to the LCA results and explained the key trends observed across the product and farm types assessed, as well as revealing positive impacts of an innovative case study farming system, regarding landscape quality, social wellbeing, system diversity and the agri-environment. We conclude that multi-criteria assessment tools applied a farm level can complement the LCA results, to help reveal 'blind spots', whilst encouraging 'buy-in' from the farmer.

5. ACKNOWLEDGEMENTS

The author(s)/editor(s) acknowledge the financial support for this project provided by DEFRA and transnational funding bodies within the H2020 ERA-NETs SUSFOOD2 and CORE Organic Co-fund, under the Joint SUSFOOD2/CORE Organic Call 2019.

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Table 1: *Climate impact (CO_2 equivalent) modelled to the farm gate using IPCC (2019) methods from different products from the CSF and MSF sample*

GWP (kg CO_2e yr^{-1})

Functional Unit	Beef		Tomatoes		Carrots	
	CSF	MFS	CSF	MFS	CSF	MFS
Per kg product	*20.6*	14.5	0.10	*0.14*	0.04	*0.11*
Per ha land	*3,992*	2,833	*15,134*	14,720	1,583	*3,999*

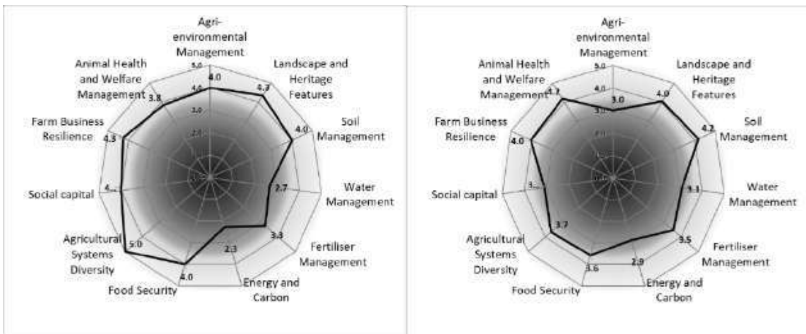

***Figure 1**: Radar diagrams showing the results of the Public Goods Assessment at (a) the CSF (year of assessment 2019) and (b) an average of the scores for the MFS sample (n= 18).*

Mapping a Path to Climate Neutrality for Nebraska Agriculture: Approach and Findings

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1. INTRODUCTION

The US state of Nebraska (NE) is largely defined by agriculture, representing 34% of the state's total economic output and 23% of employment. 92% of the state's total land area is in farms and ranches, and it ranks 2nd among US states in total cattle numbers, 3rd in maize production, 5th in soybean production, and 7th in total pig numbers. The state is also unique geographically, with more than 6 cm decrease in average annual precipitation every 100 km from east to west, along with a 1400 meter elevation gain, resulting in diverse farming conditions and a need for localized solutions for resilient agriculture. Estimates based on national inventory accounting approaches suggest that over 40% of the state's greenhouse gas (GHG) emissions are from agriculture (Holley & Liska, 2022). Given the state's unique relationship to agriculture, the Aksarben Foundation commissioned Resilient Services and Blonk Consultants to benchmark NE agriculture's total cradle-to-farm-gate GHG emissions from a LCA perspective, and to map pathways to a "climate neutral" agricultural sector, defined in this project as emission budgets corresponding to the goals of the Paris Agreement.

2. METHODS

Modeling focused on the top five commodities within NE – beef, maize, soybeans, pigs, and dairy – which collectively account for 95+% of total agricultural sales and 90+% of agricultural land occupation. US Dept. of Agriculture (USDA) statistics for 2018-2020 were used to define production volumes and key performance parameters per commodity and were supplemented with expert stakeholder input on common production practices within the state. Existing crop and livestock LCA models were adapted to implement life cycle inventories in SimaPro. Climate neutrality targets were defined by utilizing the GHG-specific reduction pathways outlined in the 2018 IPCC special report (IPCC, 2018), averaging the three social response scenarios to arrive at reductions per GHG species needed by 2030 (and 2050). These reductions were then applied to the NE agriculture baseline to establish climate neutrality targets. A wide suite of "reasonably achievable" intervention scenarios aimed at reducing GHGEs (assuming constant production volumes) were evaluated by commodity, considered individually against the baseline, and assumed to be additive. Economic and/or social/cultural barriers to adoption were not considered.

3. RESULTS AND DISCUSSION

Figure 1 summarizes the contribution by commodity to NE agriculture baseline (circa 2020 production) GHG emissions. Figure 1 also demonstrates the portion of field crops (maize, soy) attributable as feed inputs to the livestock commodities. Figure 2 summarizes the evaluated interventions, aggregated by commodity, offering conservative (low-range) and optimistic (high-range) scenarios. This demonstrates that optimistic scenario assumptions may produce sufficient emission reduction to meet the 2030 target, but more conservative assumptions fall short. Interventions with larger impact include: enteric methane inhibitors at beef feedlots, nitrification inhibitors in maize production, reducing diesel use in crop cultivation or shifts to renewable fuels, improving nitrogen use efficiency in maize production, and manure management changes in feeder pigs and dairy cows.

4. CONCLUSIONS

The overarching conclusion is that a near-term (2030) climate neutrality target is achievable with high adoption rates and effective implementation of a suite of technologies and management options for the five major commodities produced in Nebraska, but that maintaining the climate neutrality pathway in the longer-term (2050) is unlikely to be achievable with the current suite of technologies evaluated in this exercise.

5. ACKNOWLEDGEMENTS

We wish to acknowledge the Aksarben Foundation for providing funding for this project.

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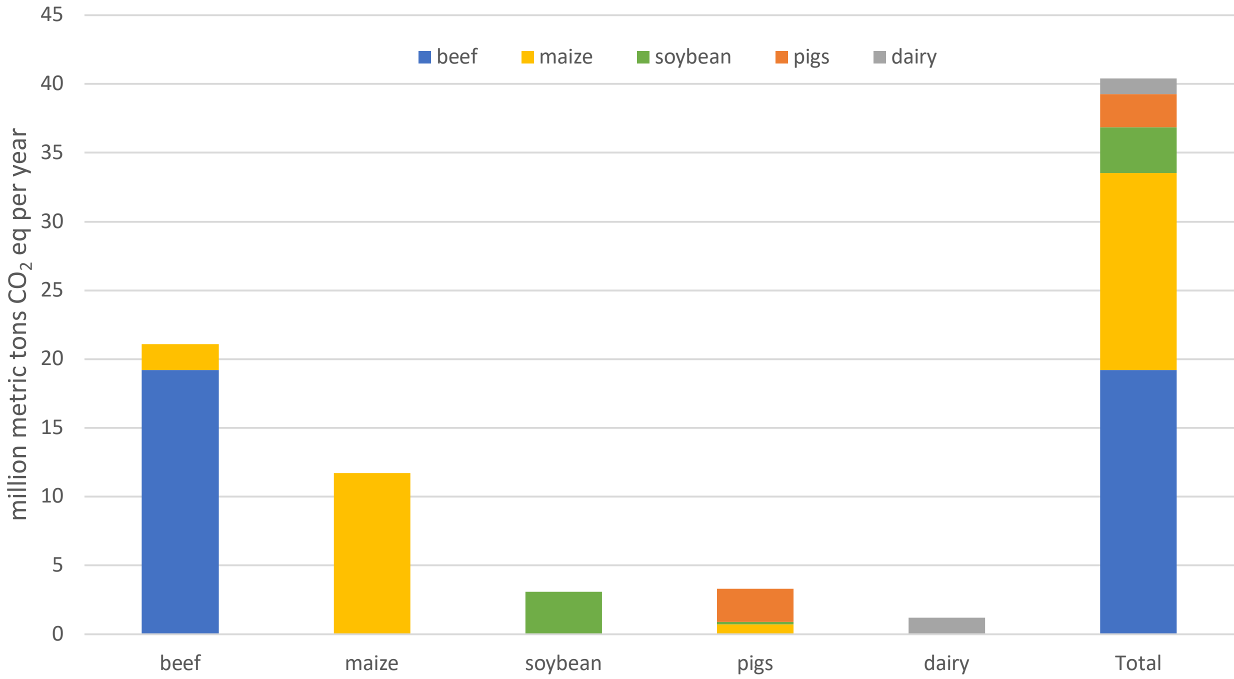

Figure 1. Baseline emission profile for Nebraska agriculture in 2020, showing total contributions by commodity.

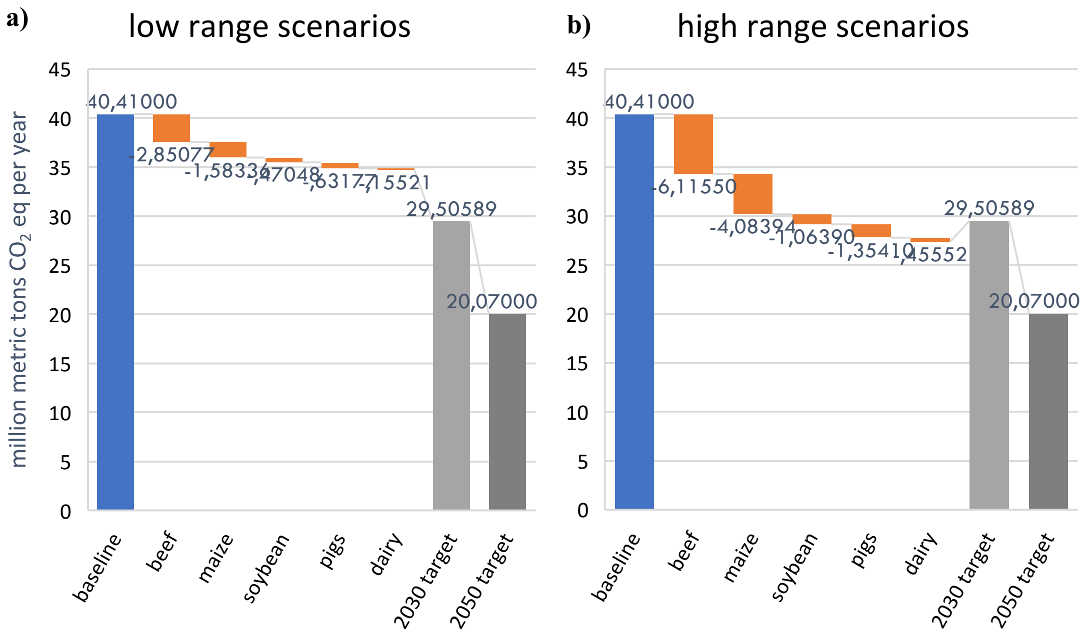

Figure 2. Emission Reduction pathways for Nebraska agriculture compared to 2030 and 2050 climate neutrality targets using a) conservative (low range) scenario assumptions and b) optimistic (high range) scenario assumptions.

Organic farming expansion: identifying areas optimal for achieving EU organic agriculture goals using spatial-explicit LCA modelling

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1. INTRODUCTION

Food production is responsible for various negative impacts on the environment, including 78% of the global ocean and freshwater eutrophication (Poore & Nemecek, 2018) and being the leading driver of biodiversity loss. Organic farming is considered a strategy to positively impact biodiversity, potentially reduce nutrient losses at large-scale adoption, and benefit soil quality parameters (Seufert & Ramankutty, 2017). Therefore, policy initiatives such as the European Green Deal's Farm to Fork strategy aim at increasing agricultural land managed under organic principles (European Commission, 2020). However, expanding organic agriculture could risk soil organic carbon stocks (Gaudaré et al., 2023), decrease yield per area and, consequently increase the greenhouse gas emissions related to the crops produced (Meier et al., 2015). These effects depend on the local conditions, such as specific agricultural management, availability of fertilizers, and soil properties. Therefore, the aim of this study was to identify areas in the EU where a transition to organic agriculture would be beneficial for the nutrient pools and fluxes without major yield reductions by comparing a business-as-usual (BAU) management with a scenario with an increased share of organic agriculture of 25% by 2030 using high resolution spatial biogeochemical modelling and a life cycle approach.

2. METHODS

The study uses the calibrated and tested spatially explicit process-based model DayCent (Muntwyler et al., 2023) as well as regionalized characterization factors (CF) for nitrogen (N) and phosphorus (P) impacts on freshwater fish biodiversity (Zhou et al., 2024) to assess the regions, where a transition to organic production would be favourable. The methodology for the target area criteria, model assumptions, and inventory comparison can be seen in Figure 1.

3. RESULTS AND DISCUSSION

The ban on synthetic fertilizers limited possible transitioning areas, with the resulting nutrient limitations having the highest impact on crop yield relative to the other assumptions. The modelled yield, nutrient, and SOC thresholds to define the target areas did not necessarily overlap, leading to trade-offs in some regions. For instance, areas benefitting from reduced nutrient surpluses also saw reduced SOC pools. Nevertheless, hotspot regions could be identified through the spatially explicit process-based model. The LCA approach using regionalized CFs supported assessing local impacts, where a transition from conventional to organic agriculture would be beneficial for reducing the nutrient loads to freshwaters and impacts on freshwater fish biodiversity.

4. CONCLUSIONS

The assessment method contributes to the broader understanding of the impacts of changed agricultural management and its effects on the nutrient pools and flows, the soil organic carbon stock, crop yields and their trade-offs. Finally, this work showcases a tool for assessing land management policy, which facilitates the projection of the local impacts of policy interventions, making a crucial step toward sustainable agriculture.

5. ACKNOWLEDGEMENTS

This research was supported by a Swiss National Science Foundation (SNSF) grant Sinergia programme (grant number CRSII5_202300) and the European Commission Joint Research Centre under the Collaborative Doctoral Partnerships.

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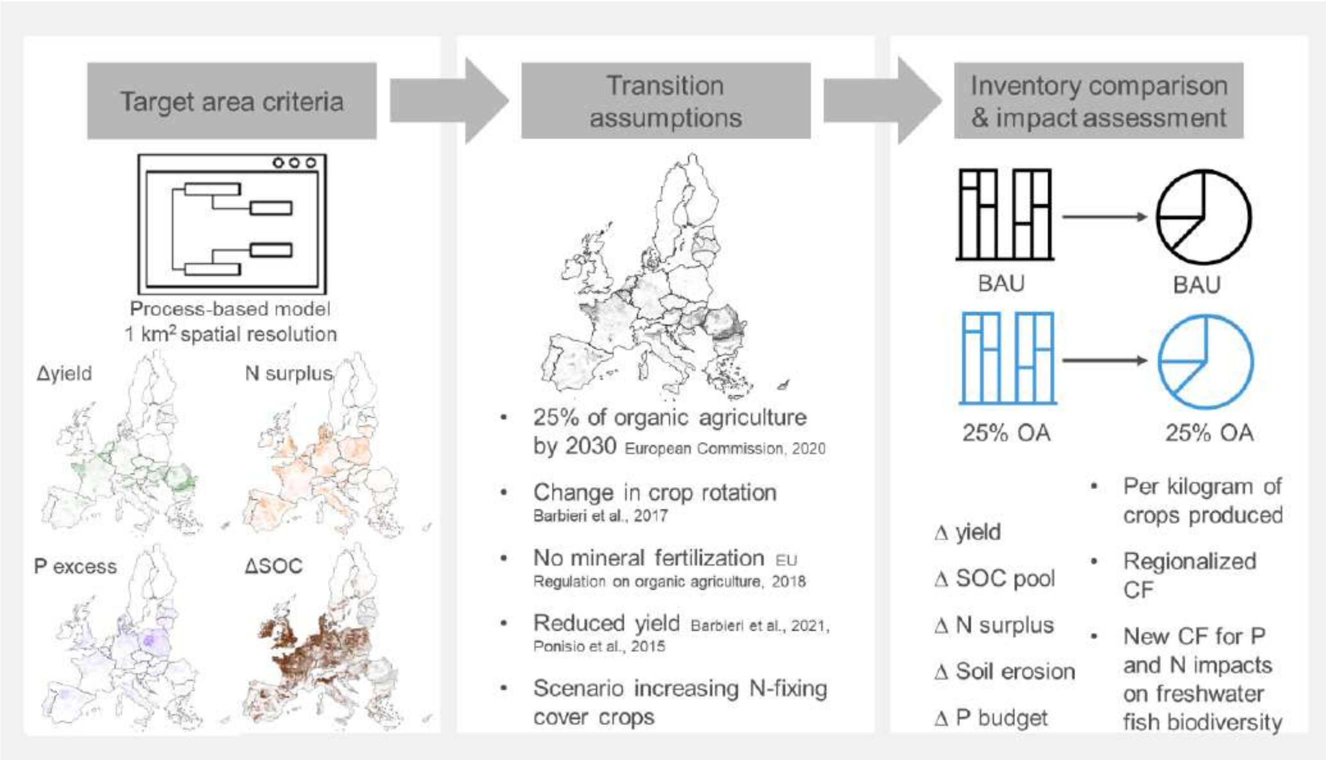

Figure 1: Flow chart detailing the methodological framework of this study, including the criteria for selecting the target area for transitioning to organic agriculture, the transition assumption, and the comparison of the business-as-usual (BAU) scenario with an increased organic agriculture scenario (25% OA) using a life cycle approach. The target area was determined by thresholds for yield reduction, nutrient surplus, SOC losses, and soil erosion based on the calibrated and tested process-based model DayCent at a spatial resolution of 1 km^2.

Combining LCA results and soil indicators for long-term decision making: a case study with Californian cotton

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1. INTRODUCTION

Companies purchasing agricultural products need to assess the environmental impact of products from different agricultural systems to inform purchasing decisions, direct reliable and traceable programs, and ultimately reduce their upstream footprint (Economist Impact 2023). Our client, a major cotton purchaser wants to compare the environmental impact of regenerative Californian cotton to conventional. Companies typically rely upon Life Cycle Assessment (LCA) results to aid environmental impact-based decision making, however this research showcases the importance of looking beyond the bounds of LCA to gain a more holistic and long-term view on ecosystem health.

2. METHODS

This comparative LCA on the two systems covers cradle-to-ginning-gate production, with a functional unit of 1 kg of cotton fiber, using the EF 3.1 impact assessment method with normalization and weighting to identify most relevant impact categories (European Commission 2021). Data is collected from a large-scale cotton farm in the San Joaquin valley (California) with conventional and pilot regenerative fields. To calculate soil organic carbon (SOC) stock, SOC% and bulk density were measured for each field. Additional indicators of aggregate stability, microbial activity, soil health and soil fertility (obtained with Haney Soil Health test (Haney et al. 2018)) give insight to the fields' resilience to climate change and overall ecosystem health. Several sensitivity analyses were performed which supplement and substantiate the discussion and conclusions. The study is undergoing review by an external panel and will be publicly available by September 2024.

3. RESULTS AND DISCUSSION

The Life Cycle Impact Assessment (LCIA) results indicate a significantly lower **carbon footprint** for the regenerative cotton. The differentiation mainly comes from the net-negative land use footprint driven by SOC stock change, whilst similar practices for the key drivers of biogenic and fossil impacts (synthetic pesticide and fertilizer usage) are relatively similar (Figure 1). The longevity of carbon storage is essential to maintain regenerative cotton's net-negative footprint, however it still (slightly) outperforms conventional when excluding the stored carbon, as the (non-negative) impacts of regenerative cotton are slightly lower. Looking at the **full environmental footprint**, the profile is relatively similar with key drivers across all impact categories being synthetic fertilizer and pesticide use (Figure 2). Freshwater ecotoxicity is identified as highly relevant for both systems, driven by just a few specific harmful active ingredients. For the **additional environmental indicators**, the regenerative fields outperform conventional in all, indicating improved climate resilience, water management, nutrient retention, soil health, soil fertility and biological activity (Table 1). This supplements the LCA results, providing separate evidence for the wider benefits of the regenerative system.

4. CONCLUSIONS

If sequestration is successful and maintained, regenerative cotton can serve as a net-carbon-negative material, significantly outperforming conventional. For regenerative agricultural systems to achieve a holistically beneficial environmental footprint with no trade-offs, targeted elimination of hazardous active ingredients is essential. Looking beyond LCA metrics shows that regenerative cotton displays remarkable promise within <4 years of implementing improved practices – it not only benefits soil stability, health, and fertility, enhances resilience to extreme weather events but also demonstrates the ability to maintain yield over time in the transition from conventional cultivation, contrary to common expectations.

Throughout the sustainable agriculture transition, it is crucial to support initiatives that simultaneously achieve reductions, sequester and store carbon and enhance ecosystem resilience. This research highlights how a combined approach spotlighting additional metrics is valuable for assessing long-term ecosystem health and resilience in sustainable agriculture transitions. Further research should investigate how to harmoniously integrate soil metrics with LCA to aid more straight forward decision making.

5. ACKNOWLEDGEMENTS

Rebecca Burgess from Fibershed for coordinating data collection with farmers

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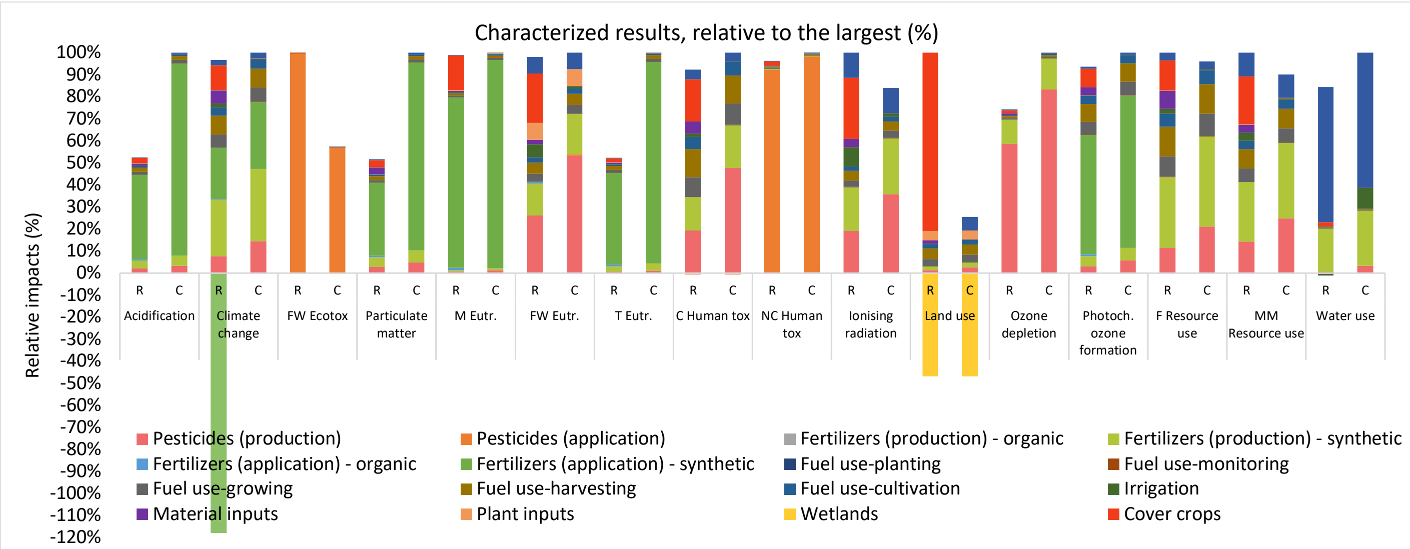

Figure 1. Characterized results, relative to the largest (%). R: regenerative field, C: Conventional field.

	Solvita SLAN (ppm)		Soil Health		Fertility Score	
	Conv	Regen	Conv	Regen	Conv	Regen
Average	29.4	78.7	16.3	20.8	73.0	81.2
Min	12.5	22.5	15	17	69	77
Max	40	152.5	17	28	77	89

Table 1. Key metrics from soil tests conducted on the conventional (conv) and regenerative (regen) fields from Haney tests conducted in 2023. For all tests, the higher score reflects a better result.

Evaluation of different fertilization scenarios in a vineyard integrating the LCA methodology and the RothC model to analyze carbon dynamics in soil

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1. INTRODUCTION

In 2015, the land-based sector (agriculture and associate land-use) was responsible for 71% of the greenhouse gas (GHGs) emissions originating from the food system, leading to a decrease in soil organic carbon and impacting crop nutrition and long-term soil capacity for sustaining ecosystem services[(1)]. To mitigate these effects, innovative products, like biochar, could be a solution allowing soil organic carbon storage and CO_2 removal[(2)]. This study examined the environmental performances of different soil amendments, implementing both the Rothamsted Carbon model (RothC)[(3)] and the Life Cycle Assessment (LCA) methodology.

2. METHODS

An experimental vineyard in Faenza, Italy, has been set with two amendment scenarios, biochar and compost, and a reference (without fertilization). Treatments were applied to three randomly selected replicates, each one of 15 plants. Biochar was applied only once in 2019 (18.2 t of dry matter ha^{-1}), while compost was applied yearly from 2019 to 2023 (13.7 t dry matter ha^{-1} on average). LCA system boundaries were set from cradle to farm-gate, functional unit (FU) was 100 kg of grapes harvested annually for 20 years. Primary data was used for biochar and compost production and transport, agricultural operations, and irrigation. The inventory of the biochar production process was divided by 20 years since it was applied just once. Background data was used for pesticides. The following impact assessment methods were chosen: EF 3.1 and IPCC AR6. The latter allowed to calculate the Climate Change projected over a 20-year time horizon, in line with the parameterization of the RothC model. This latter was calibrated based on five years of field experiments, while its validation is pending due to the experiment's need to reach a 10-year threshold[(4)].

3. RESULTS AND DISCUSSION

Table 1 shows the impact scores of the three scenarios. The best performances of reference, though not in all categories, are attributable to the absence of an amendment production process, although its annual production was the lowest one (Table 2). The biochar scenario stood out for its high values in several categories, primarily due to its outdated production process, which involved significant GHGs emissions. In contrast, the compost production process was modern and utilized biofilters, ensuring lower impacts. The curves resulting from RothC model, in Figure 1, showed, for the biochar, an initial increment of the total organic carbon (TOC) ha^{-1}, followed by a decrease, due to a slow degradation of biochar C in soil[5]. Compost, instead, displayed regular peaks due to its annual application. Taking into consideration the net carbon removal (obtained by subtracting soil TOC, counted as CO_2, from GHGs emissions), as mentioned by the European Commission[6], the biochar scenario could potentially remove a total of 168 kg CO_2/UF, while the compost 206 kg CO_2/UF (Table 2).

4. CONCLUSIONS

The study shows that the combination of LCA with the RothC model allows a more precise assessment of CO_2-eq emissions during viticultural practices. The combination considers practices like amendment, pruning and tillage, commonly overlooked in GWP calculations as potential carbon inputs to the soil. Discrepancies between Climate Change impact scores and actual CO2-eq. emissions underline the usefulness of this approach for a more accurate quantification. These initial results revealed varying impacts among amendments, however, ongoing adjustments to both models aim to enhance accuracy.

5. ACKNOWLEDGEMENTS

This study was funded by the Emilia-Romagna region, Italy, within the PSR 2014-2020 project: “ENOCHAR” and by the MUR within the PRIN2020 project: “BIO-C-VITE”.

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Table 1 – LCA impact scores (FU: 100 kg of grape harvested annually for 20 years).

EF 3.1	Reference	Biochar	Compost	Max Value	Min Value
Acidification	7.88E-02	1.88E-01	3.05E-01	Compost	Reference
Climate Change, total (GWP 100)	6.22E+00	1.07E+01	7.30E+00	Biochar	Reference
Climate Change, biogenic (GWP 100)	1.61E-02	5.24E+00	3.12E-02	Biochar	Reference
Ecotoxicity, freshwater - total	5.87E+01	1.01E+02	9.39E+01	Biochar	Reference
Eutrophication, freshwater	2.20E-05	1.91E-05	3.21E-05	Compost	Biochar
Eutrophication, marine	3.94E-02	3.75E-02	4.05E-02	Compost	Biochar
Eutrophication, terrestrial	4.33E-01	8.92E-01	1.28E+00	Compost	Reference
Human toxicity, cancer - total	1.22E-09	4.05E-07	2.10E-09	Biochar	Reference
Human toxicity, non-cancer - total	5.34E-08	6.06E-07	7.48E-08	Biochar	Reference
Ionising radiation, human health	2.30E-02	2.00E-02	1.63E-01	Compost	Biochar
Land Use	3.42E+01	2.97E+01	4.01E+01	Compost	Biochar
Ozone depletion	7.95E-13	6.91E-13	2.39E-09	Compost	Biochar
Particulate matter	1.42E-06	5.08E-05	2.78E-06	Biochar	Reference
Photochemical ozone formation, human health	1.11E-01	3.13E-01	9.87E-02	Biochar	Compost
Resource use, fossils	8.14E+01	7.07E+01	1.18E+02	Compost	Biochar
Resource use, mineral and metals	4.71E-07	4.09E-07	2.60E-04	Compost	Biochar
Water use	7.79E-02	6.76E-02	4.61E-01	Compost	Biochar
IPCC AR6					
Climate Change (GWP 20), excluding biogenic CO_2	6.61E+00	2.13E+01	7.94E+00	Biochar	Reference
Climate Change (GWP 20), including biogenic CO_2	6.45E+00	2.67E+01	7.80E+00	Biochar	Reference

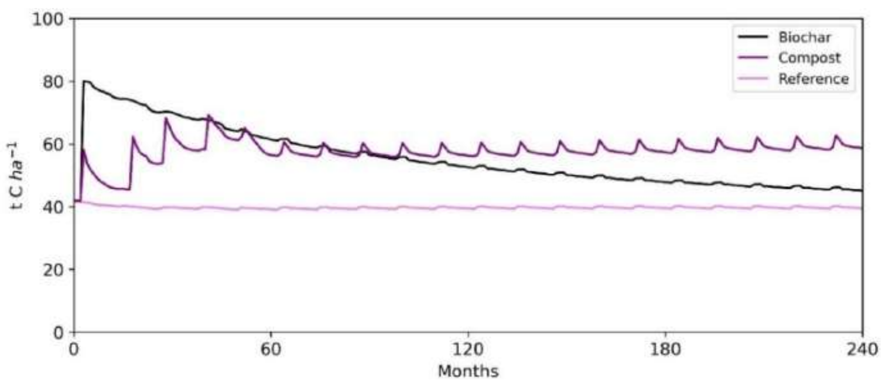

Figure 1- Total Organic Carbon (tons C ha^{-1}) stored by the soil along a future timeframe of a 20 years. Graph obtained with RothC output values.

Table 2 – Annual Net Carbon Removal calculation.

	unit	Reference	Biochar	Compost
Carbon Removal $_{Reference}$ – Carbon Removal $_{Soil\ amended}$	t C/ha/y	0.00	9.50	10.7
Grape production (yield)	t/ha/y	15.4	17.9	18.4
Carbon Removal as TOC / FU	kg C / FU	0.00	53.1	58.3
Carbon Removal converted from TOC to CO_2 / FU	kg CO_2 / FU	0.00	195	214
GHGs emissions (GWP 20, including biogenic CO_2) / FU	kg CO_2-eq.	6.45	26.7	7.80
Net Carbon Removal		**-6.45**	**168**	**206**

Climate change impacts of organic crops in Canada

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1. INTRODUCTION

Organic farming and regenerative agriculture are often promoted as a climate change mitigation alternative to conventional production systems due to claims of superior soil carbon sequestration in these systems; however, these claims often ignore the life cycle impacts and fail to account for greenhouse gas emissions from agriculture. Organic production is a fast-growing agricultural sub-sector in Canada, but there are few life cycle assessment (LCA) studies that quantify the performance of organic crops, particularly using field data and considering regionally-specific production conditions. This study characterize the life cycle environmental impacts for organic crops in Eastern Canada, including both emissions and soil carbon sequestration. It provides new insights into organic production impacts, and through a hotspot analysis, identifies practices that could reduce impacts.

2. METHODS

We collected data from organic producers for 12 farms in Ontario (ON) and 6 in Quebec (QC), two Eastern Canadian provinces. The farms produced multiple crops, yielding a total of 33 farm-crop datasets for wheat, corn, and soybeans. The boundary was cradle-to-harvest gate, and the functional unit was 1 tonne of crop harvested. Emissions from N application were estimated using the Intergovernmental Panel on Climate Change (IPCC) Tier 2 methodology for agriculture, forestry, and other land use (IPCC, 2006). Changes in soil organic carbon (SOC) were modeled using Holos software based on local agro-climatic conditions (Agriculture and Agri-Food Canada, 2022). IMPACT World+ method was used with Canadian-specific modelling resolution from LUCAS (Bulle et al., 2007).'

3. RESULTS AND DISCUSSION

Average climate change (CC) impacts were 160 and 1200 kg CO_2eq/t wheat, in ON and QC, respectively (Figure 1). SOC change was greater in QC than ON (-660 vs -370 kg CO_2eq/t wheat) but nitrous oxide emissions were very high in QC due to manure application in excess of crop needs. Average CC impacts for corn were 250 and 130 kg CO_2eq/t corn, in ON and QC, respectively, with SOC rates of -110 and -230 kg CO2eq/t corn, respectively. Net CC impacts were 180 and 51 kg CO_2eq/ t soybean, with SOC rates of -270 and -190 kg CO_2eq/t soybean, in ON and QC, respectively. In all cases, field-level N emissions from nutrient application were the biggest contributor to environmental impacts (Figure 1). Notably, while there was soil carbon sequestration in all crops, it did not offset the life cycle emissions of the crops.

4. CONCLUSIONS

This LCA study of organic agriculture in Canada, the first to use farmer data and regionalized emission quantification, suggests that organic farming may not have the climate change mitigation benefits that are claimed. In one case in QC, manure was applied at high rates, because of its carbon content, resulting in high nitrous oxide emissions due to N in the manure, which was in excess of crop needs. The strong narrative on soil carbon sequestration in organic systems may be resulting in trade-offs due to other emissions not being accounted for. We will present additional impacts and data for Western Canada.

5. ACKNOWLEDGEMENTS

The authors acknowledge funding for the Organic Science Cluster III, a joint initiative led by the Organic Federation of Canada in collaboration with the Organic Agriculture Centre of Canada at Dalhousie University.

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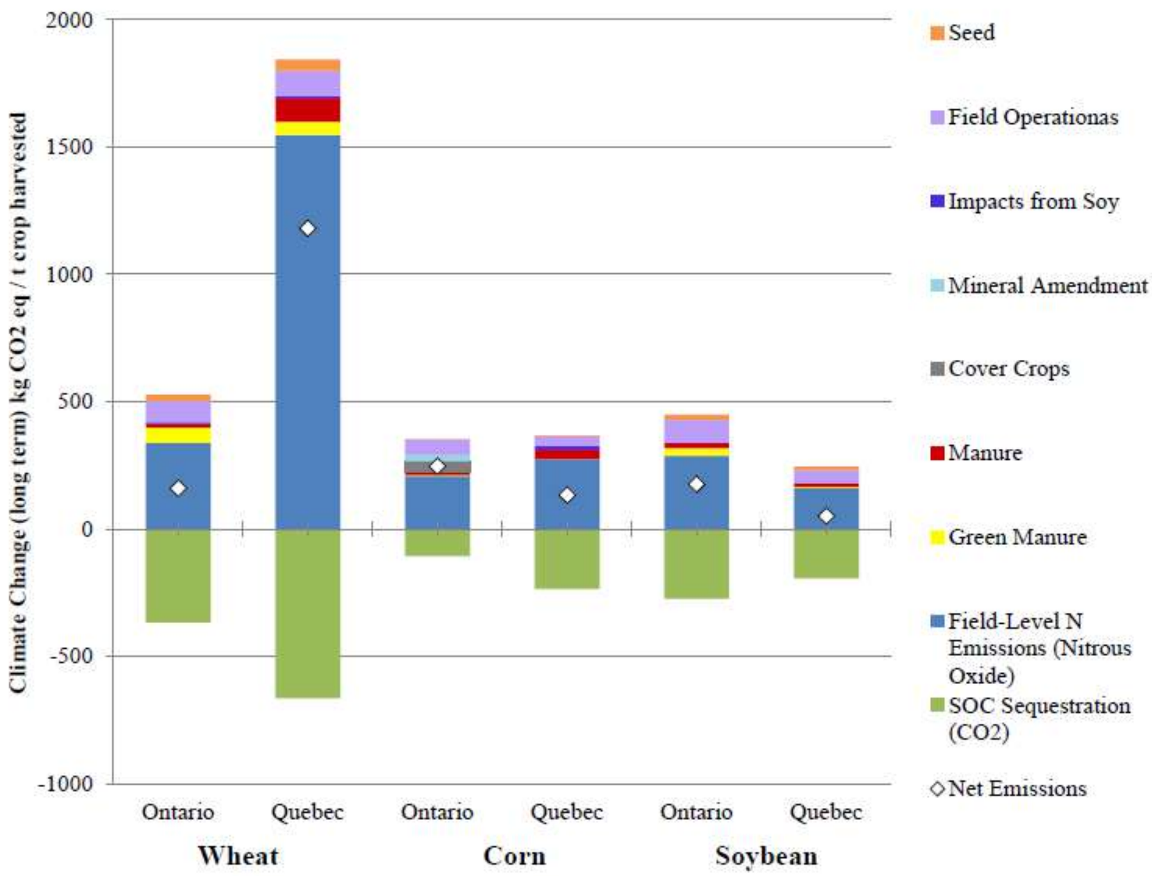

Figure 1: Cradle-to-harvest gate emissions associated with the production of 1 t of crop harvested of organic wheat, corn, and soybean in Ontario and Quebec. “Field Operations” include combine harvesting, sowing, fertilizing, rotary harrowing, rolling, offset disc harrowing, ploughing, cultivating chiseling, spring tine harrowing, hoeing, and currying (by weeder). “Field-Level N Emissions (Nitrous Oxide) refers to the Direct and indirect emissions arising from N application (i.e. nitrous oxide, ammonia, nitrogen oxide, and nitrate). “Impacts from Soy” refer to the life cycle environmental impacts allocated to the subsequent crop in a rotation. “Manure” refers to the fertilizer production and transportation of N, P, and K nutrients. “Mineral Amendments” refers to extraction and transportation of mineral amendment application. “Cover Crops” and “Green Manures” refer to the impacts associated with growing and incorporating such crops. “Seed” refers to the activities associated with producing seeds upstream. “SOC Sequestration (CO2)” refers to the net negative change in the soil carbon, reported as CO2. “Net Emissions” refers to the difference between environmental impacts and SOC sequestration.

Sustainability in fisheries and aquaculture systems

12

Building Life Cycle Inventories of IUU tuna fishing activities in the Peruvian EEZ using remote sensing techniques

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1. INTRODUCTION

Domestic Peruvian seafood consumption relies on ca. 80% of the artisanal fisheries catches (Ipsos Perú, 2022). However, the sustainability of these stocks is jeopardized by illegal, unreported and unregulated (IUU) fishing activities performed by national and foreign vessels. In 2015, the Peruvian Ministry of Production authorized foreign vessels to seasonally fish for tuna within the Peruvian Exclusive Economic Zone (EEZ), a decision contested by Peruvian fishermen whom disagreed with the policy. In recent years, IUU fishing activities by foreign flag vessels have been detected using satellite-sourced information, which can aid in estimating ecological indicators and law enforcement (Longépé et al., 2018). Hence, this study aims to provide a methodological approach using satellite-sourced information to generate a life cycle inventory (LCI) of IUU tuna caught by foreign vessels, either through unauthorized presence or exceeding seasonal permits. Fuel consumption was quantified using a machine learning (ML) model, analyzing cross-national fishing efforts and evaluating the environmental impacts to complement seafood-related Life Cycle Assessment studies.

2. METHODS

Tuna fishing within the Peruvian EEZ by artisanal and industrial vessels was examined to understand the dynamics of its value chain and the behavioural fishing patterns of foreign vessels. Our study integrates satellite-based technologies using tracking data (automatic-identification-system, AIS and vessel-monitoring-system, VMS), along with satellite imaging products to reconstruct tracks (Paulino et al., 2017). Historical fishing activities and fuel consumption registries were used as a proxy for ML-based primary data of the vessel. Tracks were used for measuring apparent fishing efforts and matching satellite-sourced information with the authorized list for 2022. Compliance with the obligation to return a third of their catch to Peruvian ports (or refund the monetary value) was not assessed for international port landings.

An LCI was constructed based on foreign fishing efforts with primary data build with geolocation registries categorized by hull capacity to mitigate variability between fishing gear (Avadí et al., 2015). Correction factors for bycatch and bait usage were also considered. Regarding assessment methods, the study focused on global warming, depletion of targeted biotic resources, and plastic emissions. Characterization factors for resource depletion and physical effects on biota were applied (Hélias et al., 2023; Corella-Puertas et al., 2023).

3. RESULTS AND DISCUSSION

A total of 81 foreign vessels, mainly from Ecuador (30) entered the Peruvian EEZ to target tuna fisheries without permits in 2022. Of these, 62 were identified, whereas 19 remained unidentified despite detection through tracking system. This contrasts with 60 authorized tuna vessels from Ecuador (50), Panama (7), USA (2) and El Salvador (1). Unauthorized vessels contributed 12,375 hours of fishing effort, 28% higher than authorized foreign vessels. Early fuel estimation results, aligned with the analysis of vessel main resource expenses, indicate that fuel consumption and cooling agents are major contributors to global warming potential. Notably, only 9 of the authorized vessels reported landing at Peruvian ports after seasonal passes, highlighting the uncertainty behind controlling the tuna stock declared. Additionally, ocean-based plastic emissions by foreign fleets within the Peruvian EEZ pose unaccounted potential environmental damage to marine biota and pelagic and coastal ecosystems.

4. CONCLUSIONS

This study presents a novel approach to acquiring remote data to estimate environmental burdens related to IUU-fished tuna stocks in a national EEZ by foreign vessels. Despite uncertainties in detailed fuel consumption modelling, the satellite-based systems provide an acceptable benchmark to complement purse seine inputs estimation.

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How do illegal, unreported, and unregulated (IUU) fishing activities influence Life Cycle Assessment results?

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Keywords: fishing stock; industrial ecology; sustainable fisheries.

1. INTRODUCTION

Illegal, unreported, and unregulated (IUU) fishing is a major environmental concern in the fishing industry, due to the high amounts of landings they represent on an annual basis (Park et al., 2023). IUU fishing can occur within national Exclusive Economic Zones (EEZs), but also in the high seas, where governance and surveillance measures are more challenging to enforce. For the latter, different national authorities have reported increasing densities of foreign fishing vessels in the vicinity of their EEZs, extending beyond their legal territory, but affecting fishing stocks and migration patterns. Despite their significant contribution, quantified at approximately one fifth of worldwide landings (Agnew et al., 2009), IUU landings remain unexplored in Life Cycle Assessment (LCA) studies, which usually focus on reported landings of industrial fisheries (Ruiz-Salmón et al., 2021). Hence, the main objective of the study is to provide a critical assessment of how IUU fishing is currently affecting the way in which seafood related LCA studies are reporting their results, and how these may be underestimated in many cases. For this, a series of specific case studies identified within and beyond the Peruvian EEZ have been used to exemplify the potential environmental damages that have been overlooked.

2. METHODS

The fishing sector in Peru was analysed in detail to understand the main fisheries and the fishing fleets that target them. Automatic identification system (AIS) and vessel monitoring system (VMS) were used to identify fishing vessel behaviours within the Peruvian EEZ and in the first few miles beyond national waters. Two different behavioural patterns were identified for year 2021. First, foreign vessels, mainly from Ecuador, entering the Peruvian EEZ to target tuna fisheries in national waters without fishing permits or extending permits irregularly. Second, a diverse fleet of vessels from various nations, mainly China, operating along the border of the Peruvian EEZ, primarily targeting giant squid (*Dosidicus gigas*) stocks. Although usually beyond the EEZ, some activity within the EEZ was detected. Once the behaviour of these vessels was identified, an effort to build an associated Life Cycle Inventory was performed. Unlike regular LCIs, which are built through questionnaires and interviews with fishermen and other stakeholders, data from the AIS and VMS were extracted to determine the pathways and fishing effort of the vessels. Based on their characteristics and vessel dimensions, diesel consumption of these vessels was estimated. Other elements of the vessels, such as fishing gear, hull design, or cooling agents, were modelled using vessel attributes. Finally, the amount of captured stock was modelled by considering the minimum economic profitability thresholds of the vessels. In terms of assessment methods, global warming, depletion of biotic resources, and plastic emissions were the main focus. For resource depletion, the characterization factors (CFs) presented by Hélias et al. (2023) were applied, whereas for plastic emissions, the CFs for physical effects on biota were used (Corella-Puertas et al., 2023).

3. RESULTS AND DISCUSSION

Results show that greenhouse gas emissions (GHG) from furl combustion and the use of cooling agents are an important source of environmental impacts in these vessels, in line with other industrial fisheries. Moreover, the giant squid fishery relies on supply ships for refurbishment, maintenance, and transportation of landings back to port, usually in China, implying that the related GHG emissions can represent an important fraction of the impact. In terms of resource depletion, results are two-fold. First, the catches of IUU fleets increase the fishing pressure over the targeted fisheries. Second, CFs applied could be potentially recalculated to account for the additional pressure. Finally, plastic emissions in the high seas represent an important risk to marine biota, being the main direct source of macro- and microplastics in international waters regardless of other sources arriving from ocean circulation currents.

4. CONCLUSIONS

The study represents a first attempt in LCA to calculate the environmental impacts derived from IUU fishing activities. Although uncertainties remain high, it provides interesting insights and quantitative trends of how IUU is affecting the fishing sector in terms of environmental damage.

5. ACKNOWLEDGEMENTS

The authors thank the DFI at the *Pontificia Universidad Católica del Perú* for funding project PI0859.

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BASES: a biophysical assessment framework for valuating ecosystem services

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1. INTRODUCTION

Following the Millennium Ecosystem Assessment in 2005, ecosystem services (ES) became a prominent research area with various conceptual frameworks and emerging typologies. Quantifying ES has led to two main trends: one focusing on economic and sociological aspects to assign economic values, and another centred on ecological, environmental, and agronomic processes, employing biophysical approaches. The BASES method, developed in this context, utilizes a biophysical approach by combining Life Cycle Assessment (LCA), Emergy accounting (EA, Odum, 1996) frameworks, to contrast ES and environmental impacts of an agriculture production. To showcase BASES' potential, it was applied to freshwater ponds, considered between natural and fully managed ecosystems.

2. METHODS

BASES, combining Life Cycle Assessment (LCA) and Emergy accounting (EA) frameworks, follows the four steps of LCA as guidelines. It evaluates the environmental work required for ecosystem services (ES) provision and the potential impacts induced. The functional unit is 1 kg of fish produced per cycle and fish production cycle was chosen as the temporal boundaries and the background boundaries of the pond systems included inputs from the ecosphere (sun, wind …) and from the technosphere (fuel, fertilizers, fingerlings). Background data utilized ecoinvent v3.8 and Agribalyse v3.1 databases, and impact assessment followed CML 2 baseline as implemented in Simapro 9.5. Quantitative indicators linked to ES were defined based on CICES hierarchical classification and aggregated using a weighted framework (Bohanec, 2020).. Commercial ponds in France's major fishpond areas (Brenne, Lorraine, Dombes) were selected to capture management practices and pedoclimatic influences on fish and ES production.

3. RESULTS AND DISCUSSION

Figure 1 indicates the scoring pattern for LCA, EA and ES assessment. Only climate change (GW) and regulation services (SR) have similar pattern. Else, no common pattern seems to emerge between Supply services (SA), Support Services (SS), and EA and LCA indicator values. In the fish ponds without feed and fertilization practices (L01, L03, L04), we can observe a good score for global warming potential (GW) and eutrophication per kg of fish produced, while the ponds with intensive practices display higher environmental impacts despite the increase in fish production. In term of EA performances, the results are more contrasted. L01 has the best results while L04 shows very contrasted results (1 and 4 scores) indicated that the fish production relies strongly on the environment (%Renewability), but is not efficient to transform environmental fluxes into fish production (Transformity=1). Conversely, intensive ponds seem to depend very little from the ecosphere to produce fish. In term of ecosystems services, there are no correlation among ES scores and each ponds has its own ES pattern. Nevertheless, it is interesting to note that the ponds with the best scores using the LCA method do not reach the best scores for the SE and EA indicators.

4. CONCLUSIONS

The BASES method makes it possible to assess both the ecosystem services provided and the impacts generated by fish production and displays a broader vision to analyse the trade-offs and synergies of practices. BASES can help to promote practices that enhance ES while reducing environmental impacts. Nevertheless, further studies are needed to analyse the correlation between services and impacts in more detail.

5. ACKNOWLEDGEMENTS

The results reported in this article were obtained in the “SEPURE” project, funded by the FEAMP. The authors are very grateful to the partners and the commercial fish farms involved in the project.

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		L01	L03	L04	D01	D02	D03	D04	B01	B02
ACV	ACD	2	4	1	1	4	1	3	2	2
	EUT	4	4	4	1	1	1	3	2	3
	GW	3	4	4	1	2	1	2	4	1
	LC	2	2	1	1	3	1	4	2	3
	CED	2	4	1	1	4	1	4	2	2
	NPPU	3	3	3	1	1	2	3	2	3
	WD	4	4	3	2	2	1	4	1	1
EMERGY	T	4	2	1	3	1	3	1	3	2
	% R	3	3	4	1	3	1	2	1	2
	EYR	2	1	4	3	3	2	1	1	3
	EIR	3	2	1	4	2	4	3	4	3
	ELR	3	2	1	4	2	4	3	4	3
	ESI	2	3	4	2	3	1	1	1	3
	EI	3	1	1	2	1	4	3	3	2
SE	SA	1	3	2	3	2	4	5	4	2
	SR	4	4	4	2	3	2	3	5	2
	SS	4	2	2	4	2	4	3	3	4

Figure 1. Pattern of qualitative indicator results from the BASES method. The ES indicators were aggregated into a global ecosystem service score using the DEXi method). The qualitative results were calculated using the quantile method (1 represents the lowest score for the environment and 4 the highest score. The darker the colour, the greater the negative impact on the environment.) SA: supply services, SR: regulation services, SS: support services

A Novel Approach to including Ecosystem-Scale biodiversity Impacts of Wild Capture Fisheries in Life Cycle Impact Assessment

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1. INTRODUCTION

Wild-capture marine fisheries are a crucial source of protein[1,2] and wider nutritional value in the human diet (*eg. Omega-3 fatty acids, vitamins, minerals and amino acids)* as well as providing a significant portion to aquaculture feedstock[3], playing a key role in current and future global food security.

Under increasing pressure from growth and development of the human population, over-exploitation of marine organisms is driving global marine biodiversity loss; with far-reaching impacts beyond exploited stocks, on the surrounding ecosystem.

Fisheries impacts on Ecosystem Quality is a newly established Lifecycle Impact Assessment (LCIA) endpoint impact pathway[4,5], quantifying direct removal of biomass from a target population (species scale). A novel approach to fisheries impact quantification is now proposed, to elevate this assessment to the ecosystem scale and take into account both direct (fishing) and indirect (trophic interactions) impacts.

2. METHODS

Dynamic ecosystem modelling defining Species Sensitivity Distributions (SSD) derive novel Characterisation Factors (CF) capturing ecosystem scale impacts per exploited target catch. The CF is based on the ecotoxicity impact pathway and USEtox© approach[6]. Typical species-specific Effect-Concentration curves are replaced by Depletion-Catch curves per exploited stock/Functional group (*substance equivalent*). This relationship is simulated using the mass-balanced, trophic model Ecopath with Ecosim [8], then used to construct SSDs (Figure 1) and derive a PAF (Potentially Affected Fraction) value per target catch.

A species-specific threshold defines the point at which a population is considered affected (EC20 in ecotoxicity)[7]. For fisheries, this threshold is defined according to a simulated pristine condition. To consider ecosystem dynamics, it is pertinent to account for both depletion and expansion of species, resulting from changing pressure from higher trophic levels. A dual threshold is therefore introduced, to capture biomass variations of +/-10% from the reference pristine state.

The CF in PAF units is computed from the SSD[9], using marginal and average approaches, applying a current fishing mortality value as the "affected" threshold (Figure 1).

Results use FAO (2018) catch data[10], for 194 species exploited in the Adriatic Sea, with biomasses estimated following the approach proposed by Helias et al. (2023), literature-based estimates for non-exploited organisms and satellite-derived primary production estimates. Organisms are categorised into Functional Groups (41) based on functional characteristics (habitat, size class, feeding regime)[11].

3. RESULTS AND DISCUSSION

The results give regionalised midpoint CFs for 26 exploited Functional Groups (Marginal CF range: 7.4×10^{-8}-8.4×10^{-2} PAF.yr.tonne^{-1}, median: 2.55×10^{-4} PAF.yr.tonne^{-1}), as a proof of concept consolidating the approach, as a precursor for regionalised, global application.

The initial categorisation by Functional Group allows inference of additional information on functional biodiversity loss, representing species that occupy a similar ecological niche. Potential links between the magnitude of CFs and Trophic Level are also explored.

4. CONCLUSIONS

This novel method of fisheries impact assessment considers ecosystem dynamics and both positive and negative biomass variations as impacts, whilst operating at an ecosystem scale. The scope of fisheries induced biodiversity damage assessment in LCIA continues to improve, providing a more holistic quantification to better inform future decision-making for fisheries resources.

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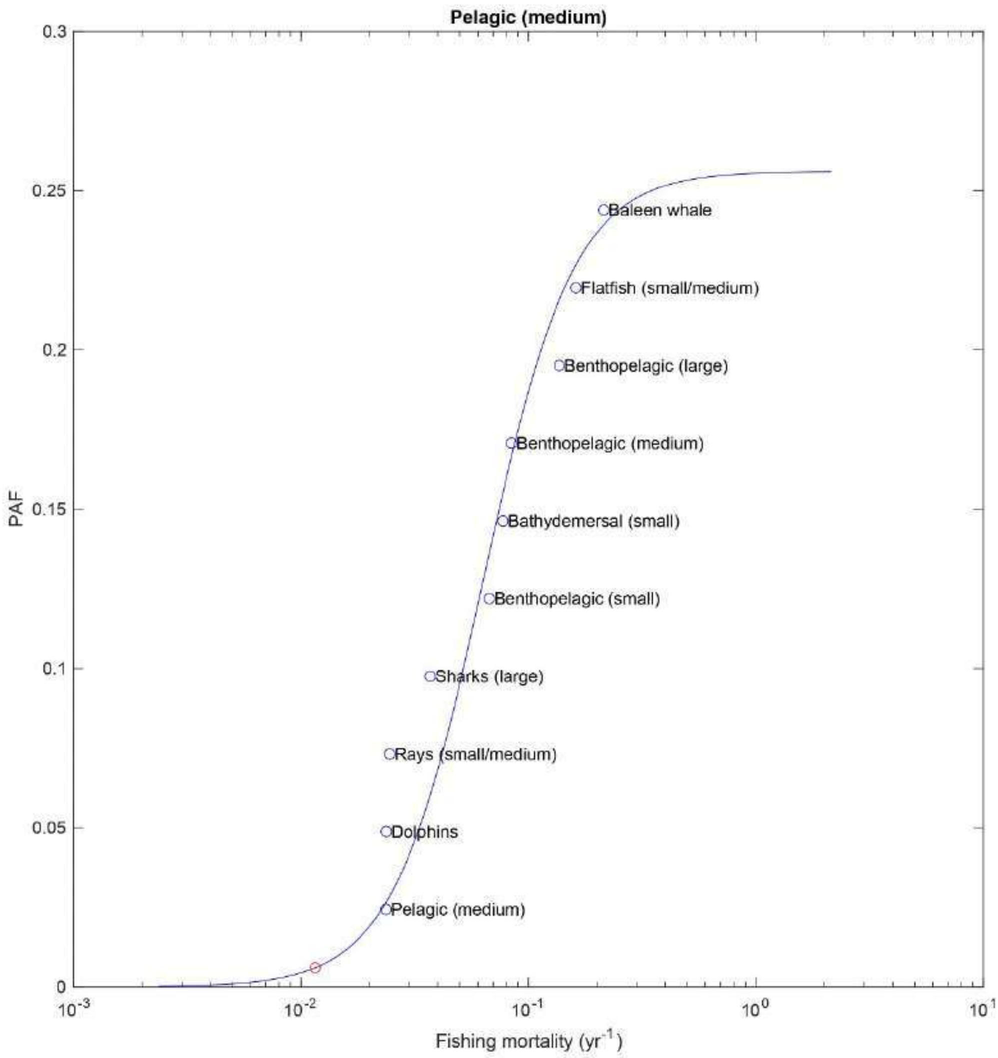

Figure 1. SSD - Cumulative logistic distribution giving PAF value for impact of fishing the Medium Pelagic Functional Group (including species of mullet *(Chelon spp)*, mackerel *(Scomber spp* & *Trachurus spp)*, pomfret (*Brama spp*) and barracuda *(Sphyraena spp*), red point indicates current fishing mortality (2018), as the “hazardous” stressor threshold used to compute CFs.

Operational Accounting of two Major Drivers of Marine Biodiversity Loss in LCA of Seafood Products

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1. INTRODUCTION

The latest global assessment report of the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES) identifies 5 main drivers of biodiversity loss for terrestrial, freshwater, and marine ecosystems. For marine ecosystems, the driver "Direct exploitation of biotic resources" is the most important, followed by "Land- and sea-use change", "Climate change", "Pollutions", and "Invasive alien species". Recent Life Cycle Impact Assessment methods of resource depletion (Hélias et al., 2023) and seabed impact (Woods and Verones, 2019) have not yet been applied to case studies beyond their respective proofs of concept.

We included those two pressures in an operational method, accounting for Resource Depletion and Seabed Impact on ecosystems. We applied it to a business case study, and we identified key parameters and data driving results. Our goal was to determine if it was feasible to include these key drivers of marine biodiversity loss – Direct exploitation and Sea-use change – in the biodiversity impact assessment of seafood products for the three realms (terrestrial, freshwater and marine). A prescriptive framework was also included to collect data and determine their quality (Wermeille et al. 2024).

2. METHODS

The method encompasses four drivers of biodiversity loss calculated with LCA. Climate change and pollution were assessed with LC-Impact while direct exploitation and sea-use change were calculated using Hélias et al. (2023) and Woods and Verones (2019) respectively. Field data provided by companies enabled us to apply it to a practical case study on 1 kg of frozen saithe fished in the North-east Atlantic Ocean, at landing. We determined the impacts of frozen saithe at landing by economically allocating the impacts of the saithe métier to the various fish captured during the campaign. Seabed impacts were spatialized based on logbook data.

3. RESULTS AND DISCUSSION

The application of the resource depletion indicator highlighted the role of bycatch species which, when vulnerable to fishing, may account for most impacts despite low catches. To date, this method does not allow evaluation of impact on the overall trophic chain. It only measures impact linked to removal of target species and bycatch. Work is in progress to take this impact pathway into account. Regarding the seabed impact indicator, case study highlighted two main parameters influencing impacts of a fishing métier (Figure 1). The first one is the yield The second one is vulnerability of marine ecoregion. In 2019, in the Southern Norwegian Coast, yield is 50% higher than for the North Sea whereas impact is 15% higher. This is due to an 89% higher average impact per m² for the marine ecoregion. The very high CF of the Southern Norwegian Coast marine ecoregion (mean CF for 2019 and 2021: 1.37E-11 PDF·yr/m^2) is explained by depth of trawled habitats. Indeed, 60% of substrates trawled in the area for those two fishing trips are located beyond 200 m depth. For the 2021 fishing trip, 100% of trawled substrates are deeper than 200 m (CF 2021: 2.04E-11 PDF·yr /m2).

Case study highlighted different orders of magnitude between pressures (Table 1). Seabed impact indicator is dominant in our case study. Despite being expressed in what appears to be the same unit (PDF·yr), level for assessing the potentially disappeared fraction of species varies across pressures. We expect Seabed impact indicator to be generally dominant for fisheries targeting sustainably managed resources with active bottom fishing gears.

4. CONCLUSIONS

Our work introduces two important impact pathways (resource depletion and seabed impact) when assessing the impact on biodiversity of fished products. It presents our method that assesses four of the five drivers of biodiversity loss and applies it to a case study. In the perspective of aggregation of pressures, homogeneity between PDF units must be achieved with further research.

5. ACKNOWLEDGEMENTS

The authors thank Euronor, Sovintex and FromNord for the data provided, Aquimer for the projet management and FFP for funding the project. Thanks to Franseca Verones for our discussion about units and indicator aggregations.

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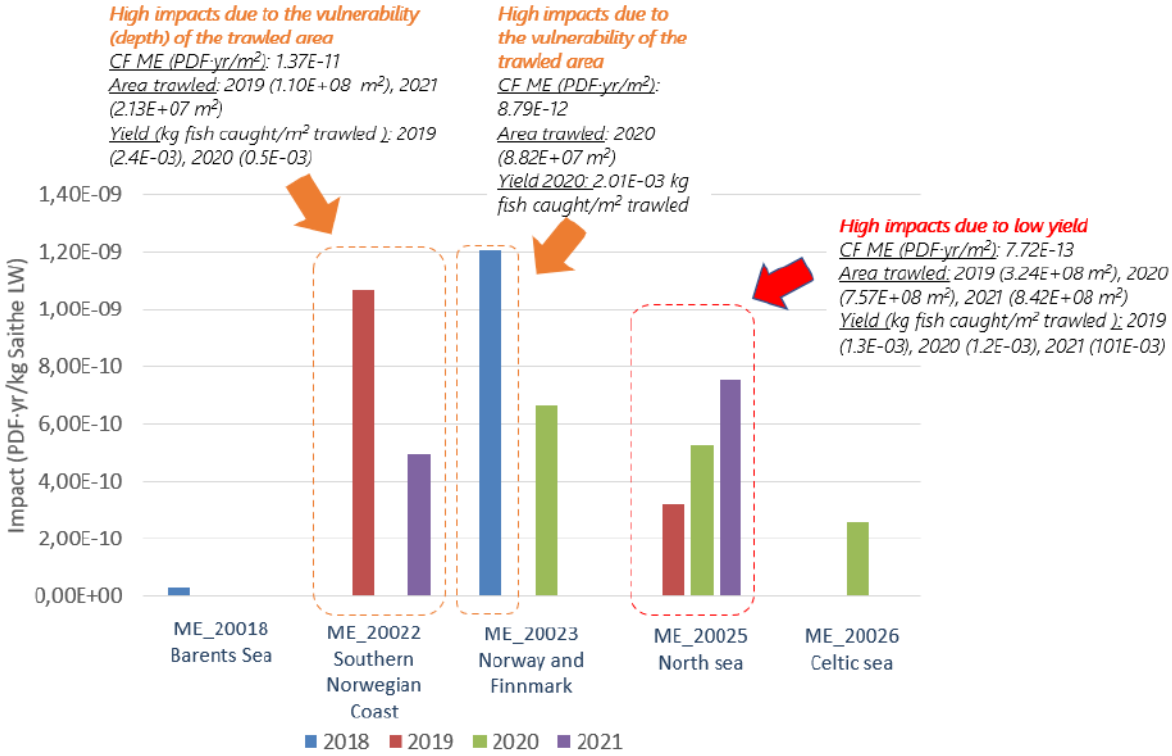

Figure 1: Sea use change impact of 1 kg of saithe at landing. Impacts are displayed for each year and marine ecoregion (ME). Impacts per ME are calculated according to substrates and depths trawled. They vary from year to year for the same ME. The x-axis represents the different MEs and years while the y-axis illustrates impacts of 1 kg of Saithe Live Weight. Bars are colored by year. They yield is the mass (kg) of fish caught (all species) per m² trawled.

Table 1 : Case study results for the 4 impacts categories studied for 1kg of saith at landing.

Impact category	Climate change (PDF·yr)	Pollution (without toxicity) (PDF·yr)	Direct exploitation (PDF·yr)	Sea-use change (PDF·yr)
Impacts for 1kg of saithe at landing	1.01E-14	1.43E-14	1.88E-14	1.36E-09

Expanding Life Cycle Impact Assessment to account for marine plastic emissions: a case study for the fishing industry

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1. INTRODUCTION

Efforts to provide new characterization factors or impact categories to assess important impact pathways in marine resources and ocean conservation and integrate these in Life Cycle Impact Assessment (LCIA) include new metrics for biotic resource depletion (Hélias et al., 2023), seabed impact (Woods & Verones, 2019), and development of coordinated efforts to include marine plastic pollution (Woods et al., 2021). Effect and fate factors for physical effects of microplastics (MP) on biota have been presented (Corella-Puertas et al., 2023), eco-toxicity effect factors (EFs) for plastic additives (Casagrande et al., 2024), and EFs for entanglement by macroplastics (Hoiberg et al., 2022).

Plastic emissions from the fishing industry are important sources of marine plastic worldwide. Emissions arise from loss of fishing gear, degradation of antifouling coatings, wear and tear and weathering losses from the fishing gear during use, or losses during terrestrial processing stages that ultimately generate aquatic emissions (Loubet et al., 2022; Deville et al., 2023). The objective of this study is to include these dissipative plastic emissions in two case studies to identify their importance in terms of damage to ecosystem quality. Case 1: landing and processing of artic cod (*Gadus morhua*) for human consumption in Norway. Case 2: landing Peruvian anchoveta (*Engraulis ringens*), processing to fishmeal for export to Norway as feed.

2. METHODS

The function of both systems was to deliver 1 tonne of seafood product to a Norwegian customer. The system boundaries are shown in Figure 1. Both cases include fishing, processing and packaging of the product, as well as waste management of packaging. For the cod system, the terrestrial supply chain stages up to the plate of a Norwegian consumer are included.

MP emissions from fishing were estimated for antifouling, macroplastics and MPs from the use of fishing gear. In addition, for the Peruvian fishing fleet, plastic waste emissions from on board activities were also included (Deville et al., 2023). Plastic emissions from mismanagement of packaging waste and tyre wear particles from vehicle transport were included, based on the plastic footprint network guidelines and Peano et al. (2020). All the macroplastic was assumed to fragment into MP over 100 years. Impact World+ (version 2.01) was the selected LCIA method to calculate ecosystem quality damage. In addition, impact pathways linked to the physical effects on biota and entanglement were included. Endpoint results were reported.

3. RESULTS AND DISCUSSION

Figure 1 shows that the environmental damage linked to entanglement depends on the time horizon that the lost gear is assumed to be able to entangle organisms. If a long time horizon is assumed, entanglement completely dominates the damage to ecosystem quality. Figure 2 shows the damage to ecosystem quality results from the physical effects on biota for MPs. MP impacts associated with antifouling paint are included for both systems. The cod system includes all parts of the gear (production and losses), whereas the anchoveta fishmeal case includes only the nylon net. Production of the components that are plastic includes some waste plastic arising from the production process. The mismanaged waste factors are also applied to these waste plastic flows for the cod case. Emissions of plastic from post-landing stages were from mismanaged waste of packaging and linked to indirect discharge to the ocean. Figure 2 shows the situation where 100% of the lost fishing gear fragments into microplastics. Preliminary results show that these dissipative plastic emissions can contribute significantly to the overall ecosystem quality damage, when compared to the impacts calculated with Impact World +.

4. CONCLUSIONS

The study provides a joint assessment of conventional and marine-specific impact categories for two fish production systems destined for Norway. The results show that combined use of these environmental categories enriches the discussion. Whether parts, or the whole of the gear (including ropes) are included affects the importance of the mismanaged waste losses in the value chain, as well as the MP impacts associated with fishing gear losses at sea. The timescale for when lost fishing gear can still entangle organisms is extremely important for the overall damage caused by fishing.

5. ACKNOWLEDGEMENTS

The authors kindly thank the Scientific Committee of the Marine Impacts in LCA (MarILCA) project for valuable scientific exchange. The Life Cycle Initiative (UN Environment) and FSLCI support the MarILCA project.

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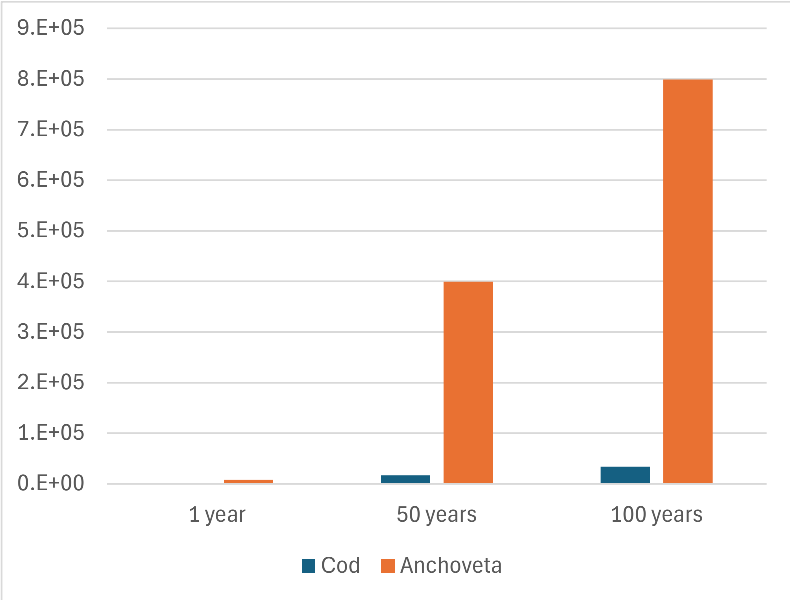

Figure 1. Preliminary ecosystem damage results (PDF.m^2.yr) for entanglement from lost fishing gear for two fishing industry cases, cod (household consumer) and fishmeal (feed for fish farms) for the Norwegian market.

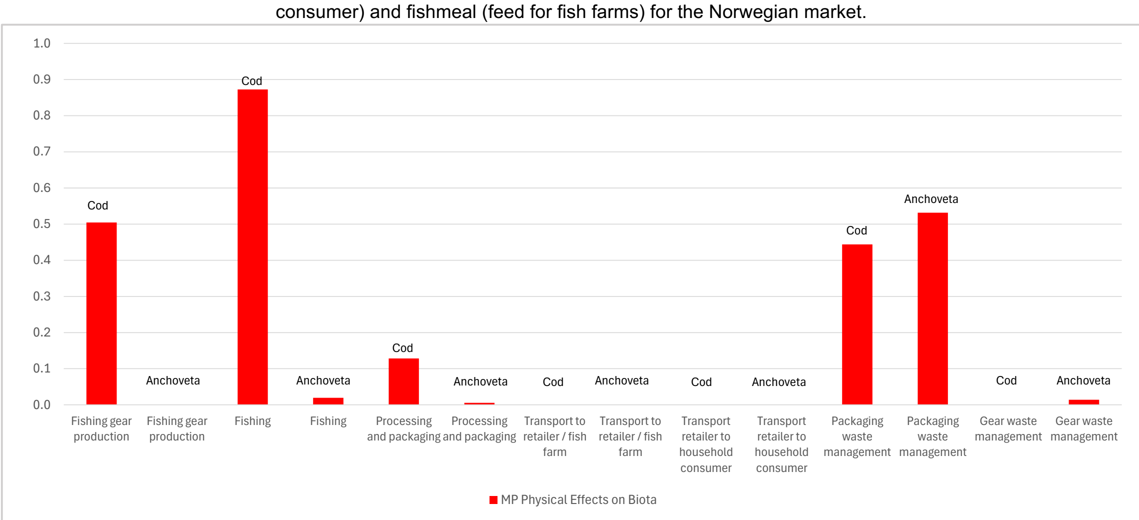

Figure 2. Preliminary ecosystem damage results (PDF.m2.yr) for MP physical effects on biota from lost fishing gear for two fishing industry cases, cod (household consumer) and fishmeal (feed for fish farms) for the Norwegian market.

LCA and footprint studies explained by companies

Assessing Oatly's Handprint

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1. INTRODUCTION

In recent years, many companies have started reporting on their Corporate Climate Footprints and setting reduction targets. While this is necessary, it might fall short of highlighting the positive contribution some companies have when they replace higher-impact options. As such companies grow, so does their footprint, a development that can erroneously be interpreted as a step in the wrong direction. This can be remedied by also calculating the avoided emissions those solutions bring to the market, also known as "handprint". In this paper, we will present Oatly's handprint, a company whose mission is to facilitate the shift of consumers from traditional dairy to more plant-based diets.

2. METHODS

Avoided emissions is a well-established concept in the consequential LCA thinking, which Oatly together with environmental consultancy Quantis have customized it to Oatly's case (Quantis, 2023). The approach is also aligned with the SHINE Handprint Method (Norris et al., 2021) and the World Business Council for Sustainable Development (WBCSD) Guidance on Avoided Emissions.

Goal and Scope of the handprint: The goal of the paper is to apply the handprint approach for Oatly, focusing on the climate change impact category. Oatly's mission is to facilitate the shift of consumers from traditional dairy to more plant-based diets. Thus, Oatly's handprint can be defined as the emissions avoided when consumers switch from dairy to Oatly products.

System boundary: The system boundary is from cradle to grave excluding the use phase, which is assumed to be similar for dairy products and their Oatly alternatives. The calculations consider the years 2019 to 2023.

Inventory for the handprint: The inventory includes product Life Cycle Assessments (LCAs) for material Oatly products and markets and their dairy equivalents at country level. The LCAs (Blonk, 2024) were conducted according to ISO14040/44 and were critically reviewed. Conversion from dairy to Oatly products has been established through consumer surveys at country level for Oatly's key markets (conducted by McKinsey & IPSOS agencies). Sales volumes were collected by Oatly's Finance Department.

3. RESULTS AND DISCUSSION

The Oatly products analysed in the LCAs have lower climate impact than their dairy equivalents with a difference ranging from approximately 0.4 to 2 kg CO2e/L depending on the market and product. Based on the market surveys, Oatly consumers have converted from dairy products (as opposed to other beverages) in 33% to 77% of the cases depending on the year, market, and sales channel. Based on the above, and Oatly's sales volume in the last 5 years, 0.85 million tons of CO2e have been avoided. Despite this positive contribution, avoided emissions go beyond Oatly's supply chain, thus reporting on them is not allowed in most frameworks and reduction target setting initiatives. This could be considered a flaw, as companies with relatively low emissions from their inception could have to deal with unreasonable absolute reduction targets that imply limitations in growth and as a result their positive impact (handprint) in society.

4. CONCLUSIONS

For companies that introduce solution products with lower impacts than their traditional counterparts, assessing only the footprint is not sufficient since it cannot capture the positive impact those companies have overall in the world. This has become clear in the case of Oatly, whose significant growth in recent years has increased its absolute footprint, while replacing higher-impact dairy products.

5. ACKNOWLEDGEMENTS

Abigail Damberg (Sustainability Research Lead, Oatly), Ashley Allen (former Chief Sustainability Office, Oatly).

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Using environmental footprint in dairy and plant-based dairy alternative sectors

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1. INTRODUCTION

Implementation of Product Environmental Footprint (PEF) methodology at real scale is becoming a real challenge to achieve European sustainability goals. Main reasons are the lack of knowledge and tools to implement the methodology, difficulty of obtaining data from raw material suppliers and lack of harmonized and agreed communication system. Within this framework, the objective of the study is to evaluate the benefits, barriers and facilitating tools of implementing environmental footprint in a food industry producing two dairy products (pasteurized milk and plain yogurt) and two plant-based dairy alternatives (coconut yogurt and soy & coconut yogurt). This study will **give insights regarding the usefulness and value** obtained by the company when performing the Environmental Footprint assessment, while identifying also potential challenges to be faced by the methodology.

2. METHODS

PEF methodology was used to analyse the Environmental Footprint of the selected products. As such 1 L of packed, distributed and consumed pasteurized milk and 125 gr of fermented yogurt or plant-based yogurt were selected as Reference Flows. The food company with the support of AZTI research centre collected the data from each stage and calculated the PEF results with *ad-hoc* developed tool. Data from primary production was selected from EF3.1 dataset. Data regarding water and energy consumption, packaging, waste, and wastewater treatment was collected from the dairy facilities and distribution points and type of vehicle used. Finally, data regarding water or energy requirements for the sales and consumption stages was estimated based on literature. For the communication, the ENVIROSCORE ABCDE level was calculated (Ramos et al., 2022). This communication system is based exclusively on the 16 environmental impacts categories recommended by the PEF method. The methodology developed new normalization and weighting factors adapted to the European food sector, and thus, the score gives the information regarding the relative impact of each product compared to the average impact of food production in Europe.

3. RESULTS AND DISCUSSION

Preliminary results from the environmental impact assessment and ENVIROCORE are still under review. However, main insights have been already worked out.

Benefits of calculating Product Environmental Footprint encompasses i) identification of opportunities to optimize resource use, such as energy, water, and raw materials, ii) identification and mitigation to potential risks associated with resource scarcity, regulatory changes, and shifts in consumer preferences towards sustainable products, iii) market differentiation, iv) facilitate compliance with existing and future environmental regulations, v) foster collaboration with suppliers and other stakeholders of the value chain or vi) increase brand reputation and customer loyalty.

On the other hand, the following barriers or challenges have been identified: i) obtaining accurate and reliable data on every stage of the product life cycle, ii) tracking and collecting data from diverse sources, especially in global supply chains, can be difficult; iii) lack of transparency in supply chains, iv) variability in agricultural practices makes it challenging to develop long term results, v) incorporating consumer stage factors into assessments, vi) uncertainty in the data and assumptions can impact the reliability of the footprint calculations, vii) complexity of impact characterization methodologies can be a barrier, especially for small and medium-sized enterprises (SMEs) with limited resources; and viii) conducting a thorough environmental assessment requires financial resources and technical expertise.

4. CONCLUSIONS

Overall, the calculation of Product Environmental Footprint may appear as a suitable method to harmonize the evaluation and communication of the environmental impact of a given product or service. However, although there are many benefits that may be valuable for industrial companies, when assessing the potential uses at real scale there is still long way to go.

5. ACKNOWLEDGEMENTS

The authors wish to acknowledge the Gipuzkoa Provincial Council for the funding support of this study (MISIOAK programme call 2023-LAB4-003-01 ref.)

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Creating Novel Value in the Pork Chain Through LCA-Quantified Carbon Reductions Enabled by Genetic Innovation

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1. INTRODUCTION

Many practices and technologies will be required for E.U. and U.S. pork industries to achieve their commitment to reduce greenhouse gases (GHG) by 40% by 2030[1,2]. Pig Improvement Company (PIC) has a 60-year history of genetic innovation, including year on year genetic improvement, resulting in pork being produced with a lower environmental impact; more productive sows result in less feed required to produce each weaned pig, more efficient growing pigs result in less feed consumed to reach the same market weight, and more robust pigs from birth to market result in a higher proportion of pigs that consume feed contributing to the pork supply chain. Each year, PIC quantifies the production system performance improvements enabled by genetic innovation (Table 1). Genetic innovation, however, is not currently leveraged to achieve the climate goals set by corporations and national governments, which are under increasing pressure from consumers and stakeholders. A Life Cycle Assessment (LCA) has been conducted to quantify the environmental impact, including reduction in GHG emissions, resulting from PIC's genetic innovations[3]. This study is focused on the critical steps required to utilize the results of the LCA to generate novel, shared value within the pork chain.

2. METHODS

PIC's credible and defensible pathway to generate carbon assets/value entails the following stages (Figure 1). First, quantify the GHG reductions resulting from genetic innovation using LCA and achieve approval by the International Organization for Standardization (ISO). Second, partner with a national pork organization to develop an industry-wide tracking and reporting framework. This framework allows stakeholders to claim the use of a LCA-supported genetic innovation through a process that has integrity for carbon market participants and is efficient to implement in the pork chain. Third, credibly ground the GHG reductions specific to the accounting required for the creation of carbon assets. This will include intervention accounting for credit generating carbon inset and inventory accounting for non-credit generating carbon insets. Fourth, pilot test the pathway to ensure commercial applicability and feasibility for pork supply chains and carbon markets. This pilot will be a proof case for the generation and transfer of carbon assets resulting from genetic innovation applied to live animals within a pork supply chain. Fifth, replicate the carbon asset generation process in priority pork markets around the world. This final step will enable PIC to unlock novel value across the global pork chain.

3. RESULTS AND DISCUSSION

LCA results show 9% lower GHG emissions for pork produced with PIC genetics in North America[3]. This novel pathway will generate value from these quantified carbon reductions enabled by PIC's genetic innovations. Rigor, accuracy, and third-party certification and/or engagement for each step is a requisite to ensure the environmental outcomes are trusted and that the carbon quality is highly valued by market participants. ISO-approved LCAs ensure claims related to environmental impact are credible, regionalized claiming and reporting processes ensure defensible use of the intervention, and accepted accounting for carbon insets ensures carbon value is created and exchanged with high integrity and value by market participants. Building on an LCA foundation this pathway, therefore, establishes a defined and defensible process, replicable across future genetic innovations and across geographies.

4. CONCLUSIONS

PIC is developing a robust pathway, replicable globally, for pork producers and food companies using our genetic innovations to deliver both a meat product and a carbon asset. By objectively measuring and accounting for GHG emission reductions, PIC will achieve an industry first and will set the standard for generating carbon value through genetic innovations.

5. ACKNOWLEDGEMENTS

PIC thanks the U.S. National Pork board for partial funding and support of the framework and pilot in U.S. where this process was initially developed before expanding into global markets.

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[2]Pork Checkoff. 2023.. Sustainable Pork: Growing A Climate For Tomorrow. https://porkcheckoff.org/news/sustainable-pork-growing-a-climate-for-tomorrow/. Accessed Jan 30, 2024.

[3]Thoma, Greg et al. 2024. Environmental sustainability of PIC pigs: a Life Cycle Assessment study (in preparation for submission to Agricultural Systems).

Table 1. Impact of PIC's Genetic Innovation Program on Production of Pork with Fewer Environmental Resources

Trait	Increase Performance Potential Enabled by 1 Year of Genetic Innovation	Annual Impact on a 5,000 Sow Farm	Annual Impact on a 2,400 wean to finish barn (180 days, fixed age)
Pre-Wean Mortality	-0.74%	> 6,000 pigs weaned	--
Pigs Weaned/Sow/Year	1.2 pigs		
Kg Weaned/Sow/Year	9.1 Kg	>220,500 Kg weaned	--
Pigs Marketed/Sow/Year	1.3 pigs	>6,500 pigs marketed	--
Kg Marketed/Sow/Year	219 Kg	>1,095,000 Kg marketed	--
Carcass Weight per Days of Age	6.2 grams	--	>-46,900 Kg feed saved
System Feed Efficiency	-0.031		
Wean to Finish Mortality	-.065%	--	>30 pigs marketed

Figure 1. Pathway for Carbon Assets to be Generated and Exchanged Credibly and Defensibly Between Pork Chain Stakeholders and Carbon Market Participants

Carbon footprint and decarbonization of a territorial agrifood research institute

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1. INTRODUCTION

The Institute of Agrifood Research and Technology (IRTA) promoted a study to establish a reference framework for its organizational Carbon Footprint, starting with one of its larger research centers located at Torre Marimon in Caldes de Montbui (Barcelona, Spain). Once fully deployed to all its 17 centers and stations, along with a more comprehensive coverage of impact indicators, this self-assessment will detect the most contributing points to the organization's climate impact in order to provide strategic information for the definition of improvement objectives, identify alternatives and evaluate solutions towards IRTA's decarbonization.

2. METHODS

Following the ISO 14064-1 (2018) and the GHG Protocol methodology, the functional unit was the operation of the Torre Marimon center during 2019, covering scopes 1 to 3. Aiming for an above-average use and precision of primary data, particularly for scope 3, the input data were obtained from interviews and questionnaires with the Center's 165 staff and, in a more classic fashion, from the consultation of records, databases and invoices. Secondary data were obtained from the ecoinvent v3.8 database (Moreno Ruiz et al., 2021) and Agribalyse (Asselin-Balençon et al., 2020), adapted to local conditions whenever possible. The spatial boundaries of the IRTA center Torre Marimon include a farm of 116 ha (52 ha arable land, 45 ha forest and nursery, 6 ha riparian land, 13 ha buildings and others (buildings occupy 16,673 m^2 of which 11,506 m^2 are listed as historical buildings, some dating back to the 14th century). The specific equipment at the center includes an experimental winery, various laboratories, a small-scale cheese manufacture, greenhouses, a rabbit and a calf farm, a hermitage, and sports facilities for public use (thus providing public services and maintenance of public, cultural heritage).

3. RESULTS AND DISCUSSION

3.1 Results

The center's carbon footprint for its operation during 2019 was 1,381 t-CO_2-equ., with contributions coming from scope 1: 19% (255 t-CO_2-equ.), scope 2: 9% (129 t-CO_2-equ.), and scope 3, dominating as expected with: 72% (1002 t-CO_2-equ.).

3.1 Discussion

In scope 1, 35% and 27% of the emissions come from using natural gas and petrol respectively, 20% from buildings, 9% from greenhouse infrastructure and 8% from the fuel used in the center's car fleet. 90% of emissions in the general section of scope 3 come from trips to go to the workplace and business trips. As for the activities section of scope 3, the calf farm stands out with 41% contribution of emissions of the animals' excretion and the rest equally distributed between arable fields, tree plantation, and the rabbit farm.

4. CONCLUSIONS

The points with the strongest improvement potential to highlight are transport, cattle farm emissions and electricity consumption.

The large number of activities carried out at IRTA increase the Carbon Footprint. These research activities are necessary to move towards a more sustainable agri-food system and its has a different function than productivity and commercial viability.

In this sense, the carbon footprint of IRTA's agricultural activities cannot be directly compared with commercial agricultural farms, neither as reference points for the sector nor as at the orientation of the IRTA in relation to the sector.

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A Comparative Life Cycle Assessment of palm oil - differentiated by RSPO-certified and non-certified, regionally, spatially, and by estate and smallholder

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1. INTRODUCTION

Palm oil producers are increasingly obligated to document the impact of their products. Due to the diverse nature of the palm oil supply chains, collecting data directly from individual suppliers can often be challenging. Both palm oil users and producers aim to distinguish between various factors, including Roundtable on Sustainable Palm Oil (RSPO) certification status, geographical regions, and the differentiation between estates and smallholders. Moreover, since the impact of palm oil production changes over time, it is essential to continually monitor the developments to ensure accurate claims can be made. This study addresses these challenges by providing data on the palm oil market and its diverse production practices. A comprehensive comparison of cradle-to-gate life cycle environmental performances of RSPO certified and non-certified palm oil is provided, building upon a previous study conducted in 2016-2019 (Schmidt and De Rosa, 2020). The present study broadens its scope by introducing additional scenarios, encompassing five countries. For the primary producers, Malaysia (MY) and Indonesia (ID), the research further investigates the various states, considers both 2016 and 2021 for a temporal analysis, and examines differentiation based on Fresh Fruit Bunch (FFB) suppliers, particularly comparing smallholders to estates as supply bases. This differentiation allows for a more granular analysis of the environmental implications associated with varying palm oil production systems.

2. METHODS

As in Schmidt and De Rosa (2020), two LCA models have been applied, namely attributional and consequential. The models vary in e.g. handling of by-products and land use modelling. The consequential model includes indirect land use changes, while the attributional model integrates direct historical land use changes over a 25-year period. The functional unit of both models is 1 kg of refined, bleached, and deodorised (RBD) palm oil at refinery gate. LCI data has been collected from statistical and literature sources. Additionally, the RSPO has supplied a database containing data for 656 certified estates and 186 certified oil mills. The Life Cycle Impact Assessment (LCIA) method applied is Stepwise 2006 version 1.8 with a comprehensive set of 14 environmental impact categories.

3. RESULTS AND DISCUSSION

Results are weighted following the Stepwise 2006 weighting module, which highlight global warming potential (GWP), followed by nature occupation, and respiratory inorganics as the impact categories causing the highest damage. Figure 1 shows the characterised results for these impact categories, relating to 1 kg RBD palm oil produced in four of the included countries. Results are presented for both the consequential and attributional model. The results following the consequential model show that GWP impacts from RSPO certified palm oil ranges from 1.5-3.1 kg CO_2 eq. while non-certified palm oil ranges from 2.1-5.1 kg CO_2 eq. Certified palm oil production leads to a reduction in impacts by 31-53% in comparison to non-certified palm oil. Likewise, RSPO certified palm oil demonstrates a better performance over non-certified palm oil in most countries, for GWP impacts following the attributional model and for nature occupation in both models. Figure 1 shows a contribution analysis for the impact category GWP, following the consequential model, showing that the primary impacts from palm oil production arise from the cultivation phase, with the use of peatland having a substantial impact, followed by effects from land use. A significant impact during the cultivation stage also results from direct emissions from fertilisers. Additionally, the oil mill stage contributes considerably, particularly from palm oil mill effluent (POME), with substantial reduction in impacts achievable through effective biogas capture.

4. CONCLUSIONS

Across scenarios, the results indicate that RSPO certified palm oil is associated with significantly lower GWP impacts than non-certified production (31-53% reduction). Moreover, the findings reveal significant variations in palm oil production among the included countries and regions, primarily explained by the proportion of oil palm cultivated on peat, whether POME has biogas capture, and by difference in crop yields.

This study offers an updated comparison of RSPO certified and non-certified palm oil, aiming to inform stakeholders in the palm oil industry, policymakers, and consumers about the environmental implications of different palm oil production systems, facilitating more informed decision-making towards sustainable practices.

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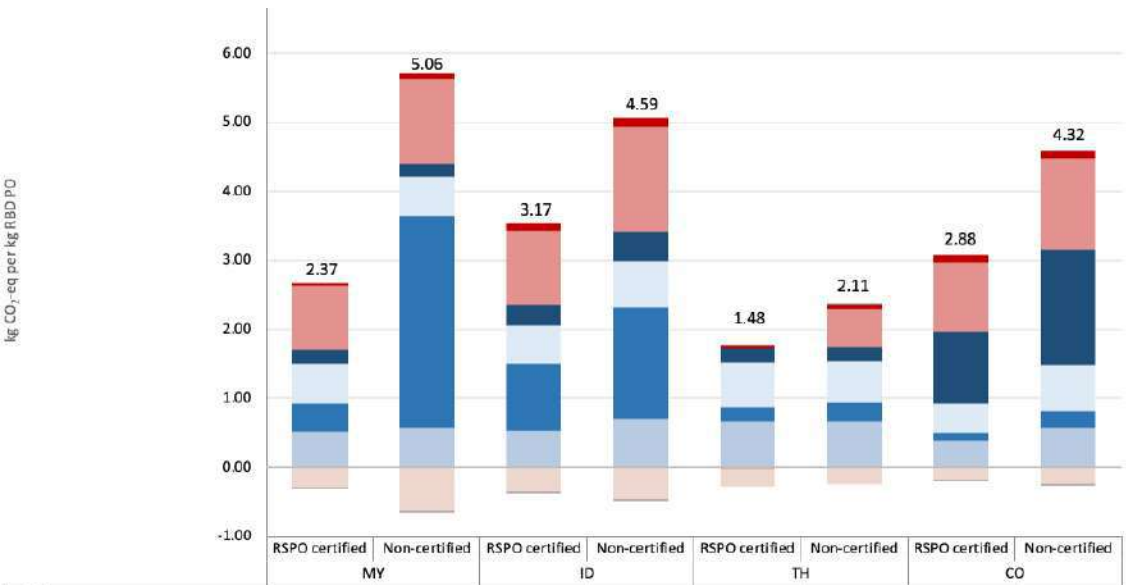
Table 1. *Preliminary results.* Contribution analysis for 1 kg RBD palm oil. Results are shown for the three most important impact categories (following weighting) and for both the consequential and attributional model.

Impact category	Unit	Methodology	Malaysia		Indonesia		Thailand		Colombia	
			RSPO	non-certified	RSPO	non-certified	RSPO	non-certified	RSPO	non-certified
Global warming, fossil	kg CO2-eq	Consequential	**2.37**	5.06	**3.17**	4.59	**1.48**	2.11	**1.95**	2.84
		Attributional	**1.92**	5.85	**2.34**	5.61	0.84	**0.30**	**0.86**	1.55
Nature occupation	PDF*m2a	Consequential	**1.71**	1.87	**1.68**	2.36	**2.13**	2.25	**1.31**	2.07
		Attributional	**0.54**	5.05	**0.33**	6.30	0.00	**-2.78**	-1.52	**-1.25**
Respiratory inorganics	g PM2.5-eq	Consequential	2.62	**2.46**	2.65	**2.27**	**2.74**	2.79	2.82	**2.78**
		Attributional	1.84	**1.44**	0.28	**-0.02**	**0.38**	2.62	3.44	**2.55**



	RSPO certified (MY)	Non-certified (MY)	RSPO certified (ID)	Non-certified (ID)	RSPO certified (TH)	Non-certified (TH)	RSPO certified (CO)	Non-certified (CO)
Refinery	-0.0061	-0.0061	-0.0026	-0.0026	0.0017	0.0017	-0.0144	-0.0144
Oil mill: Other	0.04	0.07	0.11	0.12	0.03	0.07	0.11	0.11
Oil mill: Kernels	-0.30	-0.64	-0.36	-0.47	-0.26	-0.25	-0.18	-0.25
Oil mill: POME	0.9	1.2	1.1	1.5	0.0	0.5	1.0	1.3
Cultivation: Other	0.21	0.19	0.30	0.42	0.20	0.22	1.04	1.67
Cultivation: Fertiliser and pesticides	0.59	0.55	0.55	0.66	0.65	0.59	0.43	0.67
Cultivation: Peat	0.40	3.09	0.99	1.63	0.20	0.26	0.12	0.25
Cultivation: Land use change	0.52	0.57	0.52	0.70	0.67	0.67	0.38	0.57

Figure 1. *Preliminary results.* Contribution analysis of GWP impacts (measured in kg of CO_2-eq.) for 1 kg of RBD palm oil: Malaysia (MY), Indonesia (ID), Thailand (TH), Colombia (CO). The results are shown for the consequential system model.

Circular food systems

Circular integration of insect bio-converting food waste into protein: A Life Cycle Assessment perspective on black soldier fly

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1. INTRODUCTION

Black Soldier Fly (BSF) has gained significant research attention for its potential in waste management and high-protein feed production. A study estimated that with 10 tons of food waste (FW) input, 300kg of dried larvae (48% protein content/ton) and 3,346kg of larvae manure are produced (Salomone et al., 2017). However, insect production has energy burdens impacting direct GHG emissions (Salomone et al., 2017; Smetana et al., 2019). Research concerns for more environmental study before its mass production; concerns primarily revolve around the selection of suitable insect species, feed requirements, waste management, and the potential for ecological disruption (Berggren et al., 2019). The study, performed in the framework of ADVAGROMED and CIPROMED projects, aimed to define the potential for the FW circularity of BSF through Life Cycle Assessment (LCA). The study aims to analyze i) the environmental impact of BSFL fed with various FW and the subsequent bioconversion process ii) evaluate various FW and compare substrate parameters. Our LCA offers insights into circular bio-economy strategies by evaluating environmental impacts and how this can impact the overall sustainability of the insect industry.

2. METHODS

Environmental LCA is applied following ISO standards (ISO, 2006a, ISO, 2006b). Impact categories were selected according to Product Environmental Footprint Category Rules (PEFCR). Cradle-to-gate approach was adopted which includes raw material transportation, raw material processing, and insect larvae rearing & processing (Fig 1). To explore the circularity aspect, the study considered 1 ton of FW bio digested as the functional unit. Various feed types and parameters were also assessed for comparison using already published data.

3. RESULTS AND DISCUSSION

Processing 1 ton of food waste resulted in a cumulative impact on GWP, Energy Use, and ozone layer depletion (Table 1: Results presented in 1 kg dried larvae processed). Electricity constitutes the main influencing parameter for GWP contributing over 70% of emissions. Using feed substrates such as abattoir waste or mixed waste fractions enhances the conversion efficiency; prolonged processes and development times associated with a single substrate result in elevated costs and higher GWP. Emissions can be balanced by substitution of the raw materials or products (Guo et al., 2021). Reducing the waste from its processes and recirculating it into the food chain can also lower direct emissions. When insect frass was used in agriculture as a soil fertilizer fossil depletion was reduced by 3%.

4. CONCLUSIONS

Environmental impact concerning bioconversion processes is mostly associated with GWP and Energy Use. Balancing the emissions can be performed by evaluating different parameters in the initial process; as feeds collected from vegetable overproduction auctions showed high waste reduction and survival rates, but lower protein content and conversion efficiency. Various parameters should be emphasized in the bioconversion process for achieving the overall sustainability of the production process; recirculating food waste nutrients using insect technologies depends on factors such as initial nutrient richness, insect conversion efficiency, environmental impact, and usability of derived products.

ACKNOWLEDGEMENTS

The research was conducted within ADVAGROMED and CIPROMED, both supported and funded by the European Union's Horizon 2020 initiative for research and innovation.

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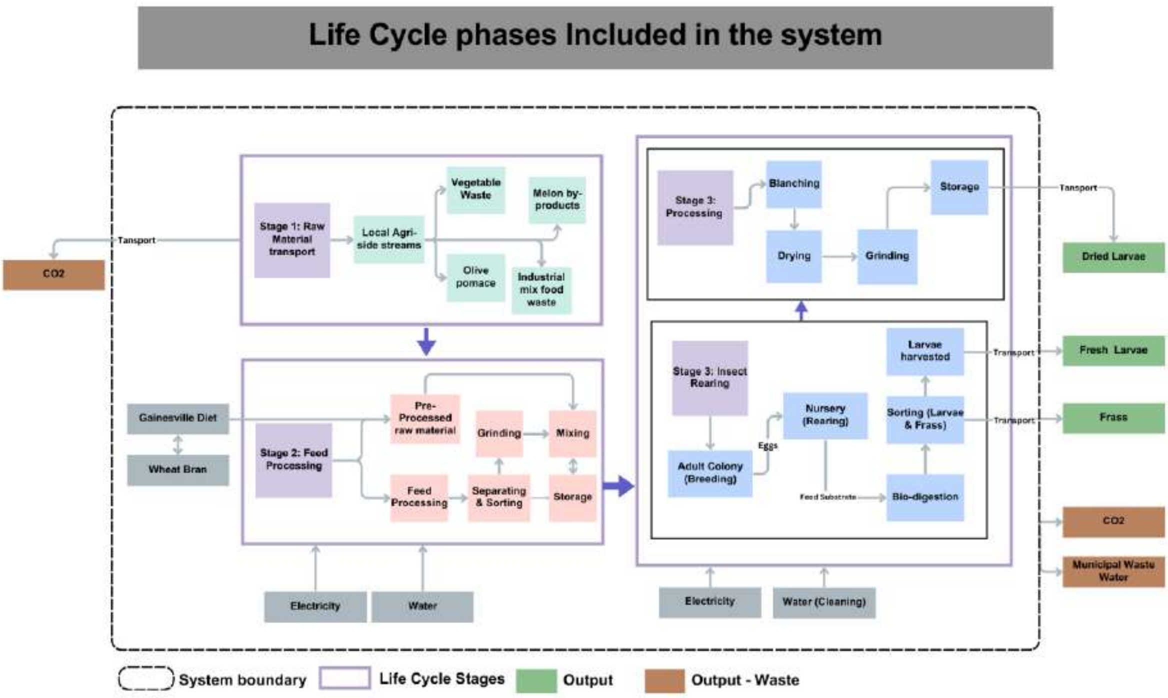
Table 1. Results of the bioconversion process: Environmental impacts of 1 kg of dried larvae

Impact categories	Unit	Amount
GWP 100a	Kg CO_2 eq	5.604
Acidification	Kg SO_2 eq	0.012
Energy use	MJ	82
Land use	m2a	-2.53
Ozone layer depletion	kg CFC-11 eq	5.34

Figure 1: System boundary – Food waste bioconversion process.



Potential of insects for the nutrient circularity in food systems through the framework of Life Cycle Assessment

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1. INTRODUCTION

Insect production has an environmental impact. However, the use of organic waste for insect feeding can mitigate the impact and even result in environmentally positive scenarios. The impact and the efficiency of such nutrient recycling are not well assessed. Insects can be used to return nutrients from manure, agricultural residuals, food waste to different stages of production system, frass (insect manure) to agricultural production, biomass to feed or food. The two potential effects are waste reduction and return of nutrients to food systems in the form of fertilisers, feed and food. Current research provides an insight into the scarce cases of circularity potential assessment (as a part of Life Cycle Assessment - LCA) of insects and the methodological approaches that can be further developed to ensure the recycling potential of insect production systems, relying on organic waste.

2. METHODS

LCA was conducted in cradle-to-grave approach based on the integrated method of IMPACT 2002+ which allows to generate characterisation values and integrated endpoint scores, which can be interpreted. The LCA relies on Life Cycle Inventory of the insect production systems in the frame of SUSINCHAIN, Advagromed and Cipromed projects. The project deals with different aspects of insects produced on residuals, and primary data for such systems was of the main interest. Literature published during the last decade and containing LCA of organic wastes or side streams used for insect production has been also considered in the analysis. Both attributional and consequential approaches have been considered.

Applying the original circularity index (Fig. 1) within our methodology involves integrating data from completed LCAs of insect production systems and relevant literature on LCAs of organic wastes or side streams used in insect production. This incorporation allows for a comprehensive evaluation of circular potential, supplementing traditional LCA metrics with insights into waste generation and environmental impact, thus enriching our understanding of the circularity of insect-based nutrient cycles within food systems.

3. RESULTS AND DISCUSSION

Biotransformation of food waste with insect technologies itself has a low integrated environmental impact (around 1%) in comparison to the whole production chain, indicating its potential for the food waste recycling. The results indicated that while it is environmentally feasible to substitute conventionally produced fertilisers with insect frass, protein and lipid sources for feed and food with insect biomass, these substitution routes have different levels of circularity efficiency. The efficiency depends on the initial nutrient richness of the food waste, the biotransformation abilities of insects, place of nutrient return in the chain and on the upstream-to-downstream transformation of the nutrients along the production chain. It was identified that even though the reduction of environmental impact (single score) for the agri-food chains reaches the level of 4-15% (depending on the type of food waste and waste treatment technology substituted), the nutrient recycling potential ranges from 10-15% for the nutrients returned into soils to 30-38% for the nutrients returned in form of food products. The overall efficiency of nutrient recycling with insect technologies therefore reaches the level of those available for other recycling materials (glass, plastic, etc.).

4. CONCLUSIONS

Currently, the methods for defining the circularity potential of insects in the food system are in the early stages of development, and it is envisioned that they will be further developed soon. Preliminary analysis performed in this study allowed to confirm the accuracy of priority options of the waste treatment pyramid. However, the preliminary research presented here allowed to define the potential amounts of nutrients being recycled in the system but also to estimate their losses and assess the associated economic and environmental costs or benefits. Moreover, the circularity potential measures should ideally identify the foreseen effects on the market, and thus, support consequential modelling with insights into the rebound effects.

5. ACKNOWLEDGEMENTS

The study has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement nº 861976. (project SUSINCHAIN). It is also partially funded by the grant agreement nº 101102316 (ADVAGROMED) and by the grant agreement nº 2231 (CIPROMED).

$$\textit{Impact of product}_{w/recycled\ material}\ (IP_{rm}) = \\ = \left(\left(N_{amount\ of\ nutrient} - N_{losses/waste}\right) * Impact_{Total}\right) + ((N_{losses/waste} \\ * \textit{Bioconversion yield}\ (BIO)) * \textit{Impact of Bioconversion}\ (IoB)$$

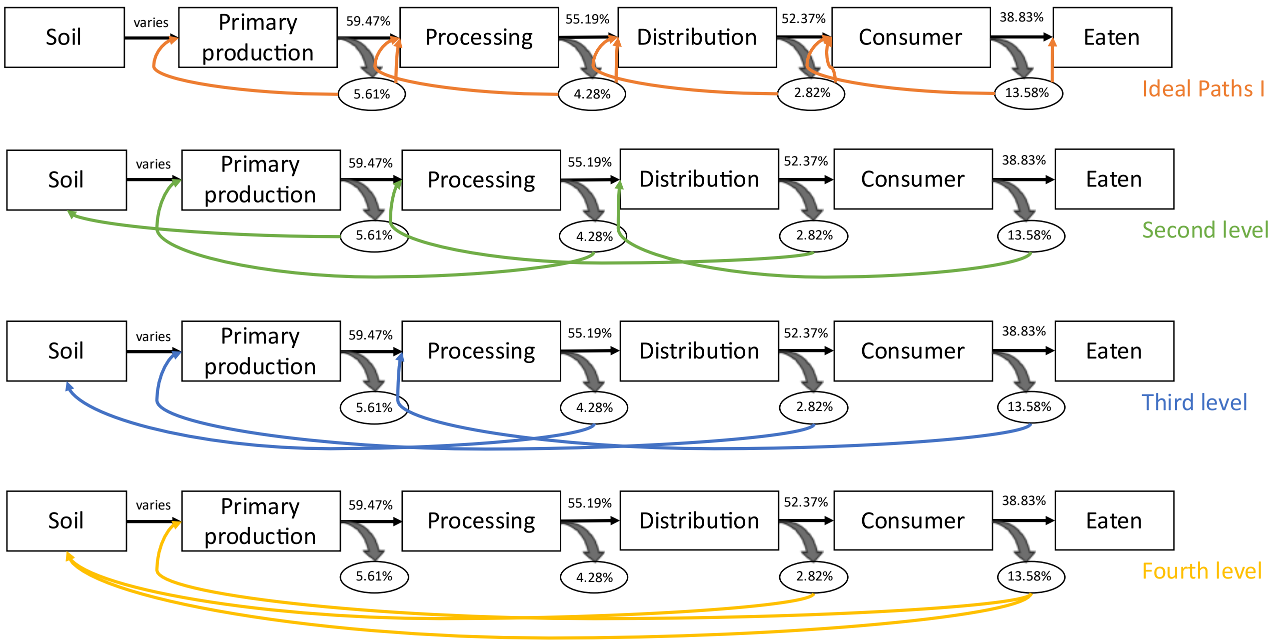

Figure 1. Circularity index equation and flowcharts representing different levels of nutrients return in food systems

Framework to assess the potential of circular food system technologies

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1. INTRODUCTION

The circular economy, specifically in relation to circular food systems, has been identified as a potential paradigm to transform food systems into a more sustainable state. (Herrero et al., 2020). A circular food system has the potential, as demonstrated through modeling, to reduce numerous environmental externalities while still providing healthy diets through the cycling of nutrients, biomass, and energy through the food system (van Zanten et al., 2023). Despite this, there are numerous gaps in the scientific literature to assess the transformative capacity of different circular food system technologies. This work presents a novel framework to analyze the combined economic, environmental, and social potential of circular practices in the food system and a matrix (Figure 1) to group them according to which policies and conditions would aid their adoption.

2. METHODS

We applied this framework to analyze three case studies of circular practices: the use of food processing by-products as poultry feed in the Netherlands (van Hal et al., 2019), the processing of waste cattle bones for phosphate fertilizer pellets in Ethiopia (Simons et al., 2023), and the biodigestion of effluent from dairy cattle farms for energy and fertilizer in Uruguay (Freeman et al., 2022). We used economic return per adopter as our proxy to analyze the market (private) benefits of adopting a circular practice. Then, for spillover (public) benefits, we used a true cost framework for the environmental and social externalities per adopter as our proxy, where a lower true cost is equivalent to higher diffused benefits. The true cost of the environmental and social externalities is based on LCAs done for each case study. Our methodology combines the respective fields of LCA, social cost-benefit analysis, technology analysis, and food system transformation.

3. RESULTS AND DISCUSSION

For each circular case study, selected to represent the wide range of current circular technologies across the world, we demonstrated that the direct and diffused benefits were substantially higher than the baseline technology. The Netherlands case study showed that the use of food processing by-products for livestock feed provides large-scale potential to reduce feed-food competition for land use. The Ethiopian case study demonstrated that local circular practices, decoupled from international supply chains, can increase local resilience and improve food security goals. The Uruguayan case study displayed the cost-effectiveness of implementing circular practices to reduce environmental impacts from our food system while delivering on climate mitigation goals.

4. CONCLUSIONS

As demonstrated through our case studies, our circular economic framework and matrix of circular practices is a viable method to assess the potential of circular food system practices.

5. ACKNOWLEDGEMENTS

We would like to thank Koen Deconinck for his assistance in developing these concepts.

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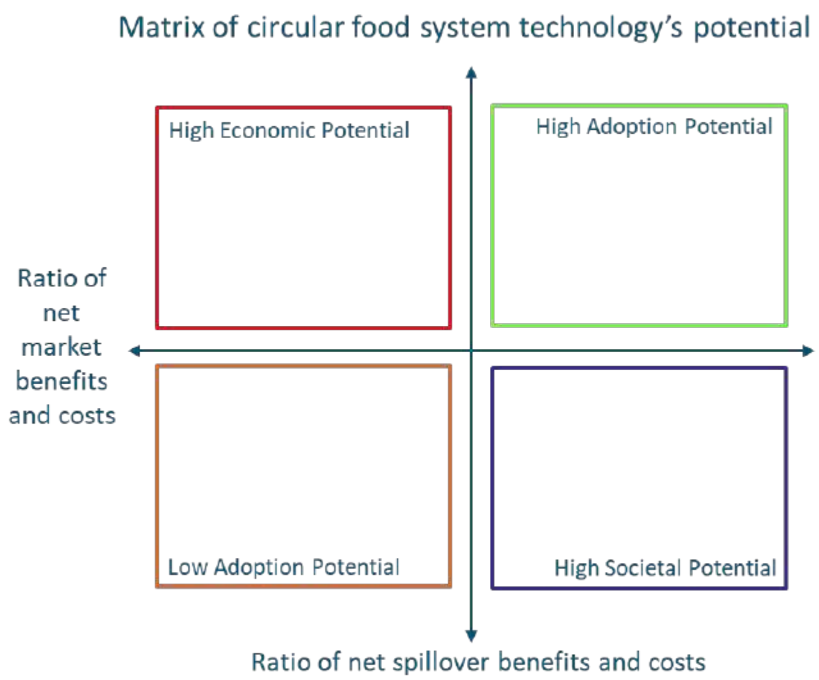

Figure 1. Matrix of circular practices. Market benefits and costs are the private financial benefits and costs per adopter. Spillover benefits and costs are the reductions in the environmental and social true costs per adopter.

Leveraging circular nutrients to improve the sustainability of urban agriculture

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1. INTRODUCTION

Urban agriculture (UA) will require several transformations to become as competitive as conventional agriculture and outperform its environmental sustainability (Hawes et.al, 2024). Such transformations include circular strategies to recover nutrients from municipal solid waste and wastewater systems and their recirculation in urban food production systems. Previous studies have found benefits in the coupling of waste management and food systems. However, there are some limitations. These studies use generic crop production practices to determine nutrient demands, some focus on one nutrient alone (Metson et.al, 2022; Tonini et.al, 2019; Powers et.al, 2019), assume average technologies for nutrient recovery (Trimmer et.al, 2018), and/or exclude system-level dynamics e.g. implications of changes in the use of mineral fertilizers on-site or sludge management (Langemeyer et.al, 2021). While these studies provide a first indication of possible benefits and optimization scenarios, they call for higher system-level studies addressing these limitations.

2. METHODS

We integrate state-of-the art knowledge on sustainable agricultural practices involving alternative nutrient sources, and on nutrients recovery from municipal sources, under the framework of a prospective-regionalized life cycle assessment (LCA) of urban agriculture (Figure 1). We apply this approach to the Metropolitan Area of Barcelona (AMB) in Spain and evaluate the direct and indirect impacts of climate change, regionalized eutrophication, abiotic resource depletion, among others. Current and transition scenarios for UA areas, as proposed by the Barcelona city urban master plan (PDU), are assessed. Further three scenarios of circular strategies are compared to the linear system: 1) compost from municipal solid waste, 2) struvite from municipal wastewater and 3) ammonium salts from municipal wastewater.

3. RESULTS AND DISCUSSION

Results show that circular nutrient strategies bring environmental benefits to cities UA production (Table 1). However, they need to be considered in terms of their life cycle as alternatives to mineral sources of nutrients and as a “shift” in waste management to capture their full potential. City crops pattern and local ecosystems are essential to determine the demand of nutrients and their impacts, and therefore, are critical for the extent of the benefits achieved. Leveraging circular nutrients in UA requires cross-scale actions considering the recovery of nutrients from waste sources, the demand by the locally produced food and the consequences of the redistribution of nutrients in comparison to a linear-nutrients based UA. Further, constrained resources such as recovered compost and struvite, may not or very marginally reduce environmental impacts. The fact that they are constrained should be considered in the analysis. Here we only address aspects related to environmental sustainability. Aspects of socioeconomic, ethical, and cultural dimensions should be considered as well. For instance, farmers preferences may determine the most valuable products e.g. forms of nutrients which allow dose management. Finally, we also address the geographical variability of practices and crops planted within a metropolitan area and express the LCI and LCIA results in maps. Further research involves placing results in the context of imported food as well as considering soil health, in the case of the AMB, where the use of circular nutrients onsite may be limited by it. Also, implementation of a similar framework for other city-regions is envisioned, given the python setup that may allow such application.

4. CONCLUSIONS

Leveraging circular nutrients is found to be a strategy to improve the environmental sustainability of UA against conventional agriculture. Yet, the availability of nutrients via constrained resources, the crop pattern, and local ecosystems of each city-region under consideration and the available technologies for each city to recover nutrients are important factors that may determine the success of circular nutrients. Therefore, their effectiveness to improve sustainability should vary from one city to another. We provide a tool to factor these city specific conditions in the frame of a prospective-regionalized LCA.

5. ACKNOWLEDGEMENTS

Thanks to the financial support of the ERC Consolidator Integrated System Analysis of Urban Vegetation and Agriculture (818002-URBAG) and from the research and innovation programme under the H2020 Marie Skłodowska-Curie Actions PROTEAN project (842460).

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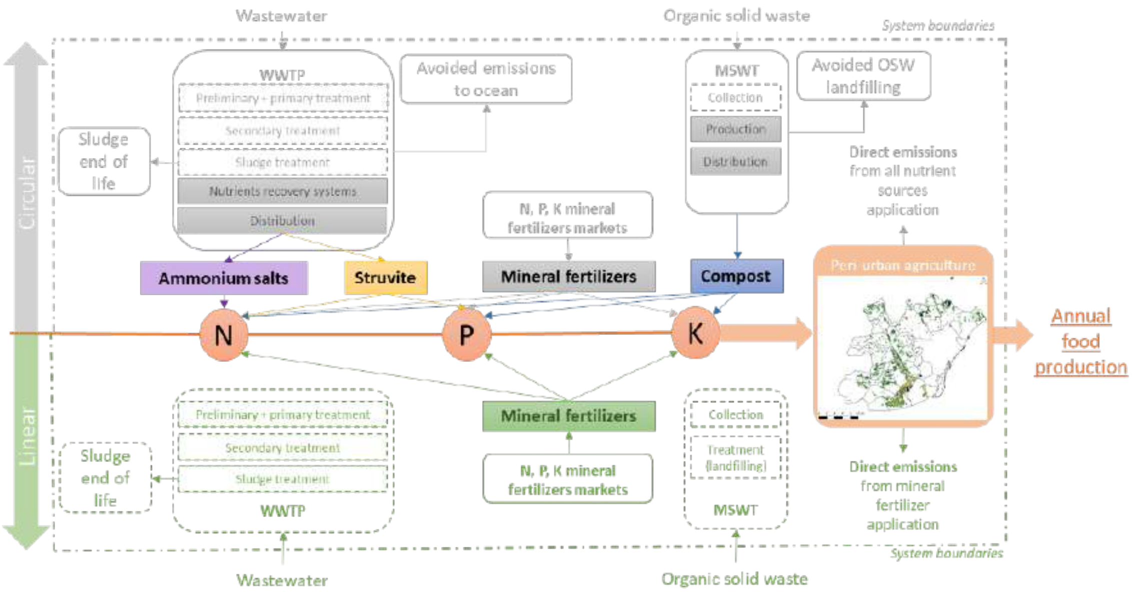

Figure 1. System boundaries for linear (in green) and circular (in grey) nutrient systems. The functional unit is the annual food production within the Metropolitan Area of Barcelona (AMB). Activities in dashed boxes are equal for the linear and circular systems and are therefore excluded from the inventory.

	S0 - Current areas							S4 - Projected areas						
	Per functional unit of 68716.3 tons of food per year (5568.5 Ha)							Per functional unit of 73673.5 tons of food per year (6984.4 Ha)						
Impact categories	Absolute impacts				% change vs MinFert			Absolute impacts				% change vs MinFert		
ADP - tons Sbeq/yr	MinFert	Struvite	Compost	Struvite + Ammoniun Salts	Struvite	Compost	Struvite + Ammoniun Salts	MinFert	Struvite	Compost	Struvite + Ammoniun Salts	Struvite	Compost	Struvite + Ammoniun Salts
ei391	0.11	0.10	0.05	0.11	✔ -6%	✔ -56%	✔ -5%	0.13	0.13	0.07	0.13	✔ -6%	✔ -46%	✔ -5%
ei391_Image_SSP2_Base_50	0.12	0.11	0.05	0.11	✔ -6%	✔ -57%	✔ -5%	0.15	0.14	0.08	0.14	✔ -6%	✔ -47%	✔ -5%
ei391_Image_SSP2_RCP26_50	0.12	0.11	0.05	0.12	✔ -6%	✔ -59%	✔ -4%	0.15	0.14	0.08	0.14	✔ -6%	✔ -48%	✔ -4%
FE_Reg - Tons Peq/yr														
ei391	1.69	1.70	0.59	1.96	✘ 1%	✔ -65%	✘ 16%	2.05	2.07	0.95	2.32	✘ 1%	✔ -54%	✘ 13%
ei391_Image_SSP2_Base_50	2.37	2.29	-5.84	2.76	✔ -4%	✔ -346%	✘ 16%	2.89	2.78	-5.33	3.26	✔ -3%	✔ -285%	✘ 13%
ei391_Image_SSP2_RCP26_50	1.00	0.91	0.29	0.84	✔ -8%	✔ -71%	✔ -15%	1.21	1.12	0.50	1.05	✔ -8%	✔ -58%	✔ -14%
GWP100 - Tons CO2eq/yr														
ei391	14812	14041	5129	13159	✔ -5%	✔ -65%	✔ -11%	17757	16873	8079	15988	✔ -5%	✔ -54%	✔ -10%
ei391_Image_SSP2_Base_50	14818	13999	2279	13125	✔ -6%	✔ -85%	✔ -11%	17761	16822	5228	15945	✔ -5%	✔ -71%	✔ -10%
ei391_Image_SSP2_RCP26_50	13896	12923	5056	11358	✔ -7%	✔ -64%	✔ -18%	16639	15524	7806	13954	✔ -7%	✔ -53%	✔ -16%
ME_Reg - Tons Neq/yr														
ei391	213	200	219	200	✔ -5.9%	✘ 2.9%	✔ -6.1%	256	242	262	241	✔ -5.6%	✘ 2.4%	✔ -5.8%
ei391_Image_SSP2_Base_50	213	200	219	200	✔ -5.9%	✘ 2.7%	✔ -6.1%	256	242	262	241	✔ -5.6%	✘ 2.3%	✔ -5.8%
ei391_Image_SSP2_RCP26_50	213	200	219	200	✔ -5.9%	✘ 2.9%	✔ -6.1%	256	242	262	241	✔ -5.6%	✘ 2.4%	✔ -5.8%
WC - m3/yr														
ei391	15.56	15.56	15.52	15.66	✔ 0.0%	✔ -0.3%	✘ 0.7%	23.85	23.85	23.81	23.96	✔ 0.0%	✔ -0.2%	✘ 0.4%
ei391_Image_SSP2_Base_50	15.56	15.56	15.50	15.66	✔ 0.0%	✔ -0.4%	✘ 0.7%	23.85	23.85	23.80	23.95	✔ 0.0%	✔ -0.2%	✘ 0.4%
ei391_Image_SSP2_RCP26_50	15.56	15.56	15.51	15.66	✔ 0.0%	✔ -0.3%	✘ 0.6%	23.85	23.85	23.80	23.95	✔ 0.0%	✔ -0.2%	✘ 0.4%

Table 1. LCIA results for current and projected UA areas, for three circular nutrient strategies.

An Ecodesign Framework for Sustainable Food Product Development

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1. INTRODUCTION

Ecodesign principles offer significant potential to address environmental challenges within agrifood chains and align with the Sustainable Development Goals (SDGs) [1]. This abstract explores the application of ecodesign strategies in the food production industry, focusing on sustainable sourcing (Design for Sustainable Sourcing – DfSS), optimized resource use (Design for Optimised Resource use – DfORU), and end-of-life optimization (Design for end of life – DfEOL). These points target specific points of the food supply chain, including the production stage, processing and distribution stage, and end-of-life stage, respectively. Furthermore, this study introduces innovative strategies for managing food biomass, representing a significant advancement in ecodesign implementation within the food production sector. Leveraging lateral knowledge transfer from other sectors where ecodesign has been successfully applied, this research pioneers the adaptation and integration of ecodesign principles into the complex and multifaceted realm of food production. These strategies, aim to enhance resource efficiency, minimize environmental impact, and promote sustainable practices throughout the agrifood chain. By integrating these pioneering initiatives into food production processes, this research not only contributes to advancing sustainable practices within the food industry but also facilitates cross-sectoral learning and knowledge exchange. The integration of these principles aims to reduce environmental impact, promote sustainable consumption and production, and contribute to broader sustainable development objectives [1].

2. METHODS

A comprehensive review of the literature on ecodesign principles and their application in the food production industry was conducted [1]. The review analysed various strategies, including sustainable sourcing of raw materials, optimisation of resource use during processing, and end-of-life optimisation to minimise waste generation. The potential synergies between ecodesign principles and the Sustainable Development Goals were also examined to understand their broader implications.

3. RESULTS AND DISCUSSION

The application of ecodesign principles in the food production industry offers a promising approach to addressing environmental challenges across the supply chain. Ecodesign encompasses strategies such as sustainable sourcing, optimised resource use, and end-of-life optimisation, targeting specific stages of food production (Figure 1) [1]. Sustainable sourcing involves transitioning to plant-based diets and implementing sustainable farming practices to reduce environmental impacts [1]. Optimising resource use entails improving industrial processes, adopting renewable energy sources, and reducing waste generation [1]. End-of-life optimisation aims to minimise food waste through reuse or repurposing of food biomass [1]. By integrating ecodesign principles into food production, significant reductions in greenhouse gas emissions, resource consumption, and environmental pollution can be achieved, aligning with Sustainable Development Goals (Figure 2) such as energy, economic growth, climate change mitigation, and biodiversity conservation.

4. CONCLUSIONS

In conclusion, ecodesign principles, including Design for Sustainable Sourcing (DfSS), Design for Optimised Resource Use (DfORU), and Design for End-of-Life Optimisation (DfEO), offer promising strategies for reducing environmental impacts in agrifood chains. By targeting production stages, such as raw material selection and agricultural practices, significant efficiency improvements can be achieved. Additionally, implementing measures for nutrient recycling and promoting plant-based dietary options further enhance sustainability. However, further research and education are needed to fully realise the potential of ecodesign principles in food production.

5. ACKNOWLEDGEMENTS

This work was supported by the European Union’s Horizon 2020 research and innovation programme through the project “Realising Dynamic Value Chains For Underutilised Crops” (RADIANT), grant agreement No. 101000622. The authors would also like to show gratitude for the National Funds from FCT—Fundação para a Ciência e Tecnologia through project UIDB/50016/2020.

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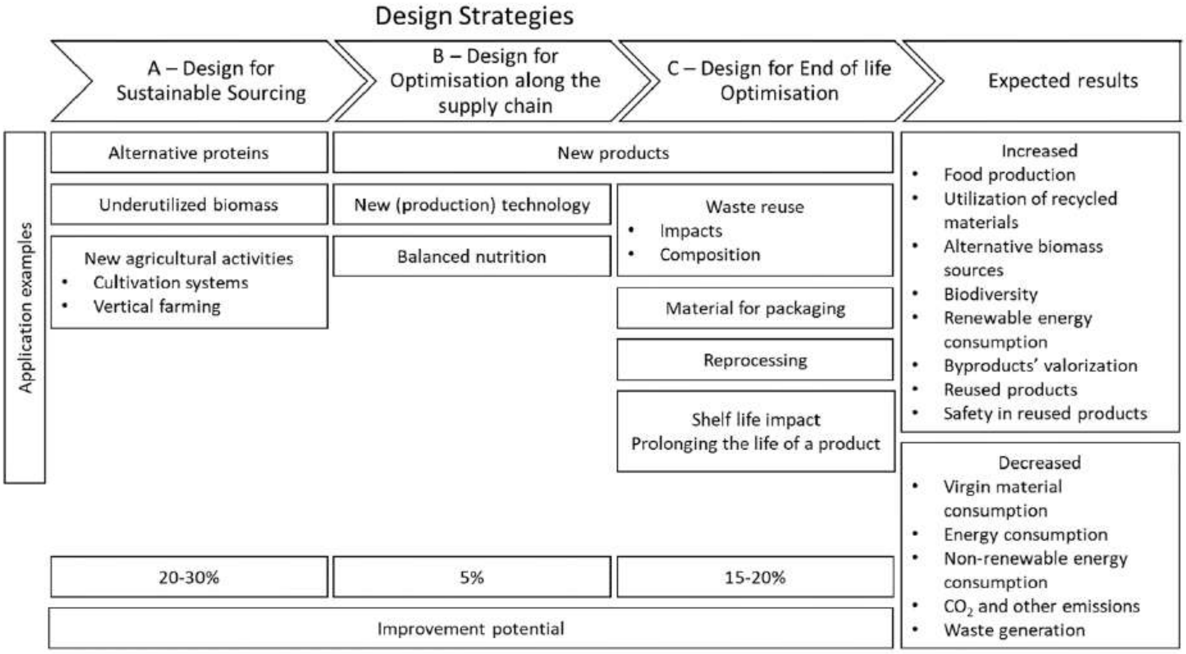

Figure 1. Conceptual ecodesign framework for sustainable food production and compilation of literature suggestions. Implementing the suggested examples can lead to a variable improvement in the system's environmental impact, from 5% to 30% [1], depending on the target point. Source: authors.

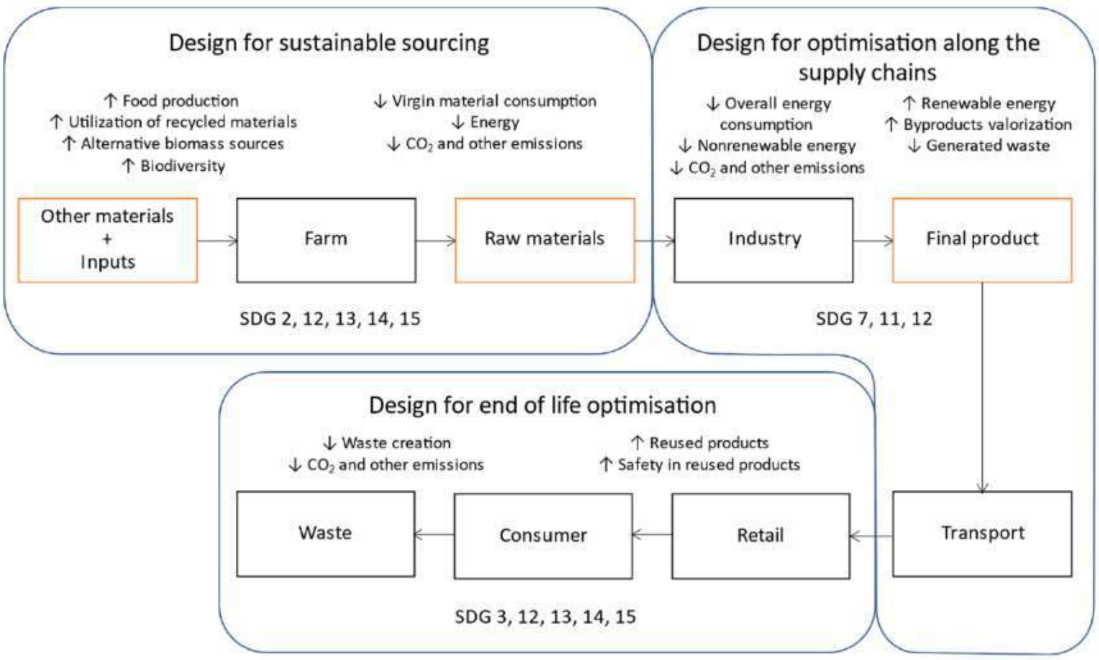

Figure 2. Potential implementation of the three main components of the ecodesign principles in a generic food chain. This implementation is in line with relevant Sustainable Developing Goals (SDGs). Possible outcomes of implementing such concepts can be found inside the same rectangle. Downwards arrow—Decrease; Upwards arrow—Increase. SDGs: 2—Zero Hunger; 3—Good Health and Well-being; 7—Affordable and Clean Energy; 11—Sustainable Cities and Communities; 12—Responsible Consumption and Production; 13—Climate Action; 14—Life Below Water; 15—Life on Land. Source: authors.

Life Cycle Assessment for the eco-design of an innovative strategy for the valorization of whey in a bioeconomy approach

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1. INTRODUCTION

Whey, a byproduct of cheese production, is widely utilized in the food industry thanks to its lactose and serum protein content. In our case study, a cheese maker and a detergent producer have collaborated to recover whey from the cheese dairy. The objective is to produce lactic acid from the whey in an eco-designed way for use in detergents, substituting the current organic acids (citric and lactic acids) sourced from suppliers in Europe and China. A laboratory proof of concept has validated the project's feasibility. Given the proximity of the companies, transportation and its associated environmental impact will be minimized. However, the challenge lies in reducing the system's overall environmental impacts. To achieve this, an environmental assessment of the current situation must be conducted as the first step.

2. METHODS

The LCA of the current route aims to quantify and analyze the environmental impacts generated by the production of detergents made from organic acids and those caused by the production of whey required for the manufacture of lactic acid. This will allow quantifying the potential environmental benefits of the new technological route. The functional unit of the LCA is the annual quantity of citric and lactic acid required to produce three commercial detergents identified by the manufacturer. From mass balance calculations, 23 tons of whey are needed to make 1 ton of lactic acid. These values were chosen for the functional unit.

Inventory data were collected at the cheese factory and the detergent manufacturer, completed by inventory data from Ecoinvent and Agribalyse. Mass-based allocations on a dry basis at the cheese factory were made to distribute the environmental impacts between the products (cheese, whey, cream). The LCA was carried out following ISO 14044 (2006) on SimaPro 9.5.0.0 software using the “Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalization and weighting set” method. Sensitivity analyses have been carried out to take into account the allocation factor, the quantity of whey in the reference flow, and the characterization method.

3. RESULTS AND DISCUSSION

As expected, milk production constitutes the predominant source of environmental impacts in the studied system (**¡Error! No se encuentra el origen de la referencia.**). Surprisingly, the production of organic acids emerges as the second major contributor to these impacts. Given the energy-intensive nature of production processes, the environmental footprint of this stage is contingent on the energy mix within the production region. Consequently, the production of 1 ton of Chinese citric acid carries an environmental impact comparable to that of 2.5 tons of European citric acid, with China's energy mix heavily reliant on coal. The other production stages do not contribute significantly to the environmental impacts of the current route.

In the future eco-designed route, the production of organic acids currently outsourced will be replaced by the production of lactic acid from whey from the cheese factory. Thus, the stages of processing whey and producing organic acid and their transport will be replaced by a single stage of lactic acid production according to an eco-designed process. Assuming negligible impacts from the new route, the maximum potential impact reduction for each impact category between the current production route and the eco-designed route was calculated. Through sensitivity analyses involving the allocation factor (economic vs. mass on a dry basis), the quantity of whey in the reference flow (15 - 30 tons), and the characterization method (ReCiPe MidPoint H vs. EF), we determined the maximum potential reduction ranges (
Table 1) which went from 3% for land use to 80% for mineral and metal resource use, corresponding to 56% in average of all the environmental impacts.

4. CONCLUSIONS

The significant environmental impacts of the current technological route are due to milk production, the processing of which generates whey as a by-product, and citric acid production. The new technological route will not be able to reduce the impact of milk production. However, it will reduce the impacts of organic acid production and transport, with an average potential reduction of 56% of the environmental impacts. Therefore, the project's next stage will consist of eco-designing this new technological route, using a prospective LCA approach to anticipate its industrial implementation in the future.

5. ACKNOWLEDGMENT

The ECOLACTIC project receives financial support from ADEME and ANRT. The authors would like to thank Stéphane Lepizzera, Géraldine Mahler, Laura Gavalda, Thierry Vagnat, Luidgi Résidant and the teams at fromagerie Masson and Laboratoires Rochex for their help.

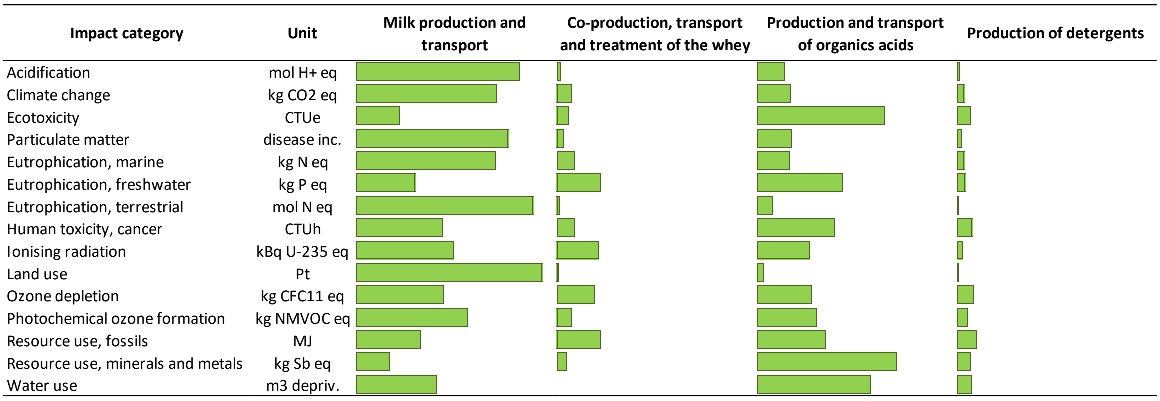

Figure 1: Contribution analysis of the steps of the current production route to the environmental impacts generat ed by the system

Table 1: Range of maximum potential reduction in environmental impact between the current route and the eco-designed route considering the different sensitivity analyses (to allocation factor at cheese-factory, to amount of whey in reference flow, and to the characterization method)

Damage category	**Range of maximum reduction o f environmental impacts**
Acidification	12% - 24%
Climate change	17% - 33%
Ecotoxicity, freshwater	57% - 77%
Particulate matter	16% - 30%
Eutrophication, marine	20% - 35%
Eutrophication, freshwater	59% - 74%
Eutrophication, terrestrial	7% - 15%
Human toxicity, cancer	38% - 55%
Ionizing radiation	26% - 45%
Land use	3% - 7%
Ozone depletion	7% - 55%
Photochemical ozone formation	30% - 47%
Resource use, fossils	46% - 58%
Resource use, minerals, and metals	14% - 80%
Water use	38% - 60%

Cocoa and olive oil: sustainability assessments

15

Land use carbon emissions linked to Ivorian cocoa exports

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1. INTRODUCTION

Land use change (LUC) impacts of agricultural commodities can exhibit significant large regional differences within producing countries. However, it is a challenge within Life Cycle Assessment (LCA) to reliably account for the spatial variability of LUC and related environmental impacts. Information on the sourcing origin of imported agricultural commodities is often unknown, making it challenging to reliably account for LUC impacts in specific supply chains. Spatially-explicit commodity supply-chain maps, can act as powerful tools to reduce the uncertainty in LUC impacts. In this study, we estimate LUC greenhouse gas emissions of cocoa exports from Ivory coast, based on publicly-available remote-sensing and supply chain data linking departments of origin to international markets via trading companies.

2. METHODS

Our goal was to understand the environmental performance of Ivory Coast cocoa exported to different countries (i.e., France, Netherlands, Lithuania, Spain and Indonesia) in terms of LUC emissions. The system boundary was cocoa production at farm gate and exported in 2020 limited to the agricultural phase and only included the sub-stage of LUC. The functional unit is one tonne of cocoa at the farm gate produced in Ivory Coast and exported as different products in 2020.

We overlayed satellite-derived maps of cocoa (Kalischek et al. 2023), deforestation (Vancutsem et al. 2021) and carbon density (Soto-Navarro et al. 2020) to estimate emission factors due to the expansion of cocoa plantations. LUC emissions attributed to cocoa expansion in 2020 were retrospectively quantified for the 10-year window starting before 2016 as it takes four years for cocoa to produce the first fruits after planting. The total deforestation emissions were subsequently annualised by the number of years of harvest (10 years here).

We use the Trase approach to link exports of agricultural commodities back to the jurisdiction of production, following Renier et al. (2023). We cannot trace the cocoa origin department of trade flows in untransparent or indirect supply chains. For these untraced flows, we assumed volume-weighted country-average LUC emissions for that export year.

3. RESULTS AND DISCUSSION

The total LUC emissions linked to the export of cocoa from Ivory Coast in 2020 reached 9.36 Million t CO_2-eq, more than 30% of Ivory Coast´s annual greenhouse gas emissions, of which the majority was imported into the European Union. We find a large sub-national variability in LUC emissions across producing departments. The largest LUC emissions are observed in the departments of the district Montagnes where cocoa production is linked to the conversion of carbon-rich forests. Importing cocoa from this district leads to up to nine times higher LUC emissions compared to the national Ivory Coast average (4.35 t t^{-1}). Among the importing countries, Indonesia had the largest LUC emissions (4.98 t t^{-1}), due to large sourcing from Biankouma (Figure 1) compared to other countries such as the Netherlands (3.98 t t^{-1}), directly importing the largest volumes of cocoa (Figure 2). We also found that for some countries the lack of traceability is large (e.g., Spain, Lithuania, Indonesia), reducing the capacity to direct attention to LUC hotspots they are linked to through their sourcing.

4. CONCLUSIONS

Our study illustrates that firstly there is a high subnational variability in LUC emissions for cocoa, secondly that consuming countries are linked to these emissions to different extents depending on their sourcing pattern and thirdly that estimating reliable LUC emissions is more challenging for countries whose supply chains are less transparent.

5. ACKNOWLEDGEMENTS

This work is supported by the Gordon and Betty Moore Foundation (7703.01), Norway's International Climate and Forest Initiative (QZA-21/0156), Quadrature Climate Foundation (01-21-000098), FNRS (PINT MULTI/BEJ—R.8002.20), Formas "Sustainable sourcing policies for biodiversity protection, climate mitigation and improved livelihoods in the cocoa sector" (2020-02482) and Horizon 2020 ERA Joint COFUND Call on "Biodiversity and Climate Change" (2020-02482).

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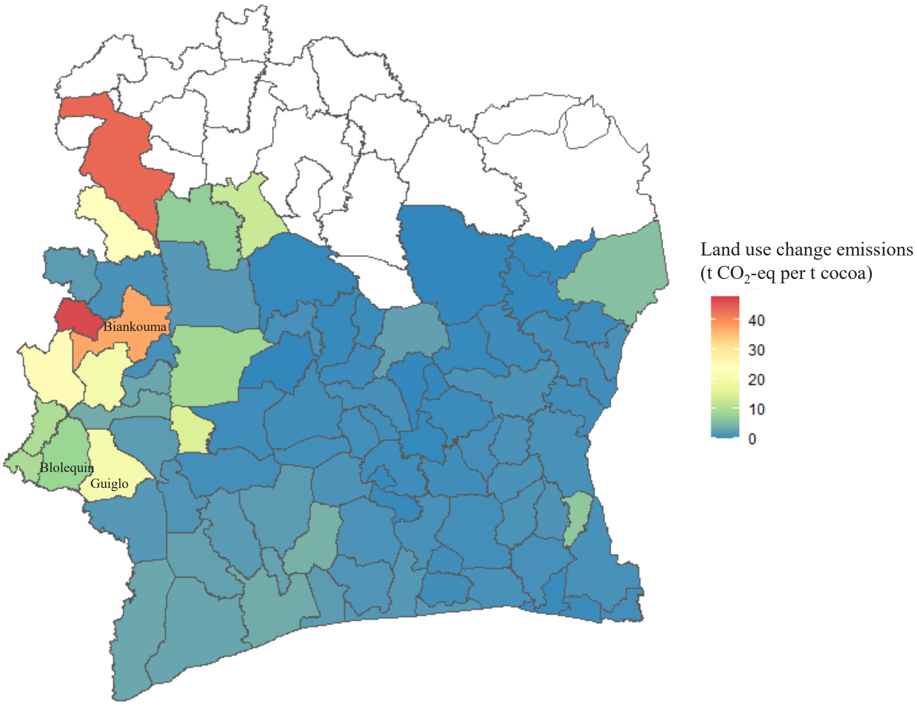

Figure 1. Land use change emissions of cocoa producing departments in 2020, as CO_2-eq. per tonne cocoa. ($t\ t^{-1}$).

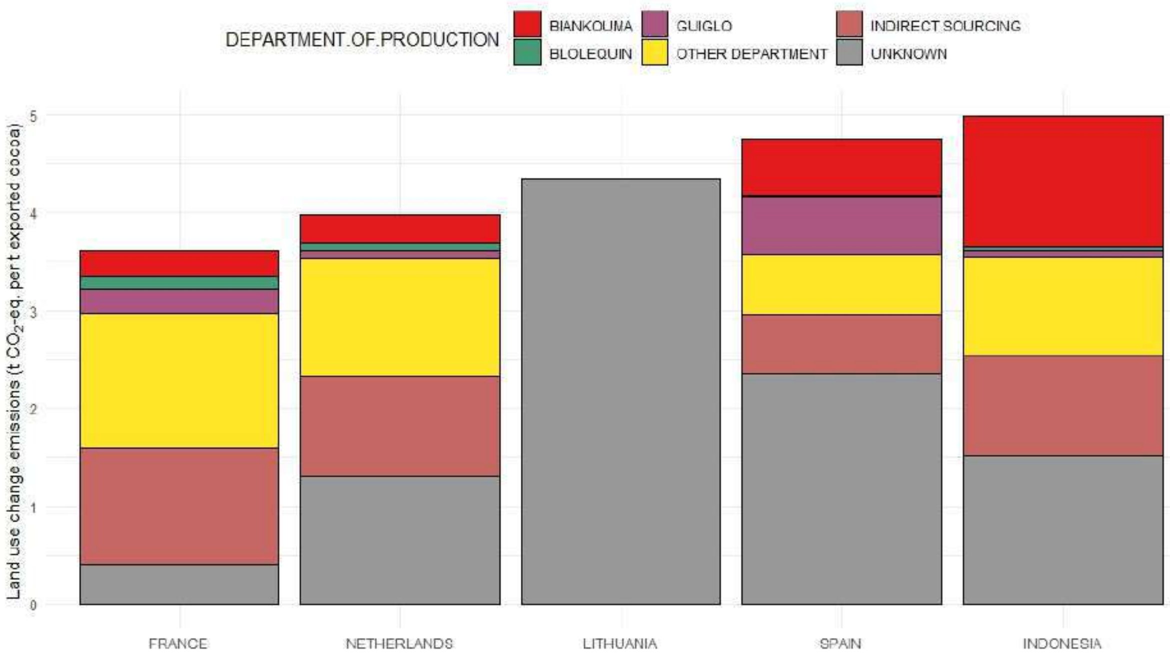

Figure 2. Land use change emissions linked to Ivorian coast cocoa exports to different importing countries.

A Landscape-scale Biodiversity Impacts Analysis of Côte d'Ivoire's Cocoa Cultivation Along Export Supply Chains

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1. INTRODUCTION

The increasing impact of agricultural production on biodiversity is a major global problem. Around 86% of threatened species are directly affected by the conversion of natural habitats to agricultural land[1]. The complexity of global supply chains places an additional burden on biodiversity, as a third of these impacts are embodied in traded goods, distorting the balance of environmental responsibility[2,3]. Conventional methods for assessing tele-connected biodiversity impacts from production to demand along agricultural supply chains lack spatial granularity in both, detailed impact assessment and trade analysis. This study addresses this gap by using cocoa cultivation in Côte d'Ivoire as a case study to introduce a refined methodology.

2. METHODS

We initiated our study by developing a harmonized land use map for Côte d'Ivoire, which served as the basis for biodiversity intactness modelling. This was followed by a detailed assessment of the biodiversity impacts of cocoa cultivation using landscape-scale biodiversity models. Our approach used the Biodiversity Impacts Metric (BIM), a met ric designed to capture biodiversity impacts by integrating two critical components: local biodiversity intactness, as indicated by mean species abundance (MSA), and global biodiversity importance, as reflected by species range rarity. We then linked landscape-scale biodiversity impacts (global loss equivalence) with sub-national export supply chains. This step enabled us to track the tele-connected biodiversity impacts of cocoa cultivation driven by exporting groups and importing countries specifically. Subsequently, our enhanced spatially explicit approach offers the possibility of multiple assessments. We pinpointed the impact hotspots in cocoa production and export. A comparison was made between the biodiversity impacts of full-sun cocoa cultivation and agroforestry systems. We also highlighted the disparity in biodiversity impacts from absolute vs. relative perspectives. Our methodological framework is shown in Figure 1.

3. RESULTS AND DISCUSSION

- The harmonized land use map that we constructed for Côte d'Ivoire has enhanced spatial detail, capable of reflecting the landscape characteristics of Côte d'Ivoire.
- Cocoa cultivation accounts for ~44% of the biodiversity impacts in cocoa cultivation areas (Figure 2a), with >90% attributable to cocoa exports.
- Figure 2b shows the biodiversity impacts per ton of cocoa produced in different production departments, exhibiting strong spatial heterogeneity with differences between departments reaching up to a factor of five, as a function of differences in yield as well as BIM.
- European and North American countries have the largest biodiversity footprint (Figure 2c). Asian countries have a higher biodiversity impact per ton of cocoa beans imported.
- We found that agroforestry systems overall have lower biodiversity impacts than full-sun cocoa. However, this is not always the case, especially when agroforestry systems are established in areas of high biodiversity importance, which leads to high BIM.
- A disparity in biodiversity impacts between absolute and relative perspectives was identified: cocoa cultivation in departments like Guiglo can account for up to 30% of the local impact share, while other departments can have higher absolute impacts.

4. CONCLUSIONS

Using the example of cocoa cultivation in Côte d'Ivoire, a novel method is presented that can be used to accurately model and track the biodiversity impacts along the export supply chain. This method can be adapted to global scale studies by integrating global datasets and can be extended to other agricultural activities and areas to help policymakers, producers, and consumers make informed decisions for more sustainable food consumption.

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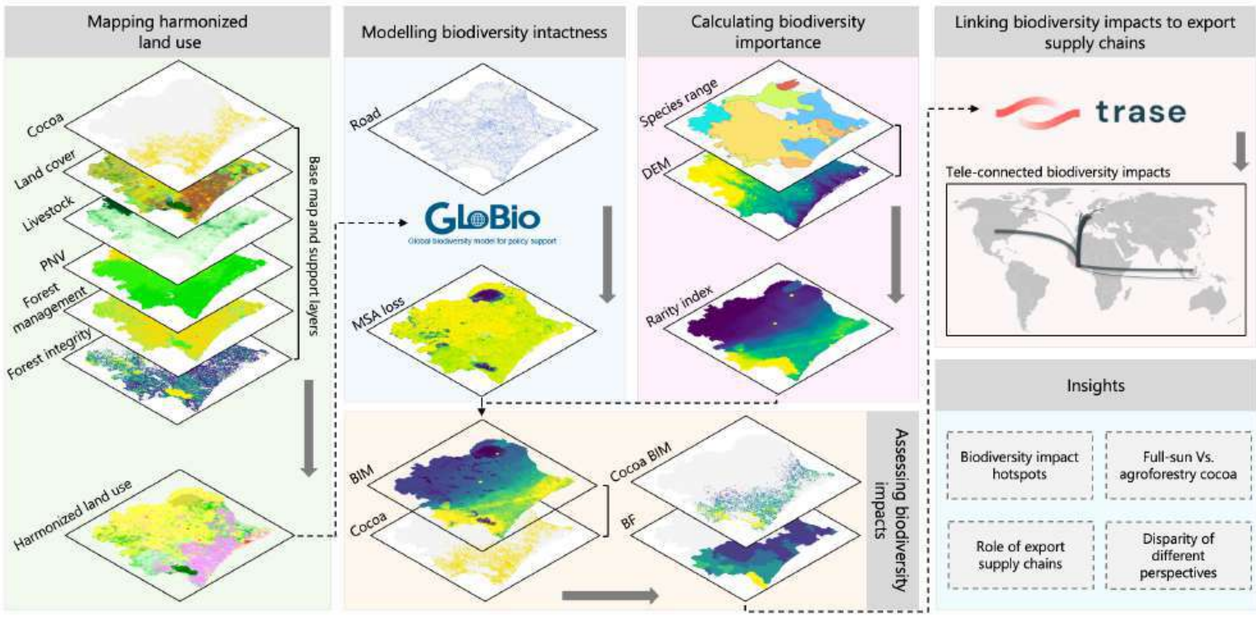

Figure 1. The methodological framework of this study: (1) The process begins with the development of a harmonized land use map based on earth observations and land use statistics; (2) The harmonized map is then fed into the GLOBIO model to estimate the biodiversity intactness, using mean species abundance (MSA) as an indicator; (3) Biodiversity importance is calculated at the grid cell scale using species range and Digital Elevation Model (DEM) data; (4) Biodiversity impact metric (BIM) is then calculated by multiplying the biodiversity intactness loss and biodiversity importance. (5) Trase supply chain data allows for the tracking of tele-connected biodiversity impacts.

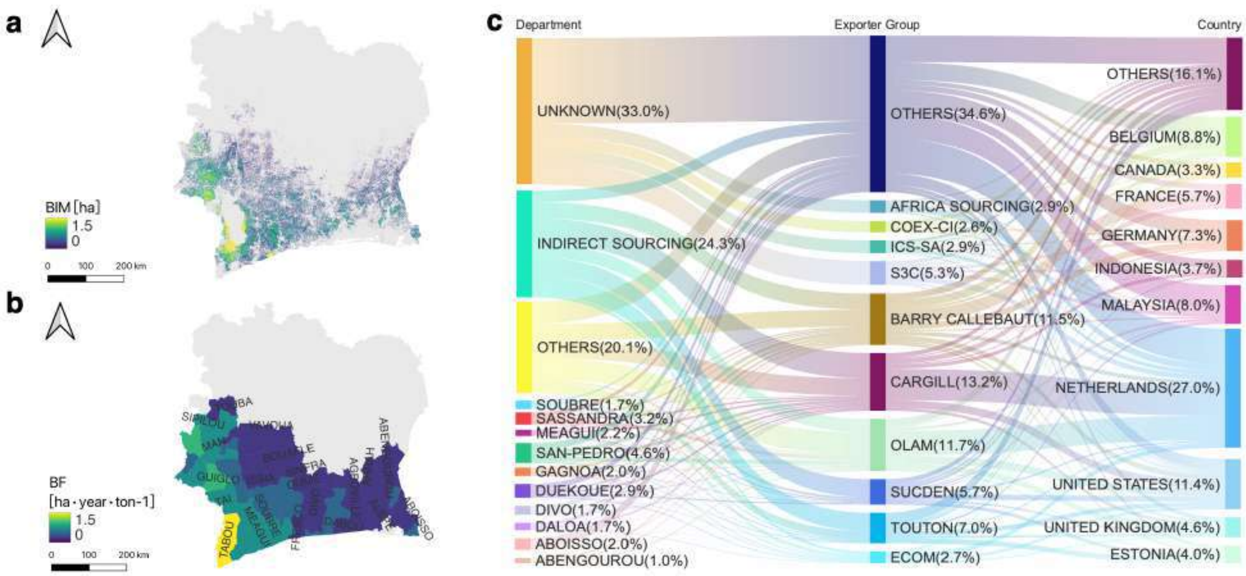

Figure 2. (a) Spatial distribution of biodiversity impacts (BIM) of cocoa cultivation in Côte d'Ivoire. (b) Spatial distribution of the biodiversity impacts per ton of cocoa beans produced (BF) in each department. (e) Biodiversity impacts flow along Côte d'Ivoire's cocoa export supply chain. Production departments are on the figures' left, exporter groups are in the middle, and importing countries are on the right.

Social LCA to Support Decision-Making in the Cocoa Supply Chain

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1. INTRODUCTION

Most of the world's cacao comes from the Ivory Coast, where its production has an opaque supply chain, hindering companies' sustainability goals (Nitidae, 2021). In this frame, Colruyt Group conducted a Social Life Cycle Assessment (S-LCA) of cocoa farming in Ivory Coast to assess the effectiveness of an internal value chain project. S-LCA is an emerging tool for assessing social impacts, but still faces challenges like data complexity and sector-specific issues. This communication highlights the learnings of this study in S-LCA implementation and stresses the importance of interlinking social, economic, and environmental aspects.

2. METHODS

The S-LCA was conducted in accordance with the UNEP Guidelines(2020), employing an attributional static perspective. Relevant social themes were identified *via* a survey sent to cocoa supply chain actors, empolying a 50 % threshold with a ±20 % bandwidth for discussion. Qualitative data was collected *via* interviews with stakeholders from the cacaosupply chain and cacao farmers farmers from regions benefiting from specific social projects. This allowed cross-referencing the farmer's perspective with hotspots identified through value chain interviews, and enabeled the proposal of concrete social actions for improvements.

3. RESULTS AND DISCUSSION

3.1 S-LCA Results

The results show that improvements in the social well-being of farmers are observed through various stakeholder actions, mostly through projects on improving general infrastructure, direct purchase from the farmers, and various training programs.

3.2 Limitations and Suggestions

Throughout the assessment, three main areas of difficulty were encountered: allocation, data collection, and social themes.

Allocation: the mass balance chain of custody model typically used in the chocolate supply chain complicates the allocation of social impacts to the final product.

Data Collection: Since existing S-LCA databases lack a baseline scenario for cocoa cultivation in Ivory coast, and social issues are geography and product specific, relevant social themes were identified through stakeholder surveys. Moreover, additional data collection was required to compare different cocoa sources to a general scenario. Finally, cross referencing the results from the stakeholders with those from the farmers helped counteract the qualitative nature of the collected data.

Social Themes: The interviews highlighted concerns about cocoa-driven deforestation and the impact of climate change on farming, which are challenging to integrate into the existing UNEP social impact themes as they overlook the impact on farming communities. To bridge this gap, the category "environmental and climate change issues" was added at the local community level to better link environmental and social concerns, particularly prevalent in the agricultural sector. Finally, an "economic viability" indicator was introduced to assesses the link between a project's social impact and its economic sustainability, as considerable planning is required to successfully scale up social efforts while maintaining economic viability.

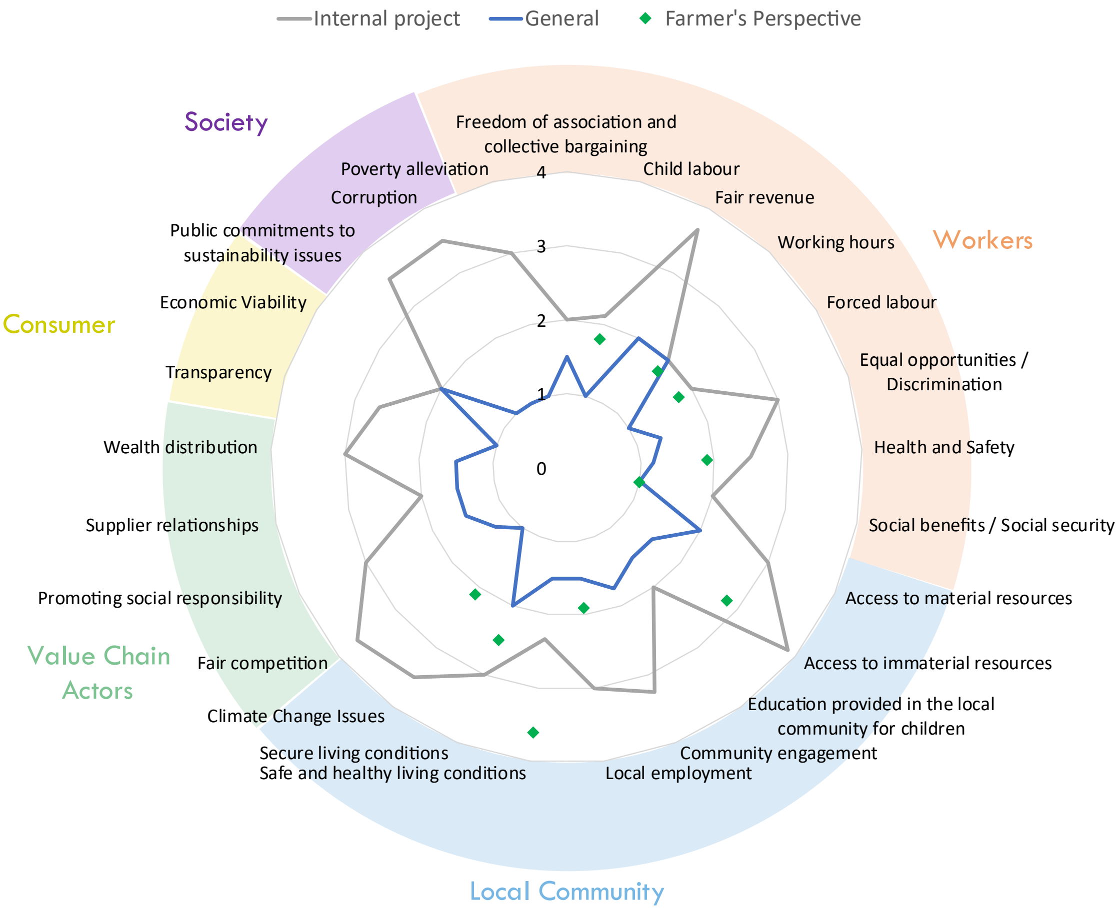

Figure 1. Spider graph comparing the social performance of the general cocoa cultivation and trade in Ivory Coast (blue), a tablet from the internal value chain project (grey), and the farmer's perspective (green markers) across all social impact categories.

Plastic biopolymers: a second life to olive oil

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1. INTRODUCTION

Olive oil is one of most consumed and essential oils in Atlantic and Mediterranean diets. However, it contributes significantly to lipidic waste, with a mismanagement rate of 28 % in industry and food sector; and 95 % in private households (UE Studio, 2023). Separate collection rates should be increased, especially from private households, to reduce pollution and to provide it added value.

The national funded project ECOPOLYVER (https://biogroup.usc.es/ecopolyver) aims to valorize industrial lipidic waste streams by producing polyhydroxyalkanoates (PHA), i.e. biodegradable polymers produced by microorganisms from renewable sources (Oliveira et al., 2016). After having proved the feasibility of the production process under different conditions (Argiz et al., 2021; Roibás-Rozas et al., 2021), efforts are focused on the extraction stage which so far seems to be the cost and environmental bottleneck (Saavedra del Oso et al., 2021) as well as on the end-of-life (EoL) due to the data gaps and methodological limitations that are still present (Roibás-Rozas et al., 2022).

The objective of this work is twofold: on the one hand, PHA extraction methods are revised and evaluated to select the alternative(s) with the lowest economic and environmental impacts; and, on the other photooxidation times of plastic biopolymers ending (and staying) on terrestrial environments are obtained to calculated the associated characterization factors (CFs) in order to include also the impacts associated to the degradation of plastic biopolymers before reaching the oceans (generally assumed to be the final environmental compartment where mismanaged plastic waste will end up and the focus of the MarILCA project (https://marilca.org/)).

2. METHODS

To define the best PHA extraction method, more than 30 papers and patents were identified by a literature review and after screening, 9 extraction scenarios using different biomass inhibition and extraction solvents (Table 1) were constructed.

To calculate the photooxidation times of plastic biopolymers, four samples based on different combinations of PHA and polylactic acid (PLA) with triethyl citrate (TC) or coconut oil (COCO) as additives (Table 2) and provided by the Spanish national association of canned fish and seafood manufacturers (ANFACO-CECOPESCA) were used. Accelerated photoaging treatments were conducted using a Suntest XLS+ and changes in mass, functional groups, colour, melting and glass transition temperatures were performed to evaluate the photodegradation of plastic biopolymers (more details on Vazquez-Vazquez et al. (2024), paper in preparation).

3. RESULTS AND DISCUSSION

In the PHA extraction process, the biomass inhibition method before the extraction and the type of solvent were identified as key parameters. The extraction method is currently being defined on an industrial scale to quantify the environmental impacts of the different extraction methods.

It has been proved that the release of additives is earlier than the fragmentation of the samples, which remain constant until the photooxidation reaction starts (2,000 hours of experimentation). The required time for complete photooxidation has been compared with polypropylene (PP) and low-density polyethylene (LDPE) (Figure 1), two petrochemical plastics with similar properties to plastic biopolymers. CFs for plastic biopolymers in terrestrial compartment will be developed and compared with CFs for PP and LDPE developed from literature data.

4. ACKNOWLEDGEMENTS

This work has been financially supported by the ECOPOLYVER project (ref. PID2020-112550RB-C21). Besides, BIOCEN+ project (ref. 2021-PN070) is also thanked for plastic biopolymer samples provision. Photodegradation experiments were conducted at CIQUS and its laboratory staff is deeply recognized for their support and guidance. Finally, Brais Vázquez-Vázquez, Ángeles Val del Río and Almudena Hospido belong to a Galician Competitive Research Group (GRC ED431C 2021/37), programme co-funded by FEDER (UE).

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Method of extraction	Biomass inhibition solvent	Extraction solvent
1	NaClO	NaOH
2	NaClO	H_2O_2
3	NaClO	NaOH + H_2O_2
4	NaClO	CH_3-COO-CH_2-CH_3
5	H_2SO_4	NaOH
6	H_2SO_4	H_2O_2
7	H_2SO_4	NaOH + H_2O_2
8	H_2SO_4	CH_3-COO-CH_2-CH_3
9	H_2SO_4	NaClO

Table 1. Different extraction methods identified based on the biomass inhibition and extraction solvents.

Sample	% PHA	% PLA	% TC	% COCO
1	50	50	0	0
2	30	70	0	0
3	27	63	10	0
4	27	63	0	10

Table 2. Composition of the plastic biopolymers samples used during the experimentation. PHA: polyhydroxyalkanoate; PLA: polylactic acid; TC: Triethyl citrate; COCO: coconut oil.

Figure 1. Photooxidation times of plastic biopolymers, polypropylene (PP) and low density polyethylene (LDPE) at different locations worldwide.

Environmental Assessment of the daily intake of polyphenols derived from Extra Virgin Olive Oil in the Mediterranean Population

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1. INTRODUCTION

The olive oil industry is significant to Mediterranean countries, impacting their economies, public health, and culinary heritage. In 2022/2023, Europe produced 1.5 Mt of olive oil, accounting for 55% of world production and generating 4 billion € in export revenues. Olive oil is the primary fat source in Mediterranean diet and is rich in health-beneficial polyphenols like oleuropein, known for anti-inflammatory properties (Zamora-Ros et al., 2016). Despite its economic significance, its production has several environmental costs (wastewater and use of fertilizers) (Guarino et al., 2019). Hence, the olive oil production process needs to evolve towards more sustainable practices. This study specifically aims to assess the environmental impact of consuming polyphenols from Extra Virgin Olive Oil (EVOO) in Mediterranean populations, focusing on the integration of both environmental and qualitative-nutritional aspects, as to our knowledge, no studies consider the environmental burdens linked to this aspect.

2. METHODS

The Life Cycle Assessment (LCA) methodology (ISO 14040, 2006) was used to estimate the environmental burdens from a "farm to olive oil mill gate" (Figure 1). The Functional Unit chosen corresponds to the daily intake of oil-derived polyphenols (Zamora-Ros et al., 2016). Data on agronomic practices are primary data from a farmer located in Apulia (Italy) growing *Coratina*, while secondary data derive from the Ecoinvent® database v.3.10 (FitzGerald D et al., 2023). Concerning the olive oil extraction stage, information was taken from the literature (Guarino et al. 2019). The environmental profile was estimated considering the characterisation factors of the ReCiPe 2016 (H) midpoint method (Huijbregts et al., 2016), and the Simapro® software v9.5. (PRé Consultants, 2023) was used to implement the life cycle inventory data.

3. RESULTS AND DISCUSSION

Table 1 shows the environmental burdens associated with the daily intake of 18mg of polyphenols, which corresponds to 30g of EVOO. According to the results (Figure 2), the agricultural subsystem is the primary environmental hotspot, contributing over 80% to all impact categories considered. This is mainly due to the extensive use of fertilizers and the harvesting phase. Specifically, the combined use of inorganic fertilizers and the spreading of Wet Olive Pomace (WOP) on fields contribute significantly to emissions, especially affecting the FE and ME categories. The harvesting phase is particularly impactful due to the use of large machinery (harvester machines), which are responsible for fuel-related emissions. Therefore, improvements should be considered in the short to medium term to reduce environmental loads. For example, the contribution of N-P-K from WOP should be considered to avoid over-fertilization with inorganic fertilizers. Additionally, alternative harvesting solutions, such as battery-powered shakers, should be adopted to prevent emissions from fuel combustion.

4. CONCLUSIONS

This study reveals the need for environmentally sustainable improvements in olive oil production, especially in agricultural practices. Considering the soil-amending potential of a by-product like WOP and adopting alternative methods for the harvesting phase will not only alleviate environmental burdens but will also align with the objectives of the new Common Agricultural Policy and the European Green Deal to promote environmentally, economically, and socially sustainable agriculture.

5. ACKNOWLEDGEMENTS

This research has been partially supported by the project Transition to sustainable agrifood sector bundling life cycle assessment and ecosystem services approaches (ALISE) (TED2021–130309B-I00) funded by MCIN/AEI /10.13039/501100011033 and by the European Union NextGenerationEU/ PRTR.

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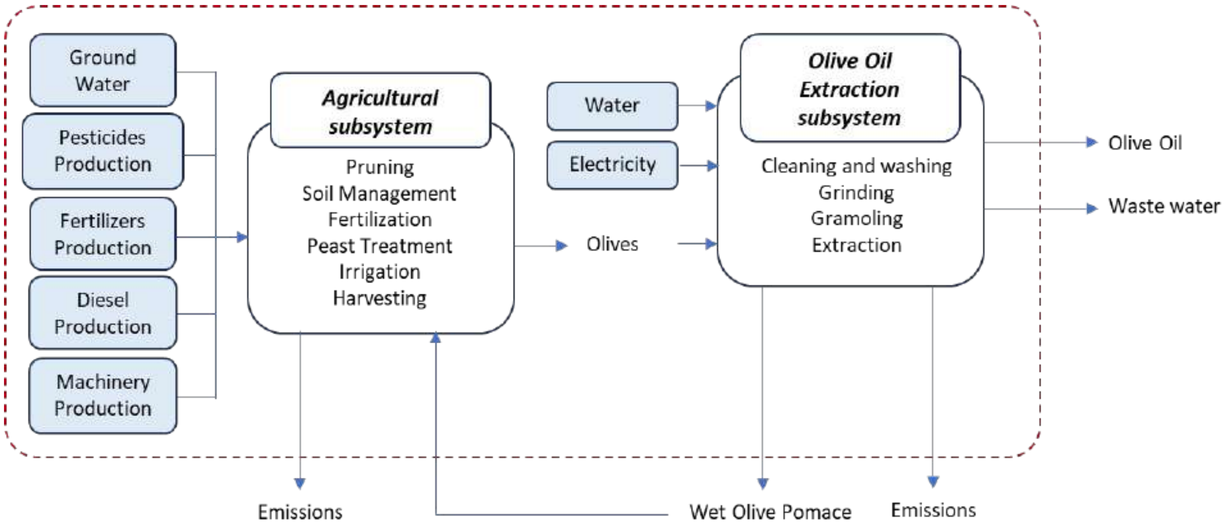

Figure 1. System boundaries of the case study

Table 1. Environmental profile of the case study

Impact Category	Unit	Agricultural subsystem	Olive Oil Extraction subsystem
Global Warming	kg CO_2 eq	$1,27·10^{-1}$	$3,14·10^{-3}$
Freshwater Eutrophication	kg P eq	$1,13·10^{-5}$	$9,52·10^{-7}$
Marine Eutrophication	kg N eq	$3,44·10^{-4}$	$7,51·10^{-7}$
Terrestrial Ecotoxicity	kg 1,4-DCB	$6,06·10^{-2}$	$6,99·10^{-3}$
Freshwater Ecotoxicity	kg 1,4-DCB	$9,50·10^{-5}$	$2,21·10^{-5}$
Fossil Resource Scarcity	kg oil eq	$1,85·10^{-2}$	$9,67·10^{-4}$
Water Consumption	m^3	$4,35·10^{-4}$	$6,38·10^{-5}$

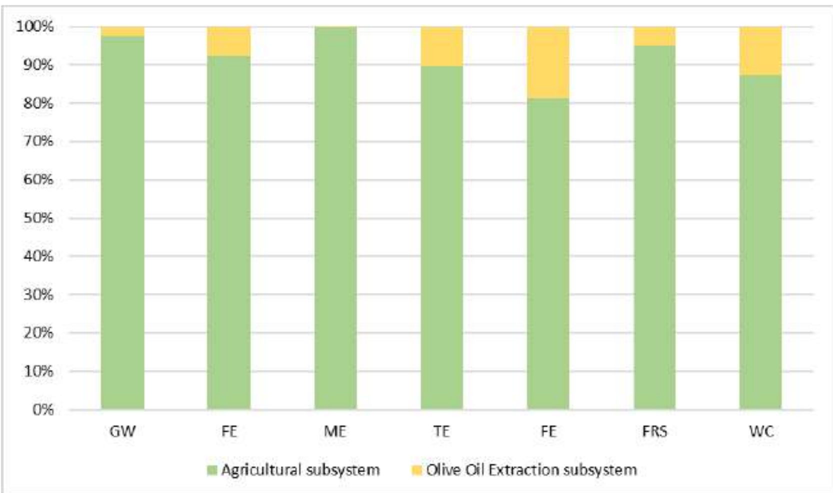

Figure 2. Characterised results of the case study

Life cycle inventory: modelling, databases and tools (I)

A food biodiversity database has been born!

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1. INTRODUCTION

The link between climate impact and food production is well established. The connection between food and many other environmental impacts is less explored, especially biodiversity impacts (Tripathi et al., 2022). To fill this gap, RISE has developed a database which features the biodiversity footprint of food items. The focus is on food products consumed in Sweden, which includes food from Swedish agriculture but also imported food and food ingredients from all over the world. The food biodiversity database is open access and was released in December 2023, see screen dump in Figure 1.

The database can be used e.g. to compare meat vs vegetarian options, compare meals and diets, compare production systems, countries of origin, to identify synergies and trade-offs with other sustainability aspects, for decision making within companies, for setting and following up on biodiversity targets, B2B information, as well as communication to consumers.

2. METHODS

There are several methods to assess the biodiversity impact of food production and consumption that can be implemented within existing LCA-frameworks, on midpoint or endpoint level (Damiani et al., 2023). Midpoint impact assessments are often based on the land use (area and intensity) in combination with parameters linked to where the production takes place and thus what biodiversity values can be affected. In our Biodiversity database we use the midpoint method described in Chaudhary & Brooks (2018), the method that was recommended for use in LCA by the UNEP-SETAC Life Cycle Initiative. The Chaudhary & Brooks method provides characterization factors for potential biodiversity loss in 804 different ecoregions for mammals, birds, amphibians, reptiles and plants, and a taxa-aggregated unit resulting from different types of anthropogenic land use.

Several challenges have occurred during the development of the database. First of all, biodiversity assessment needs specific information of origin as land use impacts vary largely between areas. Here we had to settle for country-level assessment since traceability in the food chain is an issue, especially for products with several ingredients and for animal feed. Further, the chosen biodiversity assessment method was not able to calculate positive impacts on biodiversity, nor in a good way represent impact of organic farming, so adjustment and additions had to be made to the original method.

3. RESULTS AND DISCUSSION

In the database, foods that are produced in sensitive (tropical) ecosystems, e.g. coffee, cocoa, fruits, nuts and/or require a lot of land, for example pastured based meat get a high biodiversity impact (Table 1). Products with low biodiversity impact are mostly vegetables with high yields, e.g. potatoes. Some foods have a positive biodiversity impact, i.e. meat from animals grazing on semi-natural pastures. The comparison is made per kg of food, so conclusions on what foods have high vs low impact on a dietary level might be different. Fish and seafood is not included in the database at this point, due to methodological challenges.

There are still many challenges when calculating biodiversity footprint of food. In the first version of the database, only agricultural land use drivers are included. More drivers e.g. mining for fertilizers and fossil fuels, production of electricity will be included in coming versions. In the future, also other drivers of biodiversity loss can be added e.g. climate change, pesticide use, water use and invasive species. This might require a switch to endpoint assessment methods.

4. CONCLUSIONS

Although there is need for continued development, there is now a first version of the RISE food biodiversity database available online. We expect the database to be of very good use for decision making in e.g. retail, wholesale, restaurants, public kitchens, and the food production industry. The database will continue to be developed over the coming years, and case studies will be done together with food companies and food retailers.

5. ACKNOWLEDGEMENTS

This work is financed by the Swedish Research Council Formas, project number 2023-02014.

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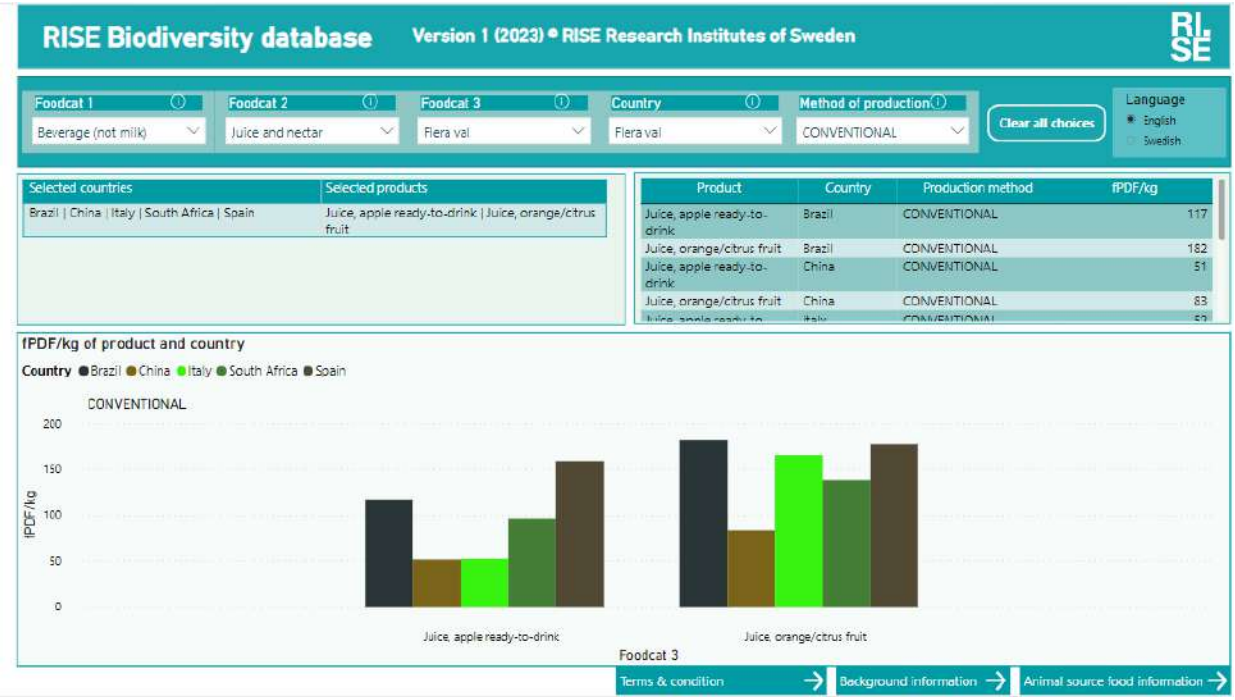

Figure 1. Screen dump of RISE food biodiversity database. Can be accessed via https://www.biodiversitetsdatabasen.se/

Table 1. Example of biodiversity impact of food items

	Food item	**Country of production**	**Biodiversity impact fPDF/kg**
High negative impact	**Coffee**	**Brazil**	**109 600**
	Lamb meat (with bone)	**New Zeeland**	**54 600**
	Cocoa	**Ghana**	**3 200**
Low negative impact	**Potatoes**	**Germany**	**8**
	Tomatoes	**Spain**	**30**
	Rice	**China**	**160**
Positive impact	**Lamb meat (with bone)**	**Sweden**	**- 470**

The Biodiversity Value Increment method in the GaBi database

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1. INTRODUCTION

Several approaches and methods have been put forth for addressing biodiversity in LCA, including the Biodiversity Value Increment (BVI) method (Lindner et al. 2019). The key to usability and user adoption for any LCIA method is database implementation. In a previous project, the BVI method was used to calculate impacts for over 2,600 food products from the Agribalyse database (Lindner et al. 2022). In that project, the inventory data were extracted from the database and the impact calculation was done in a separate application. Now we implemented the characterization factors directly in the Sphera LCA database, to be used directly in the Sphera LCA software (formerly known as GaBi). We demonstrate what can be done when a pragmatic LCIA method for biodiversity is combined with a reliable LCI database.

2. METHODS

We calculated characterization factors based on the default naturalness levels provided by Fehrenbach et al. (2019) for the land use flows endorsed by the EU JRC. The flow list follows a tiered approach, with descriptions ranging from very generic to more specific; e.g. from "arable" to "arable, non-irrigated, monotone-intensive". Implicitly, these categories include various levels of fertilization and tillage. Globally diffuse biodiversity impacts (e.g. from climate change) and regional impacts (e.g. from freshwater deprivation) are not included. According to Lindner et al. (2022), the biodiversity value is calculated from the hemeroby level, and then the characterization factor is calculated from the biodiversity value. All in all, the characterization factor refers to 1 m^2a of occupation, and addresses both the intensity level of the land use as well as the location. The spatial resolution is limited to the country level, so characterization factors refer to e.g. "occupation, arable, non-irrigated, monotone-intensive, Brazil". The BVI method was implemented as a new impact assessment method in the Sphera LCA database, with characterization factors referring to the occupation flows mentioned above. From there, it can be readily used by LCA practitioners, including biodiversity laypersons.

3. RESULTS AND DISCUSSION

As an exemplary cradle-to-gate dataset, we assessed the biodiversity impact of the German electricity grid mix, broken down by electricity generation techniques (see Figure 1). Practically the entire impact is related to biogas (¾) and solid biomass (¼), even though their shares in the grid mix are in the single digit percentages. This indicates that the inventory flow amount (areatime) exerts greater influence on the biodiversity impact than the characterization factor (quality difference). We then assessed 20 national grid mixes, breaking down the biodiversity impact per kWh by type of land use (see Figure 2). The various grid mixes show significant differences in the overall impact, but the main contributors are arable and forest land in all but three cases. This may indicate that the pattern seen in the German grid mix is valid for other national grid mixes, too. We will devote more time to further analysis in the presentation.

4. CONCLUSIONS

Land use efficiency in terms of product amount per areatime matters, at least for the comparison between renewable and fossil energy provision techniques. Regarding the database integration, this would have been impossible with individual studies of singular land-using processes. Similar analyses about other products are now just a click away. More than the numeric result, the usability and capability of the combination of a pragmatic biodiversity LCIA method and a professional LCI database is the main message of this presentation.

5. ACKNOWLEDGEMENTS

This work builds on two projects: BioVal, funded by the BMBF (Germany), and BVI to Agribalyse, funded by the ADEME (France). The authors are grateful for the support.

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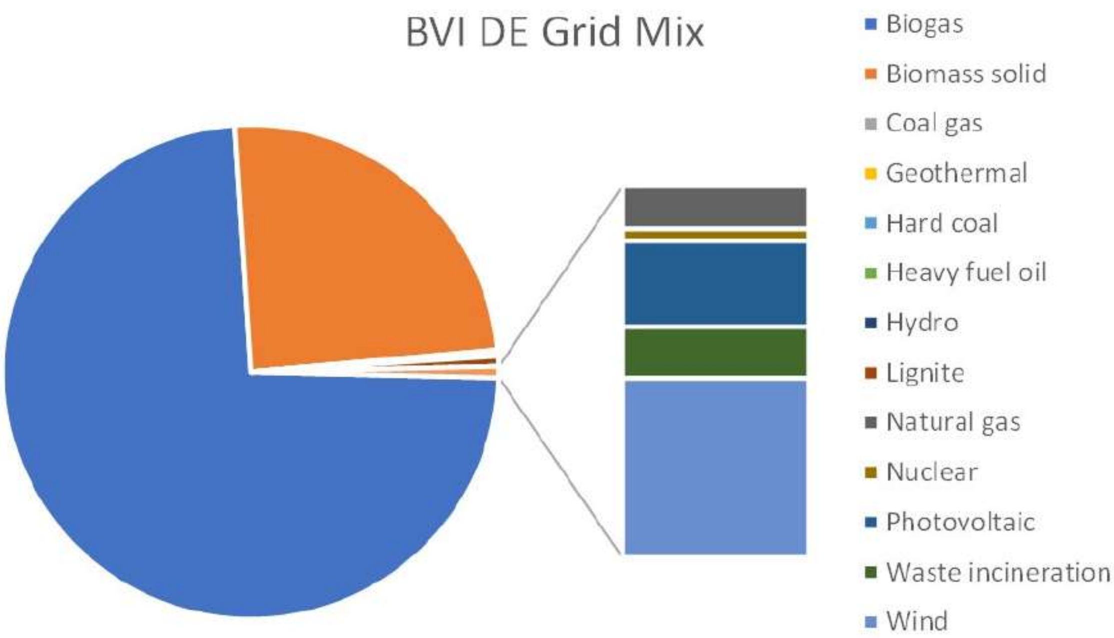

Figure 1. Biodiversity impact from land use of electricity generation in Germany, according to the BVI method, relative contributions of techniques

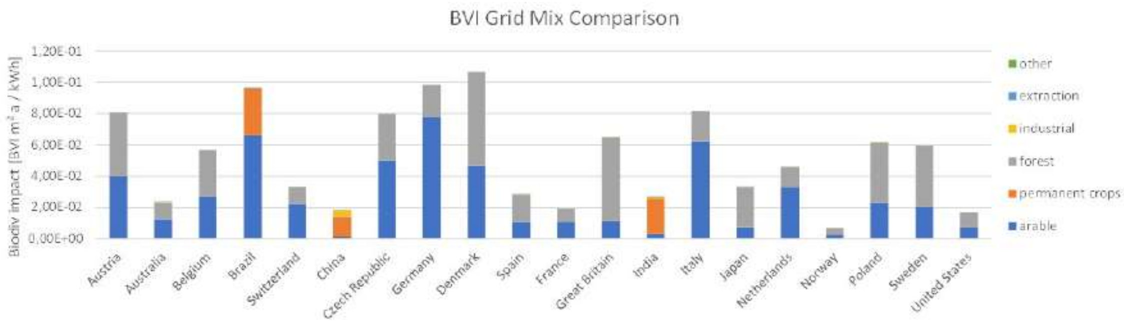

Figure 2. Biodiversity impact from land use of selected national electricity grid mixes, according to the BVI method, broken down by land use type, absolute comparison

Agro-SCAN: A new Multi-Regional Input-Output database for estimating cropland and calorie footprints of agri-food consumption

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1. INTRODUCTION

Trade growth and globalization have increased global food availability, but often at the expense of countries' self-sufficiency (Porkka et al., 2013), also causing tropical deforestation (Pendrill et al., 2022). Multi-regional input-output (MRIO) analysis provides a consistent framework to assess trade-mediated spillovers and estimate consumption-driven environmental footprints. MRIO models can be either monetary, physical or hybrid, but results always depend on the number of sectors, leading to aggregation biases. This study presents the construction and application of a new physical MRIO model that tracks production, transformation, final consumption, and bilateral trade in tonnes, for 640 products in 181 countries in 2013-2020.

2. METHODS

Agro-SCAN combines data from FAOSTAT (2023) and Input-Output (IO) techniques. The main data source is the Supply Utilization Accounts (SUAs), which provide time series of supply and demand of agri-food products for different uses in tonnes, including the quantities that go into processing. Additional data are used to track the intermediate input quantities transformed into multiple co-products, ultimately linking processed quantities in the SUAs with the specific sectors to which they become inputs, based on mass allocation. Several steps follow to build national IO tables based on the SUAs and link them based on bilateral trade matrices. These include: harmonizing product classifications, allocating domestic production and imports to final uses, matching supply and input requirements of the commodities, and balancing trade flows according to FAOSTAT export and import data. Satellite accounts are implemented to estimate cropland and calorie footprints of food consumption, considering the quantities of primary crops needed to produce the final product and all intermediate inputs required.

3. RESULTS AND DISCUSSION

Agro-SCAN is firstly used to estimate cropland footprints of cocoa and derivatives in 2020. 12.61 Mha of cocoa beans were harvested worldwide, 83.7% of which were consumed in countries other than the country of origin. Côte d'Ivoire provided 4.82 Mha, followed by Ghana (1.89 Mha), Indonesia (1.51 Mha), and Nigeria (1.08 Mha). The largest cropland footprints among destination countries are found for USA (1.51 Mha), Netherlands (0.93 Mha), Indonesia (0.89 Mha), Germany (0.81 Mha), and Brazil (0.67 Mha). Most of these footprints ended up in food uses (Figure 1): 1.33 Mha in USA, 0.61 Mha in Germany, 0.57 Mha in Indonesia, and 0.43 Mha in Brazil. The countries with the largest footprint per capita (ha/1000 people) are Iceland (10.09), Switzerland (9.13), Ireland (8.03), Germany (7.25), UK (7.02), and Canada (6.28).

Calorie footprints are calculated to illustrate another application. These quantify the amount of calories embodied in primary crops used as inputs to the products ultimately consumed for food and feed. Calories from human intake of plant and animal products are not included. In 2020, 6,067 Pcal were globally embedded in crops for food uses and 5,801 Pcal in feed. China has the largest footprint (2,626 Pcal), followed by India (1,293 Pcal), USA (1015 Pcal), Brazil (495 Pcal), and Indonesia (309 Pcal) (Fig. 2). Feed uses contribute >70% to USA and Brazil's calorie footprints, respectively. Despite being the largest meat producer, China's feed footprint is relatively smaller (>50%), reflecting the larger share of plant-based calories in the diet, relative to the West. India and Indonesia respectively have 80% and 74% of their calorie footprints associated with consumption of plant-based food products.

4. CONCLUSIONS

Agro-SCAN is a physical MRIO databased with an unprecedented number of agri-food products. The model shows great potential for estimating environmental footprints other than cropland. Future developments aim to overcome limitations, e.g., mapping feed consumption in SUAs with the corresponding livestock sectors. Agro-SCAN provides supply chain transparency to inform stakeholders' decisions towards more sustainable agri-food systems.

5. ACKNOWLEDGEMENTS

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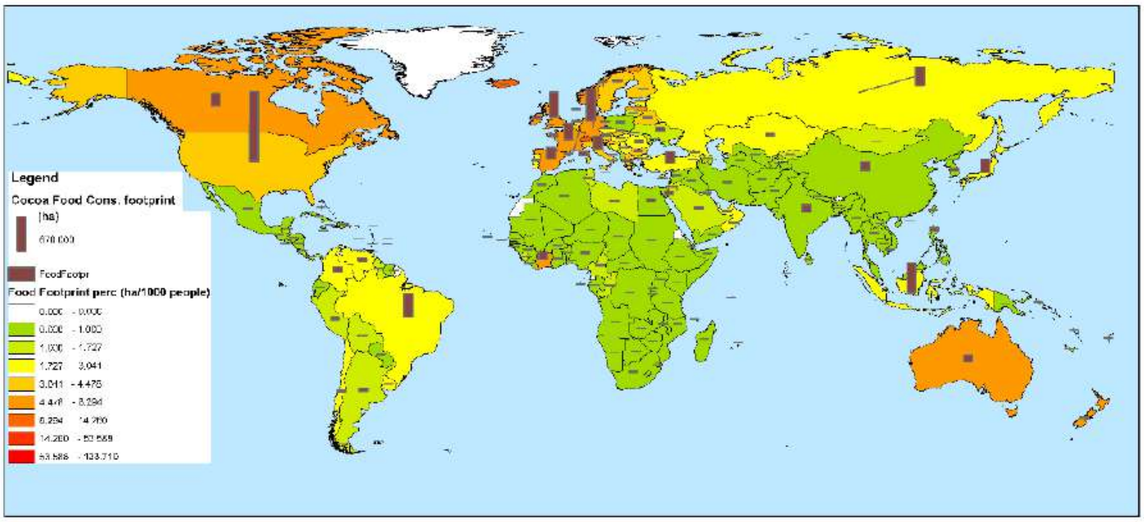

Figure 1. Cropland footprints embedded in food consumption of cocoa derivatives in the destination countries in 2020, as total cropland area (ha) and per capita (ha/thousand people).

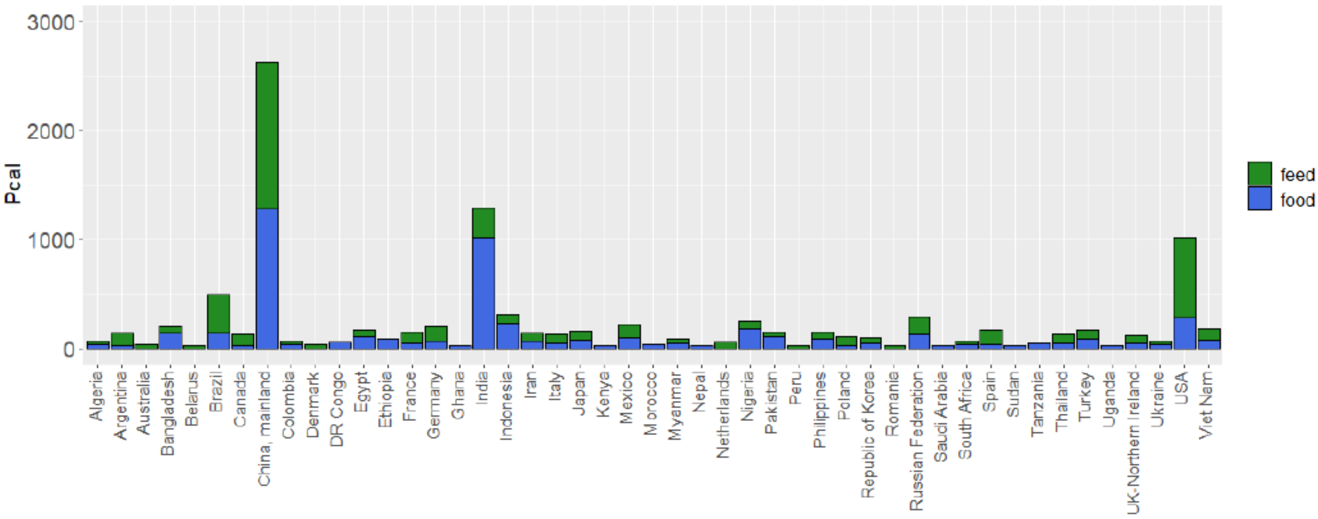

Figure 2. Calorie footprints (Pcal) embedded in food and feed consumption in the destination countries in 2020. Countries with a total calorie footprint above the third quartile are shown.

Incorporating environmental impact data in existing agri-food software using API: a case study on Haifa NutriNet

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1. INTRODUCTION

With the growing interest in sustainability of food products, the demand for life cycle assessment (LCA) information is increasing. However, the current number of LCA practitioners is not sufficient to calculate the environmental impact of the millions of products in the market with a one-time LCA. Besides that, it is cumbersome to collect farm-level data and can require farmers to fill in their data multiple times in different software programs. Therefore, we need a scalable solution that allows for the robust calculation of environmental impact of multiple products with minimal work. The SimaPro Application Programming Interface (API) can provide this. This API allows you to connect existing or new custom tools to the SimaPro calculation engine. In this abstract, we will explain how the API can be used to incorporate LCA information in software used in the agri-food supply chain. As a case study, we will present a project we did together with Haifa Group.

Haifa Group is a world leader in the field of specialty fertilizers, offering solutions for precision agriculture. Haifa NutriNet is their online software for growers and agronomy experts, that helps creating optimized fertilization programs, while taking into account growing conditions. With the API, Haifa Group can show the environmental impact for different application methods of the created fertilization program and encourage the use of fertilizer application practices that have less of an impact on the environment.

2. METHODS

To make LCA data available in existing software, a few steps are needed:

1. Analyze what data can be taken from the existing agri-food software to use as input data in your LCA.
2. Create an LCA model in SimaPro with parameters for the input data from the software and map the input data to the right parameters
3. Use the API to establish the link between the existing agri-food software and your SimaPro model. This can be simply done by adding a few lines of code containing which input data needs to be used and defining the type of results to be retrieved.

3. RESULTS AND DISCUSSION

In this section, we will share the results of the different steps in incorporating environmental impact data in Haifa Groups NutriNet.

3.1 Analyzing the existing software to see what data can be used in the LCA

From NutriNet, we can get information on farm characteristics and on the optimal fertilization programs for different application methods. (Figure 1)

3.2 Creating a parameterized LCA model

A universal LCA model is created in SimaPro, including all processes from the production of the fertilizer to the harvest of the crop (i.e. from cradle to farmer's gate). The model uses a combination of primary and secondary data, and has parameters to allow input from NutriNet. (Figure 2)

3.3 Establishing the link between NutriNet and SimaPro

The link between NutriNet and SimaPro is created and the environmental impact of the different fertilizer application methods is shown in NutriNet. The results are displayed for 1 kg of produce for a selection of indicators from the impact assessment method EF3.0 (Zampori & Pant, 2019) and some additional relevant indicators. (Figure 3)

4. CONCLUSIONS

The historical way of conducting LCAs is no longer feasible: there are not enough experts, and collecting farm-level data is cumbersome. Integrated solutions with API are a simple and effective way to make environmental information available at scale with minimal effort. The case study used in this abstract, shows just one of many possible applications. Other possible applications are including environmental impact in farm management or suppliers software.

5. ACKNOWLEDGEMENTS

We would like to thank Joshua Golovaty from Haifa Group for the nice collaboration.

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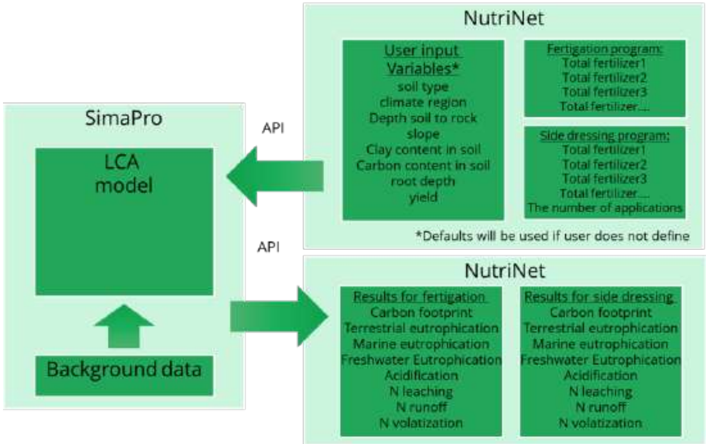

Figure 1: Overview of data flows in the connection between SimaPro and Haifa NutriNet using the API

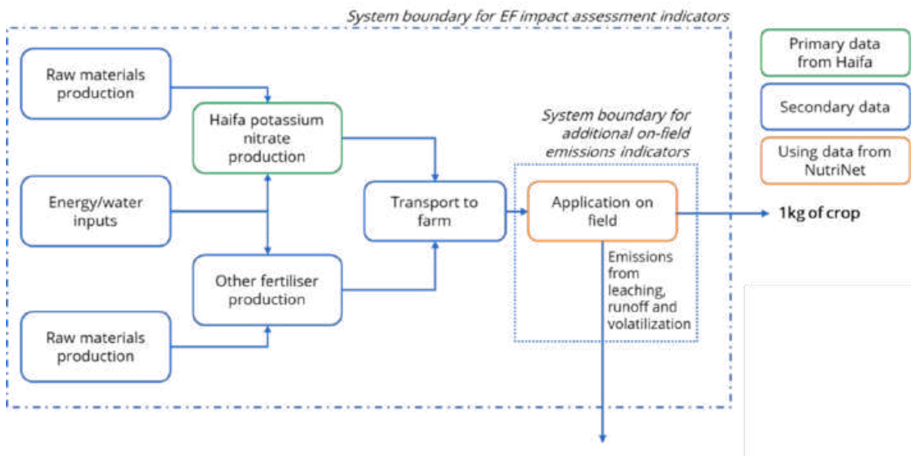

Figure 2. Universal LCA model for the production and application of fertilizer programs through different application methods

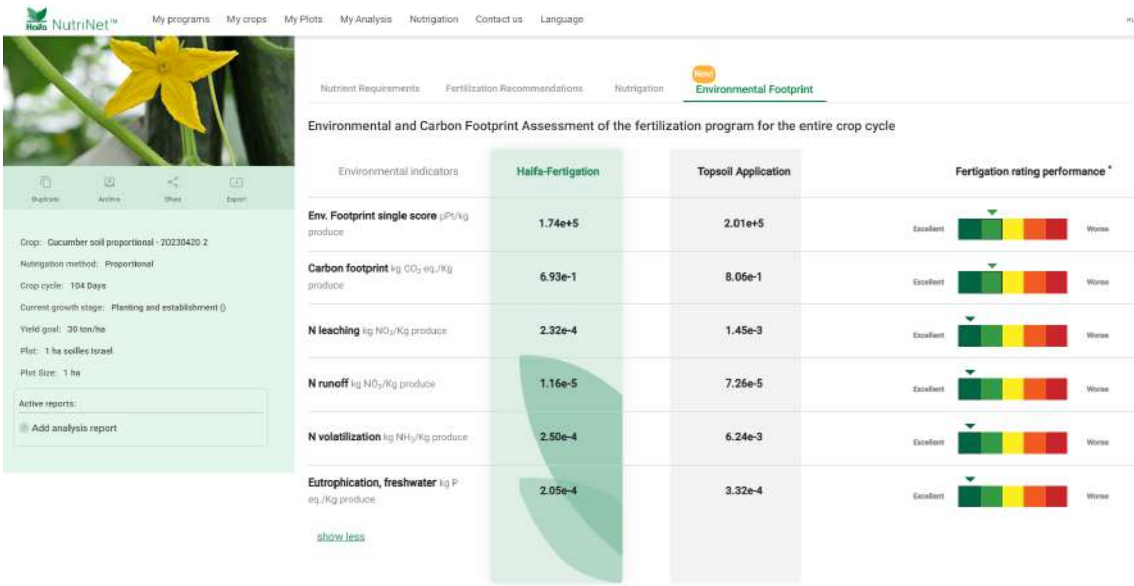

Figure 3: Environmental impact of fertigation and top soil application in Haifa NutriNet. Impact is automatically calculated in a universal model in SimaPro

Promoting harmonization of life cycle inventory and food composition databases through semi-automatic standardization

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1. INTRODUCTION

Nutritional life cycle assessment (nLCA) is used to assess environmental impacts and nutritional quality of food combined to help identifying efficient food options (McLaren et al., 2021). However, the lack of standardization or an incomplete interlinkage of life cycle inventory (LCI) and food composition (FC) databases often limit combined analyses. Although many attempts have already been made in order to connect and standardize food items (FI) from different databases, variable database structure, different data availability, accessibility and incomplete data description have hampered a successful standardization. While fully automated procedures tend to be efficient (Isiprova et al. 2017; Eftimov et al. 2017), manual matching might be more accurate in some cases and more user friendly (Broekema et al., 2019; Hinojosa-Nogueira et al., 2021). Coupling automated and manual standardization with semi-automatic standardization has the potential to include the advantage of both methods: increasing accuracy while keeping the amount for manual work at a reasonable level.

2. METHODS

Data availability, data accessibility and the data structure of LCI and FC databases was analysed using the nutritional and environmental databases, EuroFIR and Agribalyse, respectively, as an example (European Food Information Resource (EuroFIR), 2023b; Asselin-Balençon et al., 2022). Results from the analysis were used to develop a food specific nomenclature for the semi-automatic standardization approach. Harmonized descriptors were created and collected manually beforehand. For that purpose, standardized names from the LanguaL™ system were used to properly classify FI (Møller & Ireland, 2018). Food entries in the databases were tagged with those descriptors subsequently and data interlinkage was achieved by comparing the descriptors.

3. RESULTS AND DISCUSSION

FI of both databases were found to be structured into glossaries with two main parts: the meta data storing descriptive information about the food (e.g., food name) and the base structure (e.g., nutritional parameters). “Food name”, “Food specification”, “Food recipe” and “Food processing” have been identified as key parameters for the standardization of food databases because they are required to uniquely identify the type of food . FI from LCI databases are also sensitive to parameters such as “System boundaries”, “Yield”, “Country of origin of food” and “Production system”. Information on parameters could only be accessed, if available, via the name field of a FI. Data connection was facilitated when excluding composite foods (e.g., pizza) from the standardization and only focusing on single foods (e.g., apple). Five categories (name, specification, treatment, processing, production system) were identified suitable for the food-specific nomenclature. Gathering synonyms and/or LanguaL™ codes manually in a connection list beforehand allowed for a standardized and automatic assignment and description of FI afterwards (Figure 1). Using the semi-automatic procedure in a case study showed that two entries out of 54 were incorrectly matched and had to be excluded manually.

Parameter	Example	FCDB databases (e.g., EuroFIR)	LCI databases (e.g., Agribalyse)	Additional info
Food name	*“Apple”, “Mango”*, etc.	*** (III)	*** (III)	Information needs to be extracted from title of a database entry
Food specification	*“Juice”, “Oil”*, etc.	*** (II)	*** (II)	Information needs to be extracted from title of a database entry. Often inconsistently accessible information (e.g., “sunflower oil” vs. “oil, sunflower”)
Food recipe	Percentage of water added to apple juice	*** (I)	*** (I)	Information, if provided, only in base data. Difficult to extract.
Food processing	*“pasteurized”*	*** (III)	*** (II)	Information needs to be extracted from title of a database entry
System boundaries	*“at farm”* or *“at processing”*	* (I)	*** (II)	Not always provided in the database entry in Agribalyse
Yield	Yield of apple from agricultural production	* (I)	*** (II)	Information only provided in base data. Difficult to extract.
Country of origin of food	*“Germany”, “France”*, etc.	** (I)	*** (III)	
Production system	*“conventional”, “organic”*, etc.	* (I)	*** (II)	Information needs to be extracted from title of a database entry

*: little relevant or irrelevant; **: moderately relevant; ***: highly relevant
I: not provided; II: sometimes provided; III: fully provided

4. CONCLUSIONS

Applying semi-automatic standardization via the connection list showed to be a user friendly and accurate approach for standardization. Augmenting data quality by collecting additional meta data for the description of a FI would allow for a more correct matching of the same FI. Providing and agreeing on general guidelines for the structure, accessibility and format of food databases would increase the efficiency of data standardization between food databases.

5. ACKNOWLEDGEMENTS

This work is supported by the project OptiSignFood, which received funding from the European Union’s Horizon 2020 Framework programme under grant number 971242.

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Table 1. Relevant parameters for standardization of FCDB and LCI databases and their availability and accessibility in EuroFIR and Agribalyse

Parameter	Example	FCDB databases (e.g., EuroFIR)	LCI databases (e.g., Agribalyse)	Additional info
Food name	*"Apple", "Mango"*, etc.	*** (III)	*** (III)	Information needs to be extracted from title of a database entry
Food specification	*"Juice", "Oil"*, etc.	*** (II)	*** (II)	Information needs to be extracted from title of a database entry. Often inconsistently accessible information (e.g., "sunflower oil" vs. "oil, sunflower")
Food recipe	Percentage of water added to apple juice	*** (I)	*** (I)	Information, if provided, only in base data. Difficult to extract.
Food processing	*"pasteurized"*	*** (III)	*** (II)	Information needs to be extracted from title of a database entry
System boundaries	*"at farm"* or *"at processing"*	* (I)	*** (II)	Not always provided in the database entry in Agribalyse
Yield	Yield of apple from agricultural production	* (I)	*** (II)	Information only provided in base data. Difficult to extract.
Country of origin of food	*"Germany", "France"*, etc.	** (I)	*** (III)	
Production system	*"conventional", "organic"*, etc.	* (I)	*** (II)	Information needs to be extracted from title of a database entry

*: little relevant or irrelevant; **: moderately relevant; ***: highly relevant
I: not provided; II: sometimes provided; III: fully provided

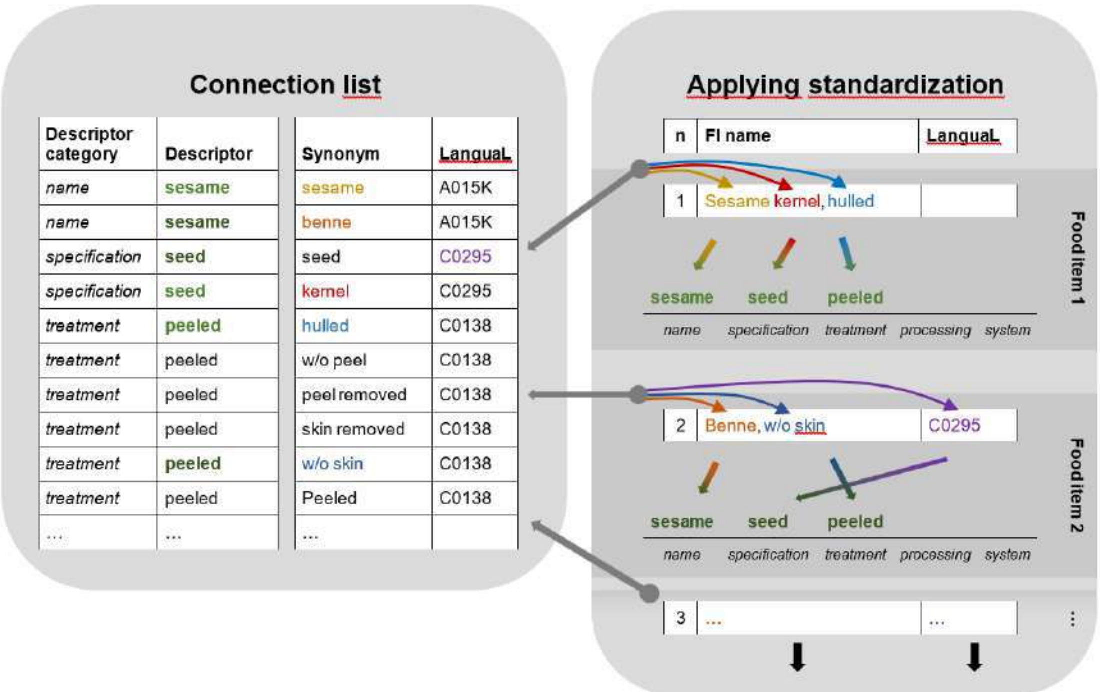

Figure 1. Scheme of the application of the standardization approach for two FI ("Sesame kernel, hulled" and "Benne, w/o skin"). For each FI where the standardization is applied, the name and the LanguaL™ codes (right), if available, are compared to the information of the connection list (left). If one or more terms or LanguaL™ codes appear in the connection list, the associated descriptor is assigned.

Batch generation of agricultural LCIs: comparison of strategies

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1. INTRODUCTION

Often, agricultural LCA practitioners need to handle large datasets representing individual LCIs, either from field surveys or from model outputs. To model such unit process datasets "by hand" can be time consuming with most LCA software usable only via graphical interface, especially if direct field emissions need to be computed.

To address this limitation, we propose three strategies for batch generation of agricultural LCIs, using open or semi-open access tools or services.

2. METHODS

A dataset of farm survey data (Avadí and Dosso, 2023) was used to construct an inventory file describing all inputs and outputs associated with each technical itinerary, including direct field emissions. ~800 technical itineraries (i.e. a technical description of an individual distinctive cropping system) were included in the inventory file. Direct field emissions were computed using context-optimal models, as recommended in (Basset-Mens et al., 2021). These models were the simplest, due to the need to perform the computations for 800 systems in Excel: EMEP/EEA 2019, IPCC 2019, SALCA-P, RUSLE2. Emissions associated with pesticide application were modelled with PestLCI, through its online batch computation capabilities (https://pestlciweb.man.dtu.dk/batchcalculation), as recommended in (Nemecek et al., 2022). The PestLCI web model implementation is inaccessible since end of August 2023.

Three batch generation strategies were tested, as depicted in Figure 1, labelled "ELDAM", "MEANS-InOut" and "Hestia". The three strategies are depicted in **¡Error! No se encuentra el origen de la referencia.**. For all three strategies, an initial data curation for data issues (e.g. internal consistency) was performed.

For the "ELDAM" strategy, the CIRAD LCA research infrastructure (Biard et al., 2011) was used for LCA computations, complemented with ELDAM software (Coste et al., 2021), PestLCI (Dijkman et al., 2012) and R (R Core Team, 2020) for automation. A random technical itinerary from the dataset was used to construct a generic model in SimaPro, which was exported as a MS Excel file and transformed into an ELDAM (MS Excel-based) file. An R script was used to replicate the template ELDA file by updating each instance from the inventory file, where each column represents an individual technical itinerary (included pre-computed direct field emissions). The resulting set of ELDAM files were reimported into SimaPro to produce ~800 individual processes, which were included into calculation setups to generate impact assessment results, which were then downloaded from SimaPro for each technical itinerary in the survey.

For the "MEANS-InOut" strategy, the data were aligned with the reference framework of technical itinerary descriptions used by MEANS-InOut (Auberger et al., 2019) (the MEANS platform's graphic user interface) in an Excel file and then uploaded for ingest. An Excel template is provided for data input, together with nomenclature keys and processed remote sensing data at the country x GAEZ region nomenclature (Fischer et al., 2021), necessary to inform direct field emissions models. The data were then automatically converted to the MEANS-InOut format (Java object) and screened for coherence and nomenclature. A built-in API then generates all LCIs, including data for direct field emissions. Direct field emissions were computed according with a hardcoded selection of direct field emission models (chosen as to minimise the requirement of additional data: EMEP/EEA 2019, IPCC 2019, SQCB 2009, SALCA-

P, RUSLE2, OLCA-Pest), and automatically integrated into LCIs. Finally, full LCIs were generated and exported in ecoSpold format, for impacts computation in SimaPro, as well as in Excel format (direct field emissions only). In MEANS-InOut there is the possibility of calculating impacts seamlessly with OpenLCA. Future refinements will enable more flexibility on direct field emission models selection, including additional remote sensing data for filling data gaps. Calculated impact assessment results were then downloaded from SimaPro for each technical itinerary in the survey.

For the "Hestia" upload, the data were aligned to the schema and glossary in a CSV file (manually, by the user). The data were then automatically converted to Hestia format (JSON), validated to the schema, automatically screened for data inconsistencies, and finally manually checked before being indexed on https://hestia.earth/. Once indexed, data gaps were filled using remote sensing data where possible. Field emissions were then calculated to the highest tier possible given the resolution of the data, using a default set of models. Inventory flows for each individual farm were then aggregated, classified, and characterised towards all impact categories where corresponding characterisation factors were available for all inventory flows. Calculated field emissions and impact assessment results were then downloaded from Hestia for each technical itinerary in the survey.

3. RESULTS AND DISCUSSION

The three strategies successfully generated exploitable LCIs, but "ELDAM" required manual computation of direct field emissions, while the other two strategies used the respective platforms' built-in computation capabilities to do so. On the Hestia platform, a default choice of direct field emission models is retained, adapted to the type of modelled system (users can chose direct field emission models only by using the Hestia Community Edition, but not through batch upload). Similarly, in MEANS-InOut the choice of models is made following expert-based parametrisation relying on the (predominantly) French context (Koch and Salou, 2022), thus also proposing a default choice. MEANS-InOut also requires additional data to inform direct field emission models, while Hestia fills all required data from prerendered remote sensing (geolocalised) products, albeit without the user's control on data selection. Hestia generates full LCIA results seamlessly using Brightway (Mutel, 2017) for background processing and their own model for foreground processing), while MEANS-InOut requires either exporting LCIs to be computed on SimaPro or seamlessly computing impacts through an OpenLCA API (which returns editable OpenLCA projects in addition to the LCIA results).

Both the MEANS-InOut and Hestia approaches required extensive data curation, due to the internal check routines associated with both platforms.

Comparative results from the three approaches will be available at the conference. ELDAM-based results are presented in Dosso et al. (this conference).

4. CONCLUSIONS

All three strategies proved useful for batch generation of agricultural LCIs, subject to different constraints. Particularly for the web platform-based ones, the ingestion of user data requires time-consuming manual curation and schema/nomenclature matching, thus an automation of these routines would be the expected evolution, especially given that batch LCI generation and impacts computation needs are increasing throughout the LCA community.

5. ACKNOWLEDGEMENTS

Angel Avadí has been financed and Guilhem Rostain supported by the MARAÎCHAGE AGROÉCOLOGIQUE PÉRI-URBAIN – DeSIRA MARIGO project (https://www.projet-marigo.org/), 2021-2025, grant number FOOD/2020/419-988. HESTIA is financed by Login5 Foundation, WWF UK, Defra, the Ardevora Charitable Trust, and the Oxford Martin School. PJGH is funded by the FORMAS Inequality and the Biosphere (2020-00454) and CAPS (2023-01805) projects, IKEA Foundation, Gordon and Betty Moore Foundation (GBMF11613), Walton Family Foundation (00104857), and the David and Lucile Packard Foundation (2022-73546). The authors acknowledge Gustave Coste (co-creator of ELDAM), and the MEANS and Hestia teams.

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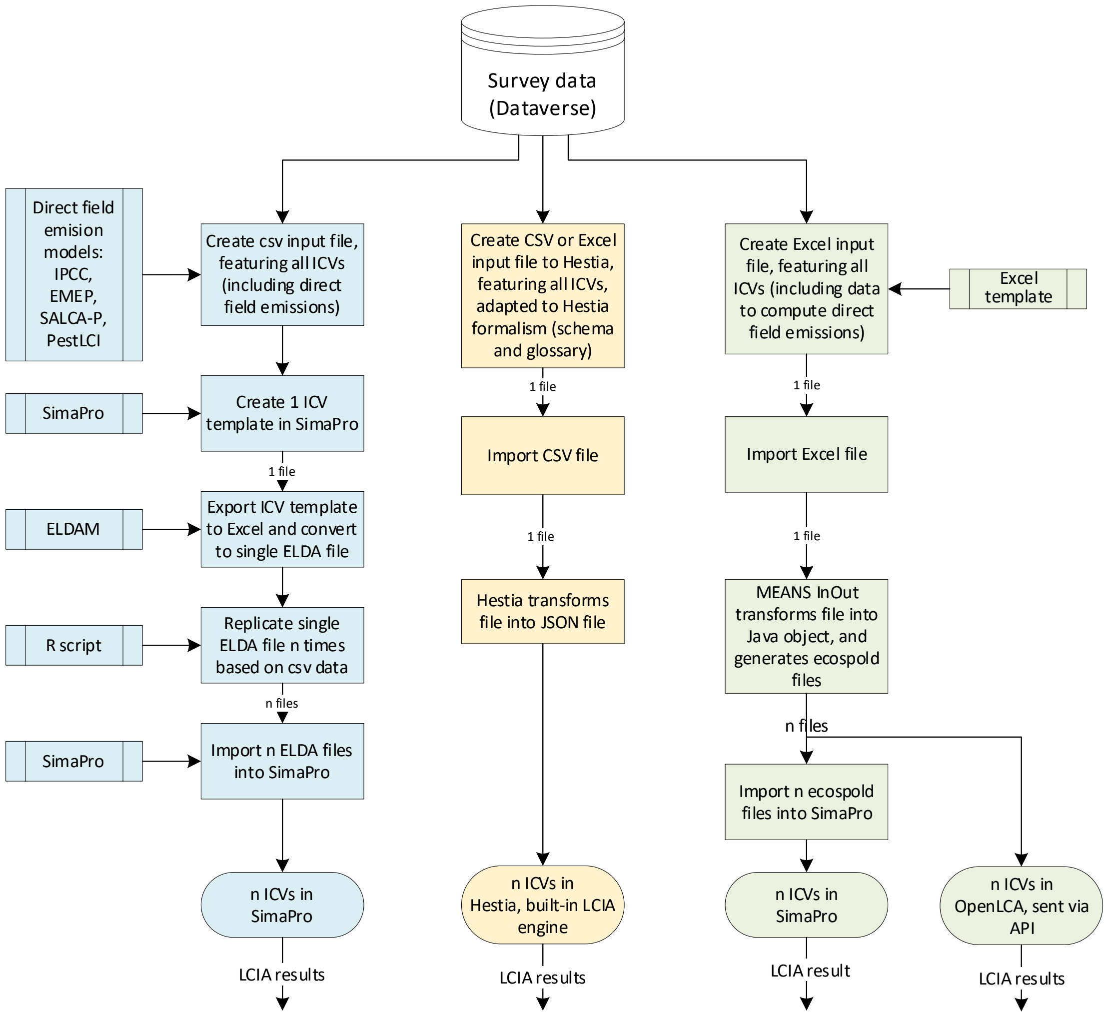

Figure 1. Three strategies for batch generation of agricultural LCIs from survey or statistical data

Life cycle inventory: modelling, databases and tools (II)

The big Climate Database - 500 food products

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1. INTRODUCTION

The big CLIMATE DATABASE is a life cycle inventory database of 500 food items at retail. This paper presents the methods and data used for the database. Further, the paper describes the flexible features of the model to be expanded to cover more countries, to update to newer years, to amend emission calculations in crop and animal production, as well as adding new food items, packaging constellations and end-of-life treatments. Finally, results excerpts of the database are presented.

The big CLIMATE DATABASE is an open and transparent database that can be accessed via: https://denstoreklimadatabase.dk/en. The database is developed by 2.-0 LCA consultants and CONCITO. The first version, which covered food items at the Danish market, was developed in 2020-21. In 2021, the big CLIMATE DATABASE was awarded the Nordic Environmental Prize. In January 2024, an updated version 1.1 was released. This version is expanded to also include climate data for Great Britain.

2. METHODS

The big CLIMATE DATABASE provides life cycles inventories and climate footprint results per kg for 500 food products at retail. The following life cycle stages are included: agriculture, food manufacturing, packaging (and its disposal), transport, and retail. The database uses consequential modelling: by-products are modelled using substitution, and indirect land use changes are included. All agricultural data refer to 2016, and EXIOBASE v3.3.16 hybrid version (Merciai and Schmidt 2018) is used as background database to account for inputs of fertiliser, chemicals, energy etc. The geographical scope of EXIOBASE is global, divided into 43 countries and five rest-of-world regions. The agricultural module of the database includes 3250 crop cultivation and 400 animal production activities. The geographical scope is the same as in EXIOBASE. The agricultural module (crops and animals) covers 180 different crops and 12 animal production systems, and the module is setup as parameterised production functions. These combine data from FAOSTAT (bulk download), IPCC (2019) emission models, and other auxiliary data to automatically generate life cycle inventories for all crop cultivation and animal production activities in all countries. For inputs of agricultural products to food manufacturing in different countries, national product market mixes are composed based on global trade data from FAOSTAT. For food manufacturing, generic recipes are established for 450 different products, as well as 70 representative packaging constellations are defined for the packaging stage. National end-of-life treatment mixes of recycling, incineration and landfill for packaging waste are retrieved from EXIOBASE.

3. RESULTS AND DISCUSSION

The highly parameterised model behind the database enables for easy updates of years (FAOSTAT data), addition of new countries, as well as addition and adjustment of product recipes. As an example, v1.1 of the database added life cycle inventories for Great Britain, so that the database now covers 500 food products in Denmark and Great Britain. Furthermore, v1.1 updated the emission models to IPCC (2019). Results excerpts are presented in Figure 1.

4. CONCLUSIONS

The model and workflow for generating the big CLIMATE DATABASE has proved to show that high quality GHG footprint data can be efficiently generated. The algorithms of the database are currently being implemented in the BONSAI database (https://lca.aau.dk/), and versions for several other countries will be published in the near future.

5. ACKNOWLEDGEMENTS

The big CLIMATE DATABASE version 1.1 was funded by the award money from the Nordic Environmental Prize.

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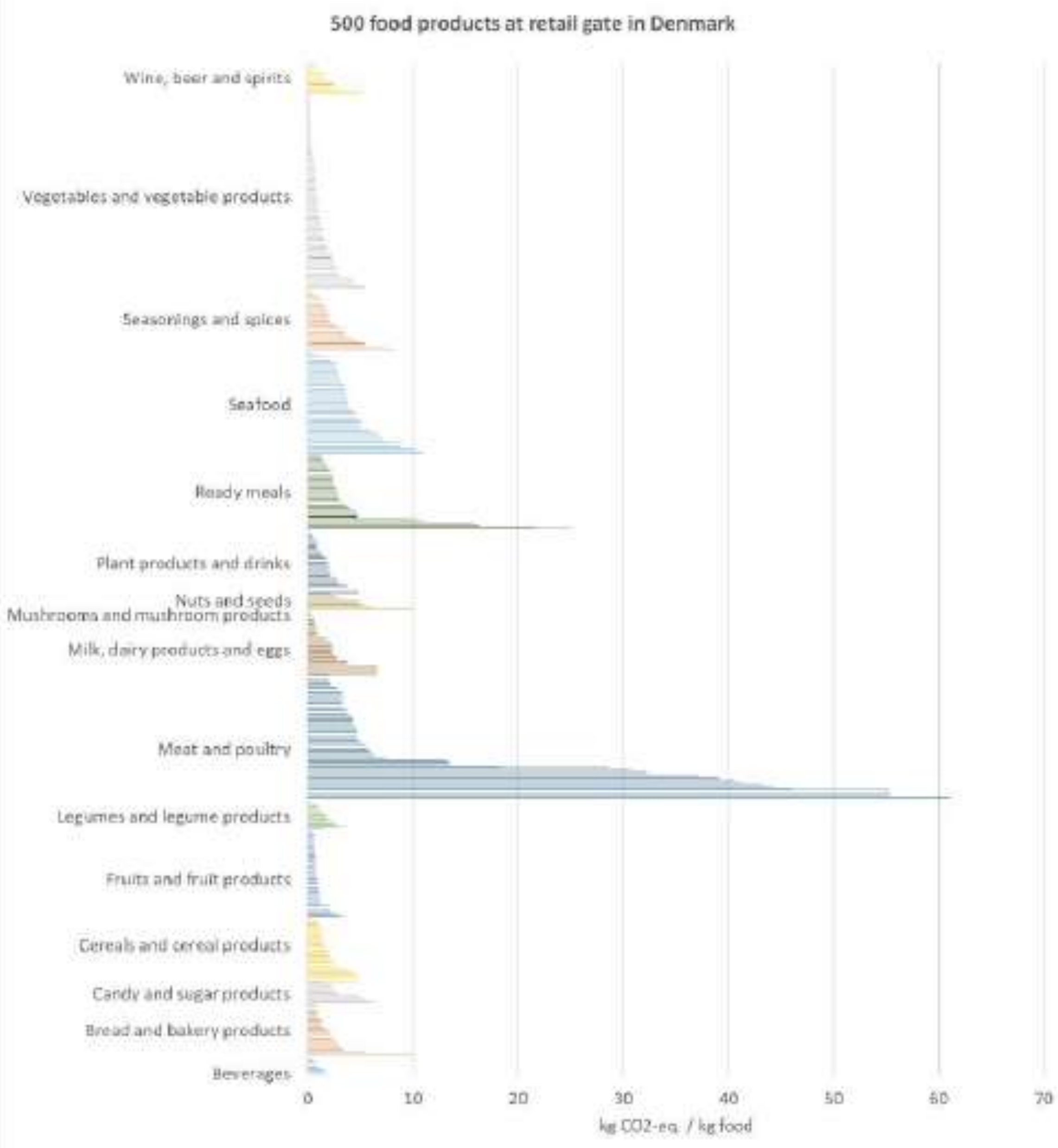

Figure 1. Illustration of results for 500 food items at retain in Denmark organised in 16 food categories (kg CO_2-eq/kg food). Data obtained from: https://denstoreklimadatabase.dk/en

Trase/Orbae: spatially-explicit supply chain mapping of forest risk commodities for scope 3 GhG emission

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1. INTRODUCTION

A key challenge for the food and agriculture sectors is to both improve the accuracy of the life cycle inventory (LCI) through regionalization and allocate responsibility to supply chain actors. We present a supply chain mapping approach for agricultural commodities that is data driven, applies to whole producing country markets, and can be deployed to different country-commodity contexts. We provide examples for Brazilian soy and Indonesian palm oil, two commodities associated with land use change (LUC) impacts in LCI databases, and that will soon be regulated under the EU Deforestation Regulation (European Parliament and of the Council 2023). Our mapping approach reveals the jurisdictions of production of commodities imported into the EU allowing for commodity-specific direct LUC and scope 3 GhG assessments for users whose supply chain information may be incomplete or unknown.

2. METHODS

Increasing transparency of supply chains is the goal of Trase (trase.earth) with a focus on forest-risk commodities from South America, West Africa, and Southeast Asia. Our approach provides market-wide and spatially-explicit commodity supply chain maps that link jurisdictions of production to countries of import, traders involved in transactions and trade hubs such as facilities and ports. Using a logic-based decision tree combined with mathematical optimization, we connect: (1) trade data of individual shipments of commodities leaving ports in countries of production, (2) in-country facilities and ownership information to link shipments to processing or storage, (3) complementary information (licenses, traceability reports, road networks) to elucidate links between ports and facilities, and (4) commodity production to balance exports with the volume of raw commodities, areas of production and domestic consumption. We combine Trase's EU-specific land use LCI with emissions factors from Orbae (orbae.eco) in line with the Greenhouse Gas Protocol Land Sector and Removal guidance. Orbae's novel LUC assessment method is powered by historical earth observation at 30-m resolution (Reinhard *et al* 2024) and, together with Trase can unlock regionalised LCI and GhG emissions at multiple scales. Here we focus on the supply chains of Brazilian soy and Indonesian palm oil and their derived products in 2020 (Table 1) for which 122 Mtonnes and 44.8 Mtonnes of respective production were assigned to exports or domestic consumption (Trase 2022a, b).

3. RESULTS AND DISCUSSION

The EU's 2020 soy and palm oil supply chains were associated with 31,000 ha and 49,000 ha of LUC respectively in Brazil and Indonesia (Trase 2022a, b) (Figure 1). The approach highlights the top jurisdictions where deforestation took place, such as Brazil's São Gabriel (Rio Grande do Sul) municipality or Indonesia's Kalimantan Barat province, as well as the exporters most exposed to deforestation in their supply chain. EU's soy and palm oil imports were respective 0.864 kg CO_2-eq (kg soy)$^{-1}$ and 4.0 kg CO_2-eq (kg palm oil)$^{-1}$ when weighted by import volume from each jurisdiction of production.

4. CONCLUSIONS

Our supply chain mapping approach helps overcome LCA challenges in regionalization while also making explicit links between actors and regions. It can be used for corporate GhG accounting, supporting carbon reduction roadmaps and deforestation exposure assessments. A broader application in LCA will become possible with subnational, regionalized emission factors tackling biodiversity loss and water stress caused by land transformation.

5. ACKNOWLEDGEMENTS

Trase is supported by the Gordon and Betty Moore Foundation (7703.01), Norway's International Climate and Forest Initiative (QZA-21/0156) and Quadrature Climate Foundation (01-21-000098).

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Context in 2020	HS product code	Facilities (number)	Commodity balance (Mtonnes)	Reference
Brazilian soy	1201, 1208, 1507, 2304	Crushing (1791) Ports (45)	Production: 122 Export: 98 Domestic consumption: 24	Trase (2022a)
Indonesian palm oil	15111, 15119	Mills (1218) Ports (376)	Production: 44.8 Export: 26.9 Domestic consumption: 17.8	Trase (2022b)

Table 1. Summary of data and methods used to map the supply chains of Brazilian soy and Indonesian palm oil in 2020

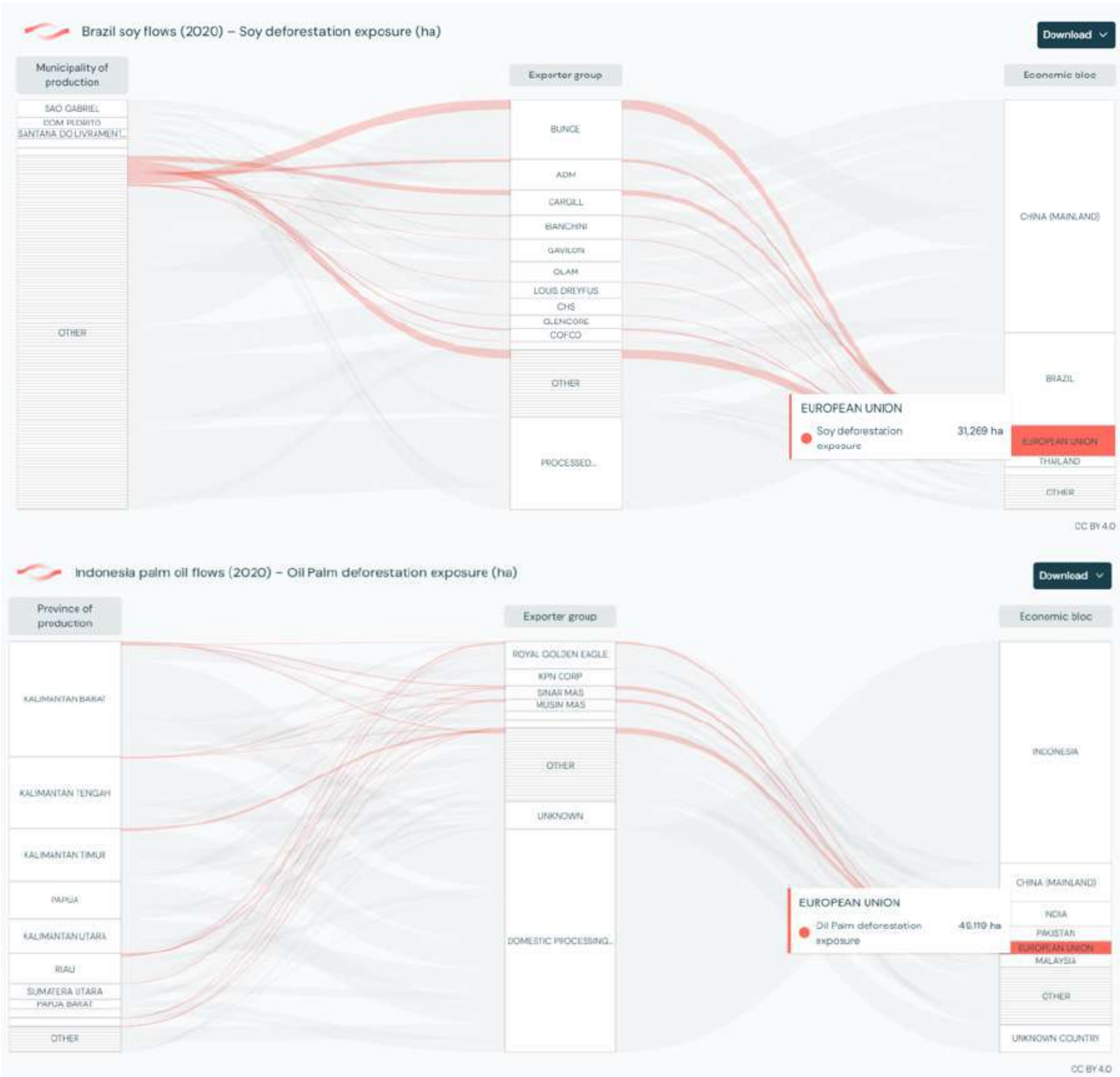

Figure 1. Deforestation exposure in the EU's soy (Brazil, top) and palm oil (Indonesia, bottom) supply chains in 2020 (trase.earth)

An open-source toolset to assess deforestation impact embodied in trade of bio commodities

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1. INTRODUCTION

The EU observatory on deforestation and forest degradation platform (https://forest-observatory.ec.europa.eu), launched in December 2023, was put in place to support the recent European Regulation on Deforestation-free products (EUDR). The EUDR aims at preventing products (defined in the Annex I of EUDR) placed and consumed in the European market in contributing to deforestation and forest degradation worldwide. In this context, our work aims to define multiple and integrable tools able to identify bilateral trade flows and production of bio commodities, assessing the impacts (land area and deforestation) associated to the consumptions of products. We distribute an open-source python package called Biotrade (Rougieux, 2023), which allows collecting, harmonizing and performing statistics and trends related to production and trade data of diverse sources. This tool paves the way for the assessment of the land footprint associated to each product and the calculation of the deforestation embodied in EU countries. The methods and tools presented in this contribution leverage existing data sources and approaches and harmonize them in a workflow that allows to access extensive datasets and to perform analyses on land footprint and deforestation embodied in trade, for the products considered into the EUDR.

2. METHODS

The Biotrade package is a preparatory tool for Life Cycle Inventory (LCI) modeling. It can be used to prepare the land occupation and land transformation inventory flows and associate them to a global database of commodities trade. Biotrade facilitates the extraction of relevant information from FAOSTAT and Comtrade enabling to identify the main trade flows of a certain commodity and the associated monetary values. Trade data are used for the calculation of the land footprint associated to each product and the related embodied deforestation. The land footprint calculation is conducted through the implementation of a physical-based trade model (De Laurentiis, 2022), considering the reallocation of traded products that are not actually produced by exporter countries (Kastner et al., 2011). The land use change and the associated deforestation are estimated through the method proposed by Pendrill et al., 2019. These approaches were adapted on the specific products and commodities included in the EUDR, i.e. cocoa, soya beans, palm oil, coffee, cattle, timber and rubber.

3. RESULTS AND DISCUSSION

Our tools aim to further our understanding of the environmental impact and the main sources of uncertainties that can arise from trade data analysis. Figure 1 summarizes the presented work. Examples of results are displayed in Figures 2 and 3. Figure 2 shows an example of statistic extracted from the harmonized database, which is automatically built by Biotrade. Figure 3 displays the embodied deforestation associated to EU for a specific commodity. Insights derived from these instruments may contribute to decision-making for individuals, policymakers, and industries seeking to promote food choices in line with environmental sustainability.

4. CONCLUSIONS

The presented tools herein serve as a pivotal resource to support the EUDR regulation and Life Cycle Assessment within the context of environmental sustainability. We leverage modelling tools, database integration and analytical approaches into a toolset that provides timely information on the land occupation and deforestation impacts of the products included in the EUDR, with a specific focus on food commodities, timber and rubber.

5. ACKNOWLEDGEMENTS

This work is partially funded by Directorate-General for Environment (DG ENV F.3) under AA JRC N 35920 NFP.

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Figure 1. Workflow: 1) Production and trade monitoring (Biotrade); 2) land footprint model (based on De Laurentiis et al., 2022 with trade reallocation, Kastner et al., 2011) and 3) deforestation embodied assessment, modified from Pendrill et al., 2019.

Figure 2. Tree map showing the top 10 producing countries of soybeans in 2021 (data source: FAOSTAT).

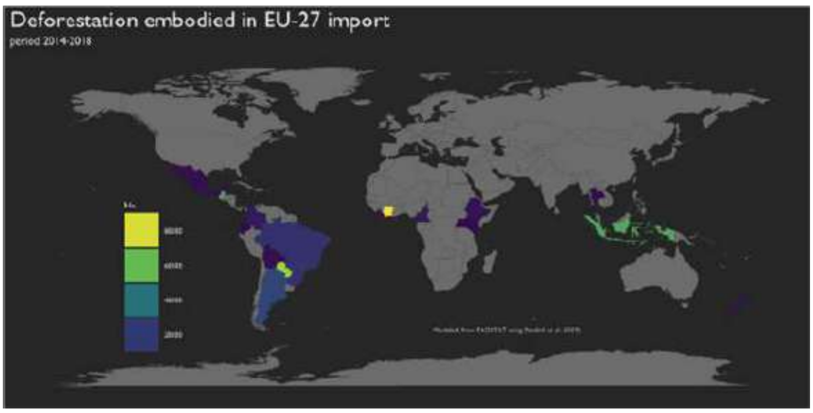

Figure 3. Embodied deforestation average impact of coffee based products imported by EU (period 2014-2018).

Development of the Crop System Efficiency Index

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1. INTRODUCTION

Multiple cropping is a practice that increasingly implemented worldwide, where a plot of land is subsequently planted and harvested multiple times in a year (Waha *et al.*, 2020). In the Land Use Change (LUC) methodology implemented in the Blonk LUC Impact tool and in the lifecycle inventory databases such as Agri-footprint and GFLI, multiple cropping activities have previously not been considered. To represent multiple cropping practices more accurately in LUC and land occupation calculations, we propose the use of the 'Crop System Efficiency Index'(CSEI): the (average) length of the harvest cycle of temporary crops (yr/harvest). The index considers both land efficiency gains from multiple cropping, and efficiency losses due to temporary fallow land and is based on publicly available data.

2. METHODS

As only temporary crops are associated with multiple cropping and fallow land, information of the hectares of crops harvested in a country, and determination of crops belonging to a productive period < 5 years (these are considered "Temporary Crops", but may be defined by FAO as either annual or perennial) is required. The other component required is the amount of surface harvested of Temporary Crops and the surface of Temporary fallow. Data is obtained from FAOstat, (2022). The first step is to determine the Multiple Crop Index as follows:

$$Multiple\ Crop\ Index\ (MCI)[\frac{yr}{harvest}] = \frac{Temporary\ Cropland\ [ha * yr]}{Harvested\ area\ of\ temporary\ crops\ [ha * harvest]}$$

In case the result is smaller than 1, multiple cropping occurs: the sum of harvested area for temporary crops is larger than the total temporary cropland. An MCI > 1 can be associated with incomplete FAO data (e.g. missing data for fodder crops in harvested area) and does not always point to land use inefficiencies. Therefore, the following rule is implemented: If MCI > 1, the value is adjusted to 1, leading to a MCI corrected value (MCIc). As fallow land is associated with crop rotation and multiple cropping, it is allocated to all temporary cropland. This is expressed in the Fallow Land Index (FI):

$$Fallow\ land\ Index\ (FI)[-] = \frac{Temporary\ Fallow\ Land\ [ha * yr]}{Temporary\ Cropland\ [ha * yr]}$$

In the last step the adjusted Crop System Efficiency Index is obtained:

$$Crop\ System\ Efficiency\ Index\ (CSEI)\ \left[\frac{yr}{harvest}\right] = MCIc\ [\frac{yr}{harvest}] * (1 + FI\ [-])$$

3. RESULTS AND DISCUSSION

3.1 Interpretation

The resulting CSEI values, calculated on country level, can be interpreted as the (average) length of the harvest cycle of temporary crops (in yr/harvest). Values smaller than 1 indicate land use efficiencies (more than one harvest per year), whereas values larger than 1 indicate land use inefficiency (more than one year per harvest). See Table 1 for a comparison of results from different countries.

3.2 Application

The CSEI should affect only the environmental impact linked to a proportion of time that the land is occupied by a harvested crop. An example is emissions linked to Land Use Change: if there are 2 crops produced in a year per hectare, the amount of LUC emissions will be split by 2 (50 % for each crop). Within Blonk we apply the CSEI in various models, such as Land Use Change, Peat, Land Occupation, Carbon Sequestration and Land Transformation.

4. CONCLUSIONS

The Crop System Efficiency Index is meaningful, straightforward to calculate based on publicly available data and can significantly improve representation of multiple cropping and crop rotation in LUC emission calculation and land occupation impact in LCA.

5. ACKNOWLEDGEMENTS

We thank Anna Flysjö and Jannick Schmidt for indicating the importance of double cropping on the statistical LUC calculations, and Renan Milagres Lage Novaes for the methodological support.

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	Brazil	**Argentina**	**Netherlands**	**Germany**	**United States**	**China**
CSEI results (yr/harvest)	**0.67**	**1.03**	**1.01**	**1.04**	**1.05**	**0.60**

Table 1. Crop system efficiency index (CSEI) from different countries.

Exploring HESTIA – a platform storing standardised data on agricultural production systems.

Data and models to achieve more sustainable agriculture.

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1. INTRODUCTION

Currently, Life Cycle Assessments (LCAs) are presented at various levels of detail and use different methodological choices. Discrepancies among LCAs data therefore prevent the results from being compared directly, which reduces the ability to use LCAs to inform policy and promote environmentally conscious decision making. This presentation will showcase HESTIA, the Harmonised Environmental Storage and Tracking of the Impacts of Agriculture platform, a platform aimed at standardising food LCA data.

2. METHODS

We built and tested the HESTIA platform to evaluate its capacity to archive agri-food LCA data. The HESTIA team has developed a schema and a comprehensive glossary to define unit process data and additional meta-data relevant to agri-food production for individual farming cycles. The schema describes the inputs, practices, products, transport, site(s), and emissions for each cycle, as well as Impact Assessment results if the data were derived from an LCA study. The Glossary includes a definition of each term, definition of standard units, and links to relevant external databases, such as Feedipedia. We also developed a HESTIA pipeline that validates the data against the Schema and Glossary as well as checking for errors in the data. Errors are automatically checked using rules (e.g., rainfall must be greater than 0mm), using external datasets (e.g., rainfall must be between X and Y given recent satellite data), and against other data on the platform (e.g., yields are likely to be between X and Y given existing data). Finally, studies are manually reviewed before being indexed.

3. RESULTS AND DISCUSSION

We have successfully uploaded over 700 studies to HESTIA successfully, 50,000 harmonised production cycles and data from multiple partners (including FiBL, CIMMYT, and WorldFish). The uploaded data represent production systems ranging from algaculture, to multiple cropping agricultural systems, to intensive livestock farming. We thereby conclude that HESTIA schema and glossary are robust for most agri-food LCA data to be indexed. Once successfully indexed, HESTIA can also recalculate emissions and environmental impacts using the underlying unit process data from the uploaded study and gap fill missing inputs and environmental emissions. Researchers can check their results in the original view (data included in the upload) and the recalculated view (including additional data recalculated by HESTIA). This allows researchers to upload their data and compare their results with other studies using a harmonised and LCA approach. Researchers can also download unit process data from HESTIA in a standardised format. The amount of data on HESTIA is constantly growing and we periodically release aggregated datasets grouped by geography, time, production practice, and food commodity. For example, HESTIA has automatically generated aggregated data for maize grain production in India covering 2010-2019 (HESTIA, accessed 08/02/2024). This is based on data from 1413 farms. HESTIA aggregates the activity data across these cycles. In this example, 189 kg/hectare (ha) of cattle manure is required to produce an average yield of 3120 kg/ha maize grain. HESTIA automatically recalculates all the impact indicators, using ~45 models coded on the platform. In this example, the IPCC (2021) model automatically recalculates the Global Warming Potential (GWP) (100 years) – 0.539 kgCO_2eq. Figure 1 compares the aggregated maize grain data for India to the global average (Poore & Nemecek, 2018).

4. CONCLUSIONS

HESTIA provides a robust data format for agri-food LCAs, as well as an expanding repository for harmonised food production data. It offers a resource for researchers, producers, consumers, and policy makers to understand the food system using a harmonised and transparent approach.

5. ACKNOWLEDGEMENTS

HESTIA is financed by the Login5 Foundation, WWF UK, Defra, the Ardevora Charitable Trust, and the Oxford Martin School.

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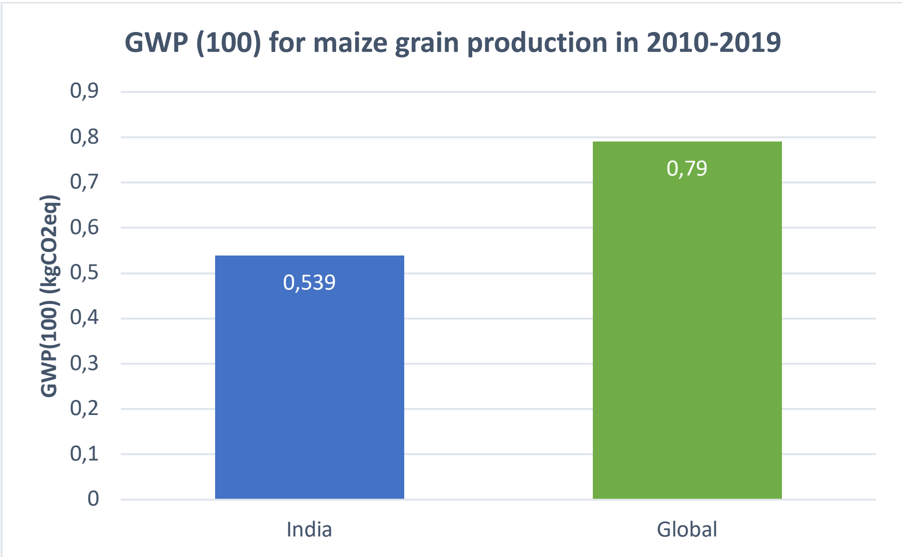

Figure 1. The Global Warming Potential (100 years) for maize grain production in India and Globally.

Development of an Italian Life Cycle Inventory Database of Agri-Food Products (ILCIDAF)

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1. INTRODUCTION

It is widely known that the implementation of LCA methodology implies the collection of primary field data inherent to the studied system and the use of secondary data from reliable and accurate databases, the quality of which is crucial as it influences the overall results of the study (Guinée et al, 2002). Very often, in Italy, for agrifood systems, the LCA practitioners use data from foreign databases (available in most commercial LCA software) that are not representative of the specificities of Italian systems. There is thus a need for the development of projects and initiatives aimed at the creation of national databases referring to products characterising specific national economic systems such as the Italian ones. In this regard, the Project of Significant National Interest (PRIN, 2017), financed by the Ministry of University and Research (MUR), entitled "Promoting agri-food sustainability: Development of an Italian Life Cycle Inventory Database of Agri-Food Products (ILCIDAF)" aims to develop an Italian Life Cycle Inventory (LCI) database, which is regionalised and dedicated to four national agri-food supply chains which are considered among the most relevant for the Italian economic sector, namely bread and pasta, wine, olive oil, citrus fruits).

2. METHODS

Each of these supply chains were studied by the Scientific Research Units of the University of Bari, Chieti-Pescara, Messina and Reggio Calabria. Each supply chain was developed considering the agricultural phase, the intermediate processing phase and the final product processing phase. The common methodological aspects for the selected food chains and the peculiarities and criticalities that each Research Unit has accounted for in a rigorous and scientific manner are described in "Notarnicola et al., 2022".

3. RESULTS AND DISCUSSION

At the end of the 3-year project, more than nine hundred datasets, available free of charge on the project website in excel format, were compiled using a statistical and field approach for the collection and processing of inventory data. The inputs and outputs of the generated datasets are representative not only of a national scale, but also of a regional scale. In particular, the SALCA-HM model (Freiermuth, 2006) for the quantification of water and soil emissions of heavy metals (by leaching and erosion) was characterised for the entire Italian soil (Notarnicola et al., 2023) and as a function of the agricultural crops under study. In this paper, for each of the above-mentioned specific supply chain LCI inventory, the results, the problems encountered and the solutions implemented will be described. The next step is to render the datasets in a format suitable for use in LCA software and this involves associating inputs and outputs with purpose-built or background processes. The Ecoinvent v 3.9 database was chosen for this purpose.

4. CONCLUSIONS

The overall results of an LCA study depend heavily on the quality of these databases. The creation of national and regional databases is crucial for the development of LCA methodology in the agri-food sector. The use of unrepresentative background data for a given system negatively influences the application of this methodology. The ILCIDAF Project intends to solve these application difficulties for four relevant supply chains of the Italian food context. It is therefore necessary to extend such initiatives to other food chains.

5. ACKNOWLEDGEMENTS

This article describes part of the results of the research project "Promoting Agri-Food Sustainability: Development of an Italian LCI Database of Agri-Food Products (ILCIDAF)" (PRIN – Research Projects of National Interest 2017-Prot. 2017EC9WF2, ERC SH2, Line C- funded by the Ministry of University and Research - MUR).

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Life cycle inventory: modelling, databases and tools (III)

The GRINS Project for the development of Life Cycle Inventory databases of beef cattle raised in Italy: preliminary results of the statistical dataset

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1. INTRODUCTION

As part of the activity of the Extended Partnership "Economic-financial sustainability of systems and territories" (GRINS Spoke 1 Project, WP3), this work aims to propose datasets concerning the beef cattle breeding specific for the Italian territory. This arises from the requirement to fill the absolute lack of data representative of cattle farming in Italy, in term of specific cattle breed, agricultural crops and breeding practices. Numerous studies highlight beef production's significant contribution to agricultural emissions of climate-altering compounds and the exploitation of natural resources. These systems are recognized for their role in emitting climate-altering, acidifying, and eutrophying compounds, while depleting natural resources. Livestock beef cattle accounts for 14.5% of human-induced greenhouse gas emissions, with enteric fermentation and manure management as key contributors. Emission shares vary regionally, influenced by agricultural and breeding practices as well as geographical factors. Finally, optimal feed ratios and appropriate stable management play a key role for mitigating the environmental impact of cattle breeding, affecting water and soil use.

2. METHODS

The Statistical section of the Italian Ministry of Health offers detailed data on the bovine population, categorized by breed, gender, and age group for each region. The research considered meat breeds with an average population equal to or greater than 1% (2019-2022). Greenhouse gas estimates (from enteric fermentation and manure management) were conducted using IPCC level 2 models, considering parameters like weight gain, type of farming system, and diet composition. In crop production, boundaries encompass manufacturing processes (including raw material extraction), as well as the supply and utilization of inputs essential for the whole production cycle (fuels, fertilizers, pesticides, transport, seeds, other necessary materials). The inputs from stable management (water, soil occupation, fuel, electricity, and manure management) were also considered. The LCA analyses of 11 meat cattle breeds adopted a cradle-to-farm gate perspective. The functional unit was 1 kg of live weight of animals (LEAP guidelines). The dataset was characterized by EF 3.0 method (16 impact categories).

3. RESULTS AND DISCUSSION

In this work, 66 of the nearly 500 national and regional statistical datasets expected to be included in the whole project were analyzed. Specifically, 11 meat beef cattle were designated at national or regional level. For each of these cattle, 6 different groups were formed based on their age (6-12 months, 12-24 months, and over 24 months) and gender (male and female). Each dataset provided detailed and breed-specific information related to climate-altering gas emissions (CH_4, direct and indirect NO_2 and NO_x), as well as stable management (water and electricity consumptions, soil occupation) and feed ration. This aspect was deeply investigated considering the agricultural phase of each crop (both forage and concentrate parts) employed in the preparation of the feed cattle. Detailed national and regional data related to the analyzed four-year period (2019-2022) were gotten considering cultivated area, crop yield and import/export volume to provide a model fitting with the Italian situation.

In the LCA analyses, *Piedmontese* breed (the main meat Italian pure breed) was chosen as model and the impacts for each category (age and gender) were evaluated. Concerning to the six analyzed *Piedmontese* cattle, calves female (6-12 months) returned the highest environmental impact (+81% respect to the bulls, low impact). The analysis highlighted as 5 indicators (climate change, particulate matter, ecotoxicity freshwater, eutrophication terrestrial, acidification, and water use) covered almost 80% of the total impact. In particular, the factors mainly affecting each indicator were identified in the biogenic CH_4 (climate change), ammonia (particulate matter and eutrophication terrestrial), pesticides employment (ecotoxicity freshwater) and crop irrigation and stable management (water use). Similar trend was recorded for the other beef cattle, with changes related to the specific analyzed breed.

4. CONCLUSIONS

The research aims to develop Italian datasets considering breed and geographical area specific parameters. The absence of national and regional datasets on Italian cattle breeding, makes this research attends as a valuable source of detailed data that can serve as models for sustainable practices with the purpose to optimize livestock husbandry environmental performances.

5. ACKNOWLEDGEMENTS

This article is part of the activities of the Extended Partnership "Economic-Financial Sustainability of Systems and Territories" (GRINS Spoke 1, WP3), to achieve the milestone "Set-up of LCI national and regional datasets for the main Italian production systems that will be part of AMELIA".

Environmental assessment of swine and beef cattle sectors in Catalonia

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1. INTRODUCTION

There is an increasing need for regionalized databases, as impact of our activities can significantly differ across geographical contexts. Catalonia is one of the main swine producers in Europe, and it holds a substantial part from the beef produced in Spain. However, there is a data gap of Southern European countries for the environmental impact of these production systems, which leads to use other countries data as a proxy. Promoted by Catalan Government, the most representative regional pig and beef production systems were analyzed.

2. METHODS

To assess the environmental footprint of Catalan pig and beef production systems, farms were classified according to geographical area, animal holding capacity and management systems. The scope of the study was from cradle to farm gate. During 2022 and 2023 primary data were collected through interviews and field visits. Production systems were inventoried, from starting (e.g. great-grandmother for swine) to finishing stages (e.g. fattening systems). Secondary data were retrieved from Catalan administrative databases, Ecoinvent 3.8 (Wernet et al., 2016) and Agribalyse 3.1 (Asselin-Balençon et al., 2020). When necessary, economic allocation was applied between coproducts (e.g. sows and piglets). Environmental impact was assessed following Environmental Footprint method 3.0 (European Commission, 2013). Impact results were weighted according to the equivalent livestock units (Table 1) (DACC, 2023).

3. RESULTS AND DISCUSSION

Two swine production models were differentiated to represent the variability of existing systems in Catalonia: open system with three sub-types (all phases are separate, sows together with piglets, and "wean to finish") and closed system (all phases in the same farm). A total of 22 farms were inventoried. For beef cattle production, three main production models were differentiated: intensive model with three sub-types (open system, calf rearing plus fattening, and beef breed), extensive model with two sub-types (open and closed systems), and "other" production models with two different sub-types (unifeed and angus cross). A total of 29 farms were inventoried. The weighted average carbon footprint of 1 kg live weight of swine produced in Catalonia was of 4.4 kg CO_2 eq. and the water footprint was of 11.2 m^3 eq. For cattle, the weighted average carbon footprint of 1 kg live weight of beef cattle produced in Catalonia was of 12.0 kg CO_2 eq. and water footprint was 18.7 m^3 eq.

4. CONCLUSIONS

The environmental impact results can vary depending on local specific parameters such as physic-chemical soil properties, water availability, or ecosystem sensitivity. This study allowed to develop specific inventories and quantify environmental impact for conventional production systems of swine and beef cattle in Catalonia. This study has also highlighted the importance of developing appropriate data registry systems in the farms. To have a complete picture of the environmental impact from the final product, the downstream value chain needs to be assessed.

5. ACKNOWLEDGEMENTS

Authors specially thank the farmers that voluntary participated in the study, and the Department of Climate Action, Food, and Rural Agenda for promoting the development of this database.

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	Models & Subtypes	Code	Phases	Feeding system	Equivalent livestock unit	Region	Carbon Footprint (kg CO_2 eq/FU)	Water Fooprint (m3 eq/FU)	Functional Unit
Swine	Open system: Separate phases	A.1.1	Great-grandmother	Compound feed	290.1	Barcelona	527.00	1420.00	Future grandmother (<115 kg)
		A.2.1	Grandmother		110.7	Barcelona	389.00	1240.00	Future breeding sows (<90 kg)
		A.3.1	Boars		26.4	Lleida	1.78	4.39	Insemination catheter dosage (45 ml)
		B.1.1	Farrow to wean		291.4	Lleida	76.80	188.00	Piglets (< 6 kg)
		B.1.2			387.5	Lleida			
		B.1.3			147.0	Girona			
		C.1.1	Transition		120.3	Lleida	122.68	11.53	Weaners (< 20 kg)
		C.1.2			99.9	Lleida			
		C.1.3			130.0	Lleida			
		C.1.4			74.5	Lleida			
		C.1.5			83.7	Girona			
		C.2.1	Fattening		240.0	Lleida	4.34	11.47	Finishers to slaughter
		C.2.2			508.3	Girona			
		C.2.3			524.1	Lleida			
		C.2.4			516.1	Lleida			
		C.2.5			441.7	Lleida			
	Open system: Farrow to transition	B.2.1	Farrow to transition		434.6	Girona	130.61	273.41	Weaners (< 20 kg)
		B.2.2			384.2	Lleida			
		B.2.3			237.5	Tarragona			
	Open system: Wean to finish	D.1.1	Wean to finish		522.0	Lleida	4.57	12.76	Finishers to slaughter
	Closed system	D.2.1	Closed system		666.4	Tarragona	5.03	7.02	Finishers to slaughter
		D.2.2			409.7	Tarragona			
Cattle	Intensive beef open system	A.1.1	Calf rearing	Compound feed + straw	80.0	Lleida	2219.80	1250.20	Weaned suckling
		A.1.2			90.0	Lleida			
		A.1.3			40.0	Lleida			
		A.1.4	Calf rearing + fattening		279.0	Lleida	10.69	14.94	Weaned to slaughter
		A.2.1			53.0	Lleida			
		A.2.2			43.0	Lleida			
		A.2.3			201.0	Lleida			
		A.2.4			158.0	Lleida			
		A.2.5			156.0	Lleida			
		A.2.6			400.0	Lleida			
		A.2.7			154.0	Lleida			
		A.3.1	Fattening		180.0	Lleida	11.18	21.00	Weaned to slaughter
		A.3.2			52.0	Lleida			
		A.3.3			173.0	Lleida			
		A.3.4			108.0	Lleida			
		A.3.5			810.0	Lleida			
		C.1.1		Unifeed	248.0	Barcelona	21.48	32.84	Calf to slaughter
	Beef breed intensive open system	C.1.2	Fattening	Unifeed	120.0	Tarragona	21.48	32.84	Calf to slaughter
	Intensive beef open system (Angus cross)	C.2.1	Calf rearing + fattening	Compound feed + straw	51.0	Lleida	12.81	14.83	Calf to slaughter
		C.2.2	Fattening		78.0	Lleida			
	Beef breed extensive open system	B.1.1	Calf rearing	Grazing + fodder + compound feed	183.0	Barcelona	5448.62	4971.55	Weaned pasture calf (line meat)
		B.1.2		Grazing + Unifeed	237.0	Barcelona			
		B.1.3			149.0	Lleida			
		B.1.4		Grazing + fodder + compound feed	144.0	Lleida			
	Beef breed extensive closed system	B.2.1	Calf rearing + fattening	Grazing + fodder + compound feed	273.0	Barcelona	18.96	23.79	Pasture calf (line meat) to slaughter
		B.2.2			271.0	Girona			
		B.2.3			177.0	Girona			
		B.2.4			69.0	Girona			
		B.2.5			66.0	Lleida			

Table 1. Weighted average carbon and water footprints of the different production systems considered for beef cattle and swine.

Cause-effect-based approach to inventory and model pig products in slaughterhouses

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1. INTRODUCTION

Nearly 60% of global greenhouse gas (GHG) emissions from food comes from production of animal-based products (Xu et al., 2021), and additionally, the demand for meat is expected to increase by 73% in 2050 compared to 2010 (Gerber et al., 2013). Reducing emissions of meat production, both on-farm and during processing, is therefore crucial to mitigate climate change impacts.

Danish Crown (DC), the world's largest pork exporter, is benchmarking and tracking their emissions over time and finding hotspots in order to reduce their emissions, both on-farm and in slaughterhouses and food processing facilities. Consequential life cycle assessment (LCA) is the methodology used in this study to develop a flexible tool that enables the user to analyse the GHG emissions from DC slaughterhouses, and specifically pig slaughterhouses in the current study.

2. METHODS

In a pig slaughterhouse, there are a number of different processing stages: slaughter, chilling, primal cutting, and butchery. One key challenge is that of multifunctionality, where each activity has more than one determining product. An algorithm was created to identify the determining products, and once identified, modelling of different cuts is performed using a ratio based on a cause-effect relationship, that ends up showing same results as for economic allocation. However, it must be emphasized that this is done only for the determining products – by-products and materials for treatment are modelled using substitution.

The cause-effect-based calculation for ratio (R) for determining product i is:

$$R_i = \frac{price_i}{\frac{\sum_{i=1}^{n} mass_i \cdot price_i}{\sum_{i=1}^{n} mass_i}}$$

Another challenge is data availability, where it is most common to receive aggregated, total data for each slaughterhouse instead of specific data inventoried for each processing stage. As pig cuts can either be sold directly from each stage or move downstream (requiring more electricity and other inputs as it moves through the processing stages), it is necessary to find the energy and material usage of each stage. We implemented an algorithm that scales generic inventory data for each process with the inputs of the facility to result in site-specific inventories for each process. This ensures that the aggregated data at site scale can adequately be allocated to the relevant processing stages in the slaughterhouse.

3. RESULTS AND DISCUSSION

The procedures implemented in the tool enable for the calculation of a detailed life cycle inventory (and further impact assessment) of any pig cut (either determining product or by-product) in any slaughterhouse for which data is available. A selection of results for different cuts is presented in Figure 1. The inventories per processing stage are based on a generic inventory for each process, which is scaled to the total data inputs for the specific site. The cuts shown in Figure 1 have different GHG emissions due to the cause-effect-based ratio; where tenderloin is the highest value cut and therefore the most emission-intense. Liver has the lowest impacts, and the impact is the same for the two slaughterhouses, because liver is a by-product and a change in demand does not cause a change in the overall production of a slaughterhouse. This can be verified from the fact that liver is only partly used for human consumption, whereas the rest is sold at low price for petfood purposes.

4. CONCLUSIONS

The Danish Crown slaughter tool that was developed to calculate emissions of meat cuts is a useful tool for the industry to be able to calculate product specific footprints, benchmark, find hotspots, and reduce emissions in the future. An existing challenge is the lack of data disaggregation, and solving this limitation is a way to further enhance the quality of results.

5. ACKNOWLEDGEMENTS

We thank Morten Pedersen and Gustaf Bock from Danish Crown for their cooperation.

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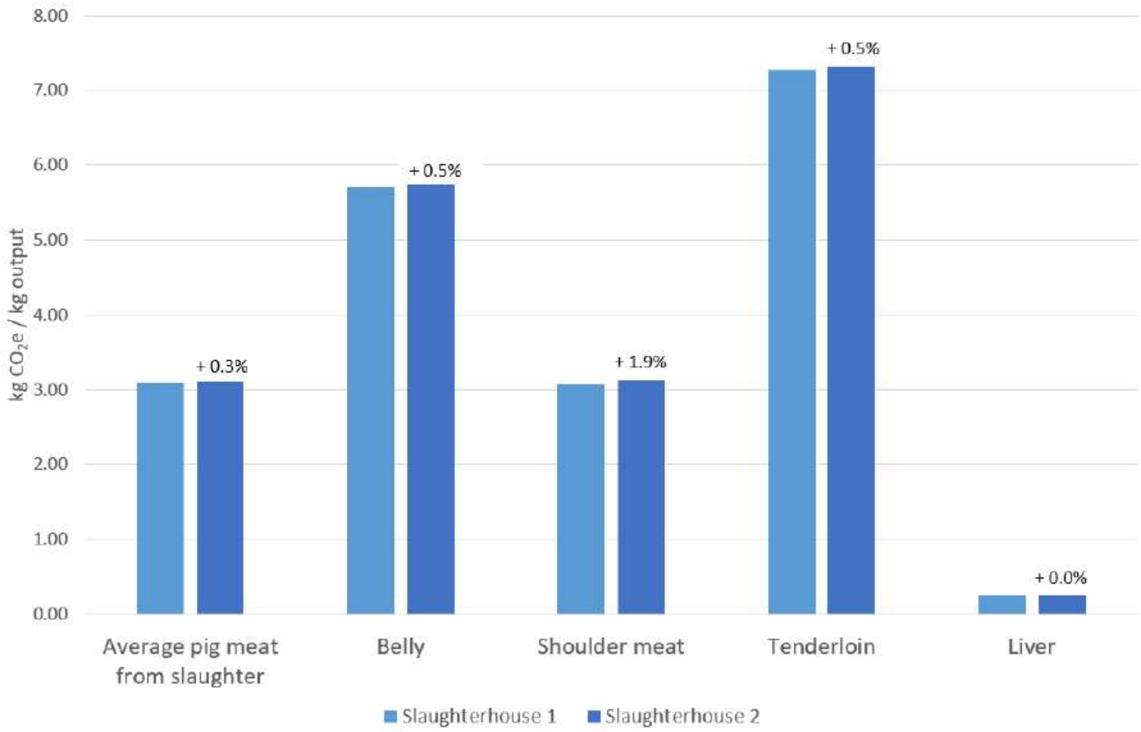

Figure 1. Results for four selected cuts compared to average pig meat, in two different slaughterhouses. Unit: kg CO_2e per kg product output.

The water footprint of global crop production – Country level and gridded LCI data for 175 crops from 1990 to 2019

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1. INTRODUCTION

As agriculture is responsible for ca. 90% of global human water consumption, reliable and up-to-date water inventory data is key in LCA studies of crops and crop-derived products. In this work, we present consumptive (green and blue) water footprints of global crop production during 1990-2019 using state-of-the-art input data and the global gridded crop model AquaCrop-Earth@lternatives (ACEA, Mialyk et al. 2024). The generated water footprint dataset provides new LCI data inputs for 175 crops on a global scale at grid and national levels.

2. METHODS

ACEA is a global gridded version of FAO's water-driven and process-based crop growth model AquaCrop (Vanuytrecht et al., 2014). The key features of ACEA are direct tracing of green and blue water fluxes in the soil, consideration of historical changes in rainfed and irrigated croplands, and efficient large-scale computation. For more details, please refer to Mialyk et al. (2024). The main input data sources are:

- Soil and daily climatic data as used in the Inter-Sectoral Impact Model Intercomparison Project (Inter-Sectoral Impact Model Intercomparison Project, 2022).
- Crop parameters from AquaCrop's default files and crop-specific literature.
- Average monthly gridded groundwater levels (Fan et al., 2013).
- Gridded rainfed and irrigated harvested areas from SPAM2010.
- Annual production and harvested area statistics per country from FAOSTAT (2022).

The simulation of crop water footprints in ACEA has several stages. First, green and blue ETs as well as crop yields are modelled. Then, the latter is scaled together with harvested areas to fit the official national statistics from FAOSTAT. This allows accounting for historical agricultural developments such as an increase in fertilizer use, cropland expansion, or impacts of socio-political instability. Finally, three consumptive water footprints are estimated: green, blue from irrigation, and blue from capillary rise.

3. RESULTS AND DISCUSSION

As a result, our analysis provides the following water footprint datasets (available in Mialyk et al. 2024) covering green water, blue water from irrigation, and blue water from capillary rise for the period 1990-2019:

- National average unit water footprints ($m^3\ t^{-1}\ yr^{-1}$) for all 175 crops
- Global gridded unit water footprints ($m^3\ t^{-1}\ yr^{-1}$) for major crops
- Global gridded water footprints of aggregated crop production ($m^3\ yr^{-1}$)
- Global gridded crop water use ($mm\ yr^{-1}$) for major crops

A more detailed description of the dataset, the underlying methodology and a comparison to other datasets can be found in Mialyk et al. (2024). First results show that global crop water consumption increased by 30% since 1990, approaching 7 trillion m^3 in 2019 (Figure 1a) with China, India and the USA being the largest water consumers (Figure 1b). In contrast, unit water footprints of most crops reduced – median decrease of 19% (Figure 1c) due to increased yields resulting from improved agricultural practices. Thus, the increase in total water consumption mainly results from an expansion of harvested areas and the increase in total production.

4. CONCLUSIONS

Using the global gridded crop model ACEA, the blue and green water footprints of global crop production have been determined during the period of 1990-2019. Especially the national and gridded unit water footprints of 175 crops can be an important source to update current Life Cycle Inventory datasets to enhance LCAs of crops and crop-derived products.

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Data

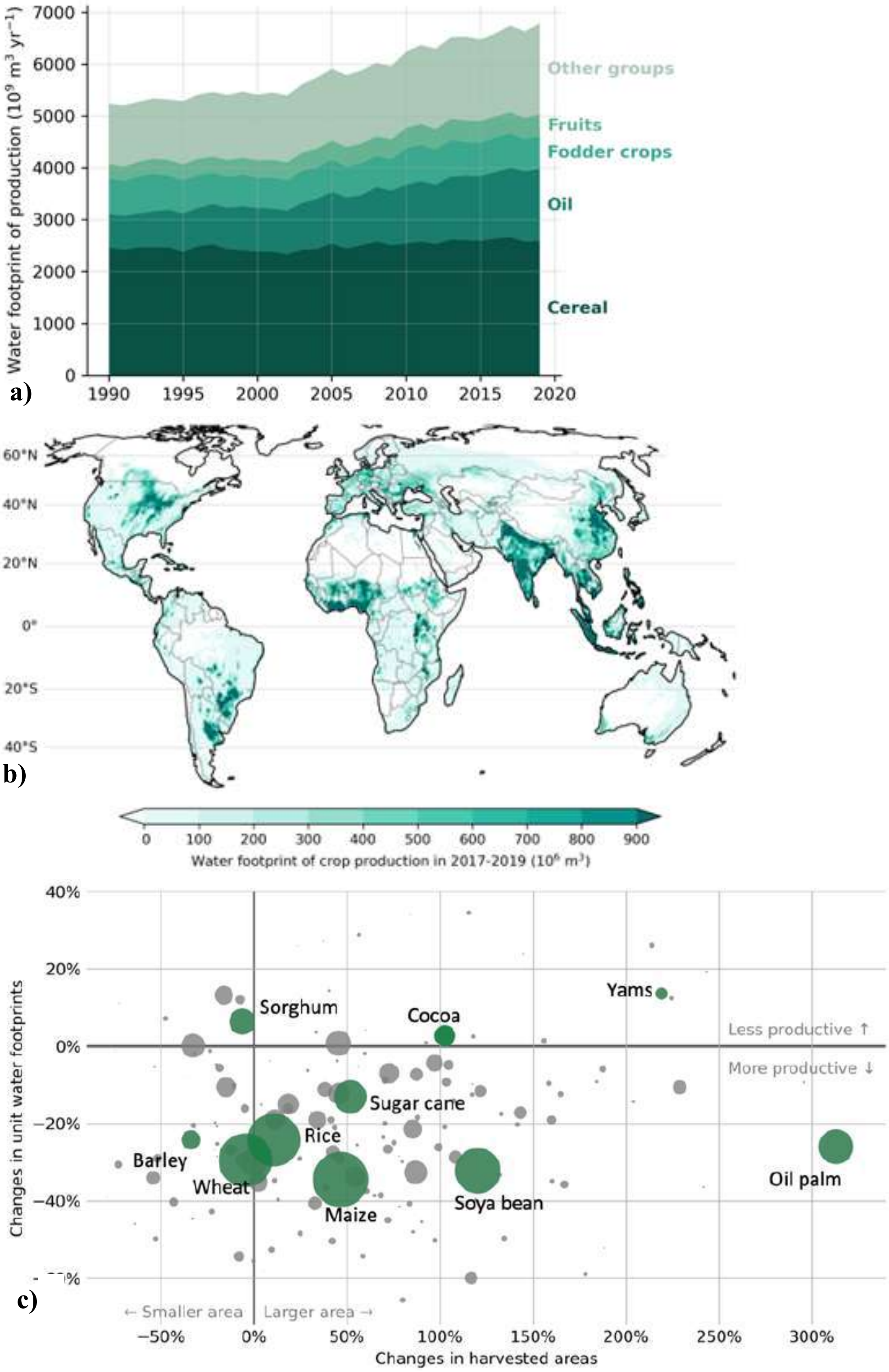

Figure 1. a) Time series of global water footprints of crop production in 1990–2019; b) Global gridded water footprint of crop production in 2017-2019 c) Changes in global average unit water footprints and total harvested areas per crop from 1990–1992 to 2017–2019

Can we account for all agri-food chemicals in the impact assessment?

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1. INTRODUCTION

Antibiotic resistance (ABR) development is one of big challenges facing modern human society (Murray et al., 2022; O'Neill, 2016). However, LCA have not been able to deal with ABR in the LCIA-step, as only ecotoxicological impacts to animals are evaluated. These impacts are, arguably, of marginal importance in relation to the potential consequences of ABR development. To improve the coverage of impacts from antibiotic use, we present an approach to calculate potential antibiotic resistance (ABR) development from the use of antibiotics in throughout the value chain (Nyberg et al., 2021). Moreover, data on the ecological impacts of pesticides and pharmaceuticals used in agri-food systems are severely limited, considering the widespread use of these chemicals for securing food production. We also scrutinize the availability of the ecotoxicological effect data available for chemicals, and present an approach to quantify the uncertainties of these data.

2. METHODS

Using the USEtox model (Fantke et al., 2017) as a starting point along with bacterial susceptibility data from the EUCAST database (https://mic.eucast.org/search/) we suggest calculating effect factors for antibiotics using concentration thresholds below the onset of ABR development in bacteria i.e., as a NOEC endpoint. This enables calculation of niched CFs for antibiotics that can be used in the LCIA step of an LCA.

To estimate the coverage and calculate uncertainty in ecotoxicological CFs, we gather openly available ecotoxicological effect data and compiling a state-of-the-art ecotoxicological database. We then apply weighted nonlinear least-squares regressions to data when constructing species sensitivity distribution models (SSDs) for each chemical to assess uncertainty in the concentration response slope factor (CRF) that is underpinning freshwater aquatic ecotoxicological CF.

3. RESULTS AND DISCUSSION

Our presented methodology to calculating the onset of ABR development in the environment enables LCA users to assess the most important aspect of antibiotic pollution in LCAs, which is necessary if the full range of impacts of antibiotics are to be evaluated.

Despite gathering over 118.000 ecotoxicological tests for over five thousand chemicals, we are able to assess the uncertainty in the CRF for only 1117 chemicals, due to limitations of the weighted nonlinear least-squares regression approach on handling chemicals with few data. Many chemicals have insufficient data to construct robust SSDs for explaining toxic effect, and these CFs are thus highly uncertain. Meanwhile, LCA software lack ability to account for uncertainty in the impact assessment, which is necessary inform practitioners on the precision of the LCIA results.

4. CONCLUSIONS

While an approach to capture impacts for antibiotics is presented, there are still a large number of agri-food chemicals that are missing CFs, and a large portion of the ones that have been characterized for ecotoxicity remain highly uncertain. In order to improve the transparency in the LCIA-step for ecotoxicological impacts comes a need for improvements in LCA software to inform users where data is missing and the precision of the potential toxicological impact. Novel approaches for improving chemical coverage, such as the use of generic CFs for different groups of pesticides could be an option. But such generic CFs are attached with large uncertainty and we would argue that uncertainty must be reported throughout the assessment for these to be valid.

5. ACKNOWLEDGEMENTS

ON is funded by the Walton Family Foundation (00104857), and the David and Lucile Packard Foundation (2022-73546).

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Global pesticide application data for use in LCA

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1. INTRODUCTION

Pesticides (referred to as the active ingredients used in plant protection product formulations) are vital for global crop protection and food security, but their release into the air, soil, and water contributes to environmental pollution and poses risks to human and ecosystem health (1). Accurately assessing such impacts from local to global scale requires detailed assessments of pesticide emissions, fate, exposure, and effects, which vary based on the type of pesticide used, crop growth stages, application methods, and regional characteristics. Reliable life cycle inventory (LCI) data for emissions of pesticides based on detailed pesticide use information are essential for policy and practice development to balance effective crop protection with minimal health risks (2). Presently, global estimates of pesticide usage fall short of effectively supporting emission, risk, and impact assessments, primarily due to their focus on single countries, reliance on sales and trade data, and lack of details on key factors like crop growth stage and application method and pesticide. The present study addresses this knowledge gap by generating a comprehensive and granular global dataset of actual pesticide mass and rate (mass applied per crop treated area per treatment). Our dataset provides a resolution at the level of country/region, crop, and pesticide, including crop growth stages, application methods, and targeted treatment compartments. Additionally, we present high-resolution global maps depicting spatialized annual average pesticide usage per crop. As an initial step towards quantifying LCI emission data, this dataset can be integrated with (eco-)toxicity characterization factors, providing a more robust foundation for environmental impact assessments and LCA.

2. METHODS

The foundational data for this study is sourced from GfK Kynetec AgroTrak^{TM}, encompassing a period from 2016 to 2020. This includes data from panel reports, industry statistics, market research, and internal data collection initiatives by Bayer CropScience. To construct a comprehensive global profile of average annual pesticide application in terms of mass, rate, and spatial distribution, we curated the dataset via a series of key processes. (1) Data cleaning and harmonization focused on consolidating information by country/region, crop, pesticide, application method, and crop growth stage, augmented with spatial details on crop allocation, climate, Human Development Index (HDI), and Gross Domestic Product (GDP). (2) Data and scenario imputation aimed at estimating pesticide application in countries without reported data and filling gaps in application details, utilizing conformal prediction and XGBoost techniques. (3) The final stage involved generating outputs, which included spatial mapping and characterizing the uncertainty associated with the results.

3. RESULTS AND DISCUSSION

Data imputation was carried out for 81 countries, primarily in sub-Saharan Africa, which lacked reported data (Figure 1 left). Additionally, more than 50% of the reported scenarios across various country/region-crop-chemical combinations were imputed that had missing critical details regarding application methods or crop growth stages (Figure 1 right). This imputed information is pivotal in refining LCI emission estimates and enhancing the environmental efficiency of global pest control strategies, since it allows to compare pesticides, crops and countries in terms of pesticide use across regions, also where reported data are lacking.

When combined, the reported and imputed data reveal that annual global pesticide use amounts to approximately 2.9 million tonnes, encompassing 180 countries, 130 crops, and 1077 distinct pesticides. The largest contributors to global pesticide use in terms of mass applied are China, the United States of America (USA), Brazil, and Argentina. The most extensively used pesticides are glyphosate, sulphur, mancozeb, and atrazine, with annual mass applied of 0.64, 0.17, 0.16, and 0.1 million tonnes, respectively. In addition to our detailed pesticide use dataset, global application distribution maps at the crop-pesticide level were produced (Figure 1 left). These maps offer a tool for comparing pesticide intensity within countries and enable broader comparisons across different pesticides, crops, and countries.

4. CONCLUSIONS

Our comprehensive global pesticide application dataset serves as a foundational tool for creating emission and impact data for LCA studies and environmental footprint analyses of agrifood systems. Additionally, maps of spatialized pesticide applications offer insights into enhancing crop protection practices within the framework of national and regional guidelines.

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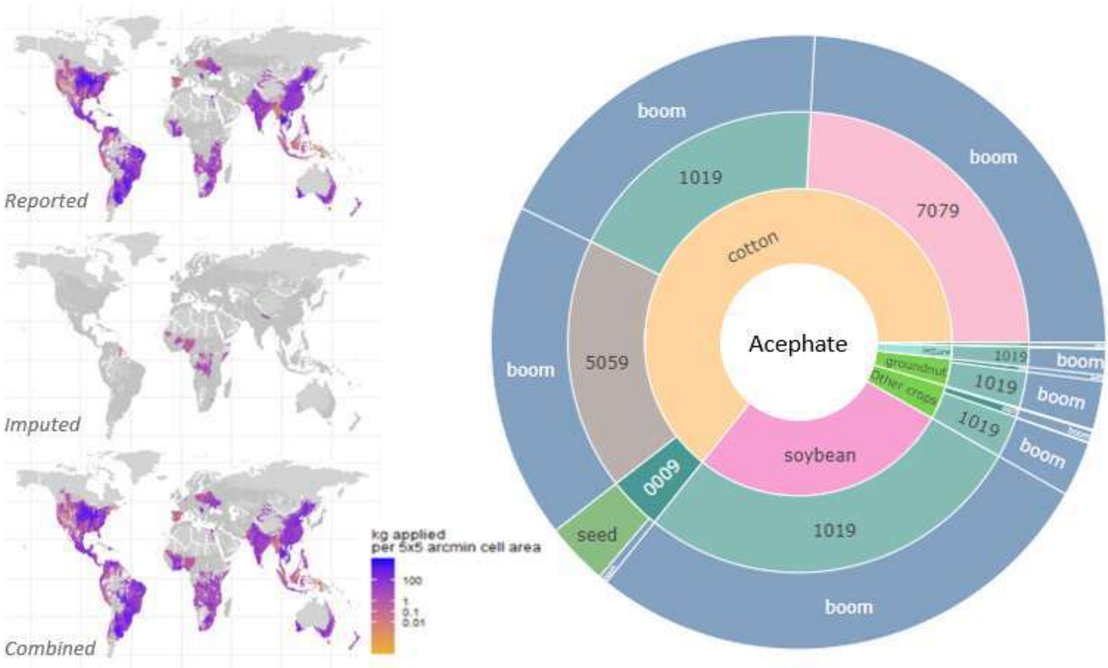

Figure 1. Global 5 × 5 arcminute gridded map for application mass of atrazine used across all respective crops (left), separated by reported data on the top, imputed data for countries with no pesticide application information in the middle, and combined data at the bottom; Mass distribution of Acephate applied in the United States of America (right) across crops (inner ring), crop growth stage ranges (BBCH, middle ring), and application method (outer ring), boom represent for generalized sprayer using mechanical application methods represented by boom sprayer, aerial represents aerial application.

Ecolabelling

19

A Comparison of Databases to assess the climate impact of labeled foods

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1. INTRODUCTION

Food production is among the largest drivers of global environmental change. Efforts must be made to provide a healthy and accessible diet for the population that is also sustainable for the planet (Willett et al. 2019). A large and increasing number of carbon and sustainability labels for food can be found in retail (Sonntag et al. 2023). However, all these labels for assessing the sustainability of food are based on different data sources. The aim of our investigation was to find out whether the use of many different data sources reduces the informative value and reliability about the climate and environmental claim of labels. This paper provides an overview over databases which are used in current carbon and sustainability food labels in Europe.

2. METHODS

This work is designed as desk research. The most common labels and their underlying data sources were collected by an internet search of homepages, as well as a literature review of background and methodology reports. From the data sources (databases, primary sources, own calculations, other sources) used for creating the labels, only free and commercial databases were considered here. Table 1 shows the databases used by selected carbon and sustainability labels in Germany and Europe. As an example, the carbon footprints of conventional whole milk, are calculated using the free databases from table 1 and are shown in figure 1.

3. RESULTS AND DISCUSSION

The publishers of the labels obtain their data from many different databases (table 1) with varying data quality and scopes. The number of databases used varies between labels and is often not evident for an individual product, as is the origin of the data source. The databases differ from each other in terms of the number of certified food items, the impact categories, the reference unit, the geographical reach, the time reference and the calculation method. The data contained in the databases refers to different countries and regions. The system boundary can only contain agriculture or can go up the entire value chain. The carbon footprint of a food item like cow´s milk depends on many different aspects (figure 1). Up to farm gate there is an average of 1,05 +/- 0,16 CO_2e /kg milk, up to supermarket the values fluctuate around 1,59 +/- 0,27 CO_2e /kg milk. The carbon footprint in agricultural production can vary greatly due to many factors, like feeding (Mottet et al. 2017), the farming system and the management strategies (Kristensen et al. 2011). Later in the supply chain, milk processing and transportation will influence the carbon footprint, as well as packaging and the electricity mix (ifeu 2014). It is often not possible to see the assumptions that the free databases are based on. An exception is Agribalyse, which is very transparent about their assumptions for calculations. However, free databases at least provide an indication of the carbon footprint of foods.

4. CONCLUSIONS

The comparability of the statements made by climate and sustainability labels is limited because of different data sources and system boundaries. When labels are based on data from primary sources, empirical values and own calculations, the comparability of the results becomes even more limited. Depending on the choice of database, production factors and allocation, the result of an LCA can vary. Calculations of carbon footprints should be carried out with comparable methods. Moreover, assumptions and calculations need transparency and generally accepted standards. A uniform, comprehensive database in Europe is necessary for the comparability of foods in terms of their ecological balance.

5. ACKNOWLEDGEMENTS

Funded by the Federal Ministry of Food and Agriculture on the basis of a resolution of the German Bundestag.

With support from
Federal Ministry of Food and Agriculture
by decision of the German Bundestag

Project manager
Federal Office for Agriculture and Food

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Table 1. The use of databases in sustainability and climate labels

Database ***(Institution)***	**County**	**Charges apply**	**Used by labels**
Agribalyse *(ADEME, INRAE)*	FR	no	Climatepartner, Eaternity Score, Eco Impact, Eco Score (Beelong), Eco Score, Planet Score
Agri-Footprint *(Blonk)*	NL	yes	Climate Partner, Eaternity Score, Eco Impact, WASA CO2 neutral
Bonsai *(Aalborg University)*	DK	no	Eaternity Score
ClimateHub *(CarbonCloud)*	SE	yes/no	Oatly Climate Footprint, Climatepartner
Ecoinvent *(Ecoinvent Association)*	CH	yes	Climatepartner, Climateline Zukunftswerk, Eaternity Score, Eco Impact, Eco Score (Beelong), Klimaneutral Fokus Zukunft, M-Check, MyClimate, WASA CO2 neutral
Hestia *(Oxford Martin School, WWF, Login 5 Foundation)*	UK	no	Eaternity Score
Ifeu *(Ifeu)*	D	no	Climateline Zukunftswerk
ProBas (under revision *(UBA)*	D	no	Climateline Zukunftswerk, Klimaneutral Fokus Zukunft
WFLDB *(Quantis)*	CH	yes	Eaternity Score, Eco Impact, Eco Score (Beelong), M-Check
RISE *(RISE)*	SE	yes/no	Eaternity Score

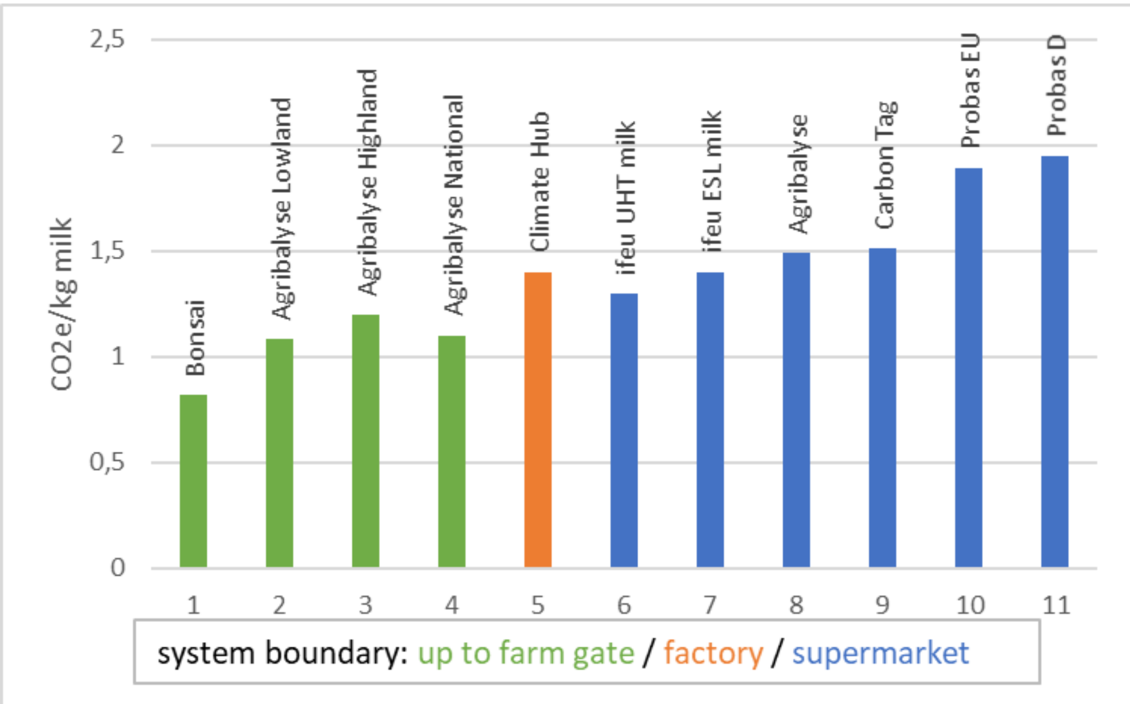

Figure 1. Carbon footprint of whole milk calculated with different free databases

How to develop robust Sustainability labels for food? Learnings from the Environmental Footprint

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1. INTRODUCTION

The last years have been characterised by rapid developments in sustainability labelling schemes for food products, especially in Europe. However, the proliferation of labels risks leading to further confusion in consumers and potential greenwashing (Brown et al., 2020). Recent legislative initiatives (such as the proposal for the Green Claims Directive) suggest that harmonizing sustainability information to consumers could be necessary to avoid greenwashing and eventually promote sustainable consumption. In the EU, the Environmental Footprint (EF) has been recommended as the reference LCA method for the environmental assessment of products and organisation (EC 2021). EF has been taken as reference for some of the labels being proposed in the market. However, several approaches exist and an assessment and comparison of the methodological foundations is still lacking. This work sets out to evaluate and compare methodologies to **indicate possible developments** for providing harmonized sustainability information to consumers within the EF. This will be key for EF communications, and therefore key stakeholders as businesses and policy makers.

2. METHODS

A mapping of the labelling initiatives was carried out based on the Mintel Global New Products Database (EC 2023). A dataset compiled by JRC includes all the mapped labels. The final selection of labels for this study focused on those that were addressing environmental aspects of sustainability that were LCA-based and analyzed multiple impacts. The evaluation framework was developed to address the general aspects of the labelling schemes (including governance, transparency and clarity) and to systematize the methodological propositions made by the label developers, particularly in comparison to the EF method. This qualitative analysis was based on available documentation and supported by interviews with the label developers.

3. RESULTS AND DISCUSSION

The inclusion criteria of the analysis turned out to be met by four labelling schemes (Planetscore, Ecoscore, Ecoimpact, Enviroscore), which were thus comparatively analysed. These labels are all associated to a graded scoring as visual information, helping consumers to intuitively understand the meaning of the grade on the packaging. Differences are found concerning the transparency of the methodologies used, as well as the assumptions behind the different scoring options. Ecoimpact and Enviroscore are EF-based, only proposing alterations to the method that range from adapting the allocation approach for certain products to the change in the normalization step. Planetscore and Ecoscore are inspired by the EF but use the French database Agribalyse as input and propose novel approaches to overcoming the limitations of LCA in capturing food system complexities (van der Werf et al., 2020). These two approaches foresee the modification of the final LCA score through a reward and penalty system (*Bonus/Malus*), addressing aspects such as agricultural practices (organic) or animal welfare.

4. CONCLUSIONS

The landscape of sustainability labelling is rapidly evolving in Europe. The analysis shows how label developers can apply different levels of methodological developments and application of the EF, ranging from minor simplifications to the devise of "patches" to LCA's gaps. While the role of labelling in changing consumer behavior is questioned the current proliferation of labelling schemes based on LCA results calls for a more consistent approach. The EF can be a starting point to further develop robust, transparent, reproducible and trustable food sustainability labelling. However, some methodological developments are needed to enhance applicability and comprehensiveness.

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Reducing complexity for a single score for food products

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1. INTRODUCTION

To make informed choices regarding environmental impacts of food, the respective information must be available to consumers. Environmental labels are one of the instruments under consideration. Consequently, the European Union's 'Farm-to-Fork Strategy' provides for the introduction of an environmental label for food products in Europe (European Union, 2020). To this end, easily understandable information must be provided; to achieve this, a possibility is to summarize various environmental impacts into a single score. Creating a single score entails the aggregation of impact indicators, which in turn requires determining the relative importance of environmental impacts by means of weighting factors. Assigning these factors is inherently normative. In the context of the European Commission's Environmental Footprint method (EF), a broad stakeholder consultation was carried out by the Joint Research Centre (JRC) to create a weighting set for sixteen impact categories (Sala et al. 2018). Sala et al. (2018) is not specific to food, thus two other models have been analysed, including other impact categories and using different weighting factors (Table 1). Here, we statistically analyse which of these impact categories can be excluded without significantly altering the signal of the respective single score. We also analyse whether there are differences between food categories.

2. METHODS

Based on the environmental impact data provided in Agribalyse (Asselin-Balençon et al., 2022), (multiple) linear regression models with the EF single score as a dependent variable and the impact categories as independent variables were being calculated. The data was supplemented with biodiversity impact data provided by ADEME. The regression models were built with different techniques of variable selection to include the variables that add the most information to the final EF and exclude the ones that do not add significant information. The regressions were analysed for three different models of aggregation of environmental impacts to a single value; different scenarios for weighting within these models were calculated: the JRC model (incl. biodiversity), the CLIF model, and the JRC model ecosystems, considering only impact categories relevant for ecosystem quality (Table 1).

3. RESULTS AND DISCUSSION

The interpretation of results will continue until June 2024, but the first interesting insights can already be provided. Across all food groups, most of the variance can be explained with very few impact categories: 95 % can be explained with two to three impact categories (depending on the scenario), and four categories suffice to explain 98 % in the JRC model (

Figure 1. Adjusted explained share of variance for different scenarios

Figure 2. Arithmetic mean and adjusted explained share of variance

). However, when a distinction is made between plant and animal products, it can be seen (i) that different numbers of impact categories are required to achieve the same degree of explained variance (Figure 2) and (ii) that different impact categories are required to explain the variance. The same happens when the plant and animal products are further differentiated; it becomes apparent that more impact categories are required for some product groups, to achieve the same level of explained variance.

In the further interpretation of the results, the results of the three models are compared to analyse whether there are differences between the models with regard to the impact categories included, namely with regard to which impact categories are included and in which order. This is analysed for all foods, for plant-based and animal-based foods, and for different food groups.

4. CONCLUSIONS

Even at this stage of analysing the results, it can be shown that not all impact categories need to be included to explain (most of) the variance of the single score. However, the variability of the results between food groups calls for a more detailed analysis of the regression results. This will be done in the coming months.

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Table 1. Models and scenarios included in the regression analyses

model	JRC model (Sala et al., 2018; biodiversity added)	CLIF model*	JRC ecosystem model (Sala et al., 2018; only ecosystem quality impact categories; biodiversity added)
scenarios	Secenarios incl. robustness: 0.1 -1 (biodiversity: 0,17) 0.1 -1 (biodiversity: 0,47) 0.5 -1 (biodiversity: 0,57) 0.5 -1 (biodiversity: 0,73) 1 scenario excl. robustness	Secnarios incl. robustness: 0.1 – 1 0.5 – 1 1 scenario excl. robustness	Scenarios incl. robustness: 0.1 -1 (biodiversity: 0,17) 0.1 -1 (biodiversity: 0,47) 0.5 -1 (biodiversity: 0,57) 0.5 -1 (biodiversity: 0,73) 1 scenario excl. robustness
Impact categories	All 16 PEF impact categories plus terrestrial biodiversity**	Climate change, Biodiversity (terrestrial), Water use, Eutrophication (freshwater, marine, terrestrial), Ecotoxicity freshwater	Climate change, Ozone depletion, Acidification, Eutrophication (freshwater), Eutrophication (marine), Eutrophication (terrestrial), Ecotoxicity freshwater, Land use, Water use, Biodiversity** (terrestrial)

* The CLIF model is based on results of a Delphi study on most important environmental impacts carried out within the CLIF project; ** Biodiversity was added to the JRC model. Weighting was carried out according to the results of the CLIF-Delphi

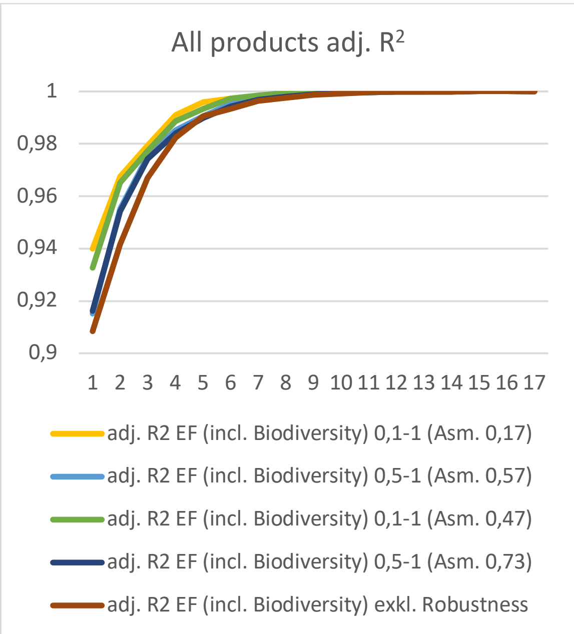

Figure 1. Adjusted explained share of variance for different scenarios

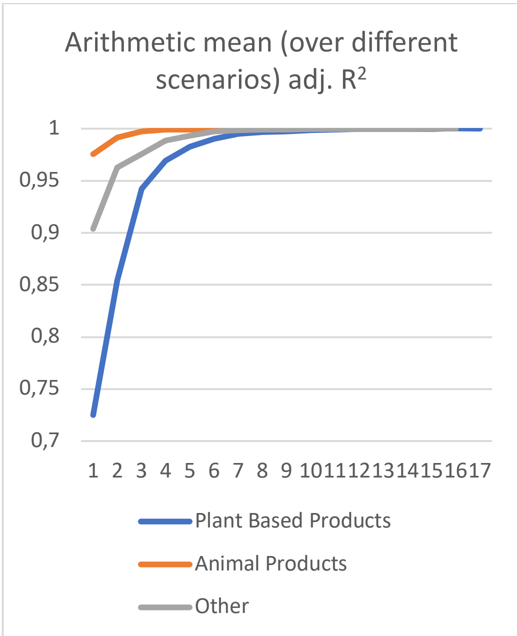

Figure 2. Arithmetic mean and adjusted explained share of variance

Product Environmental Footprints of organic food – status quo and improvement potentials

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1. INTRODUCTION

The development of product-specific rules for calculating Product Environmental Footprints (PEF) within the food sector is a collaborative effort which has been underway for more than 10 years (European Commission 2013, Antony et al (2024a)). However, as of today, the developed rules and especially the data availability are poorly tailored for organic food products. This holds also true regarding the representation of small and medium-sized enterprises (SMEs) both conventional and organic. To bridge this gap, the study at hand endeavours to calculate an "Eco-PEF" for three key food product categories, leveraging and testing available Product Environmental Footprint Category Rules (PEFCRs) (Antony et al (2024b)). Addressed research objectives are threefold: First, conducting PEF calculations of three organic food products from SMEs in Germany utilizing the pertinent PEFCRs/draft PEFCRs. Secondly, scrutinize to which extent organic farming practices are reflected within the PEF framework. Thirdly, we examine if and how PEFs can realistically be implemented for SMEs.

2. METHODS

To achieve the objectives, PEF calculations for three organic food products have been carried out based on the respective PEFCRs. Therefore, data has been collected for fusilli pasta, yoghurt and minced red meat. However, especially primary data collection on agriculturural processes turned out as particularly challenging and only possible to a very limited extent. Thus, secondary data sets from the Environmental Footprint (EF) database were used if available.

3. RESULTS AND DISCUSSION

The agricultural production of commodities is the dominant life cycle stage across all case studies ( ). However, data sets available in the EF database fail to adequately represent agricultural production in a plausible, transparent and specifiable manner, thereby hindering the adequate modeling of organic production processes. Consequently, the results obtained from the calculations so far do not furnish adequate environmental information, underscoring the pressing need for refinement and enhancement in data availability and transparency. Furthermore, notable differences in the "ambition level" of the PEFCR-benchmarks across different food categories became evident. For instance, the Eco-PEF for Pasta exhibits an exceptionally high benchmark ( ), implying that nearly all products within this category will demonstrate superior environmental performance. Conversely, the benchmark for dairy appears disproportionately low, suggesting that a majority of products within this category may exhibit comparatively worse environmental performance (Figure 1). For SMEs, engaging in PEF assessments so far presents several challenges, as they often struggle to provide the necessary information. Attempts to gather primary data on agriculture have proven to be feasible only to a very limited extent. As such, PEF calculations based on primary data may pose a challenge for many SMEs, making the utilization of secondary data the most realistic option. This, in turn, limits the accuracy and communicability of PEF results.

4. CONCLUSIONS

Several significant limitations emerge within the context of "Eco-PEFs", notably the absence of PEFCRs for various relevant food product groups like red meat, certain dairy products, vegetables, fruits, and processed foods. This hampers meaningful comparisons between different product groups and thus the ability to support environmentally conscious consumption choices. As of today, PEF fails to adequately consider animal welfare and biodiversity aspects. Moreover, the reliance on non-product-related, intransparent secondary data undermines the accuracy and applicability of PEF assessments. The theoretical feasibility but practical inaccessibility of PEF assessments for organic products underscores the need for data enhancement and methodological refinement. Therefore, concerted efforts are needed to rectify deficiencies and enhance robustness of PEF assessments within the organic food sector.

5. ACKNOWLEDGEMENTS

The "Eco PEF" project is a joint project in close cooperation with FIBL Deutschland e.V. and AÖL. e.V.. It is funded by the Federal Ministry of Food and Agriculture as part of the Federal Organic Farming Programme (BÖL).

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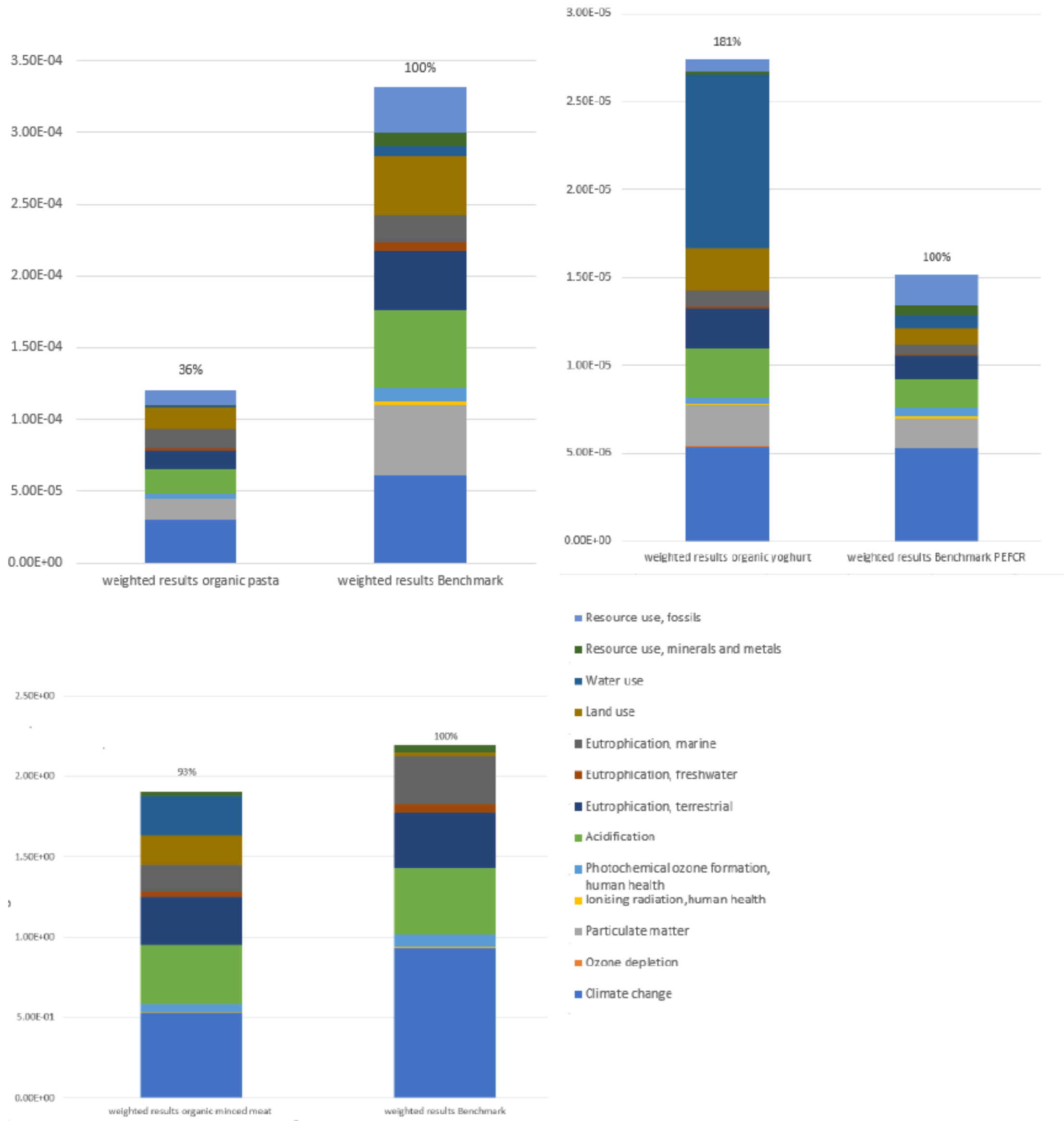
Figure 1: Single score PEF results (without use phase) for organic spelt fusilli pasta, organic yoghurt, and organic minced meat.



The environmental footprint of packaged food and beverage products in Australian supermarkets

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1. INTRODUCTION

Global food systems have significant environmental impacts and require transformation [1, 2]. Despite the increasing consumption of packaged foods, research has primarily focused on raw agricultural commodities [3, 4]. Limited studies exist on the environmental impacts of packaged food products, and those that do [5] primarily focus on greenhouse gas emissions (GHGe). This study fills this gap by estimating a comprehensive suite of environmental impacts for 63,992 packaged food products in Australia, aiming to empower stakeholders to make more sustainable choices in food production and consumption.

2. METHODS

We sourced product and ingredient data from the Australian FoodSwitch database [6] and combined these with environmental estimates from established life cycle analysis (LCA) databases [3, 7] that provides “cradle to retail” impacts of the agricultural commodities. We then assessed product-specific environmental impacts including GHGe, land use, water use, eutrophication potential and acidification potential per kg of the product for 63,922 packaged food products. The standard life cycle impact assessment methods were used [3]: IPCC AR5 100-year factors for greenhouse gas emissions (GHGe), direct land occupation for land use, CML2 Baseline for acidification and eutrophication potential, and volume of water used for freshwater withdrawals. We used Australian-specific estimates for the products that used Australian ingredients and global averages for the imported products. We also quantified the benefits of ‘switching’ to lower-impact food product alternatives within the same food category.

3. RESULTS AND DISCUSSIONS

Our study not only identified the environmental impacts of the food products but also assessed the benefits of transitioning from high to low-impact products within the food category. Among all the 17 food categories assessed (**Figure 1**), meat products had the highest impact across GHGe, land use and acidification potential with median values of 12.57 kg CO_2 eq, 48.84 m^2, and 0.11 kg SO_2 eq respectively. Nuts and seeds products are responsible for the highest water use (median = 4038 L) while seafood showed the highest eutrophication potential with a median value of 0.16 kg PO_4^3 eq. Non-alcoholic beverages and fruits and vegetables categories consistently showed minimal impacts across all the indicators. We found that transitioning from high to low-impact products across all the categories could reduce the GHGe by 96% while making swaps only within animal-based product categories (meat products and dairy) could also reduce diet footprint significantly (**Figure 2**). The results of this study represent a significant advancement in understanding the environmental footprint of packaged food products. It will help consumers and other stakeholders of the food systems to make informed choices towards sustainable food systems. However, limitations exist, such as the need for more comprehensive data for ingredients to improve the accuracy of the results.

4. CONCLUSIONS

Our study provides a comprehensive assessment of the environmental impacts of packaged food products in Australia, offering actionable insights to make choices towards a sustainable food system. Future research should delve deeper into the factors influencing consumer decisions at the detailed product level to drive sustainable dietary changes.

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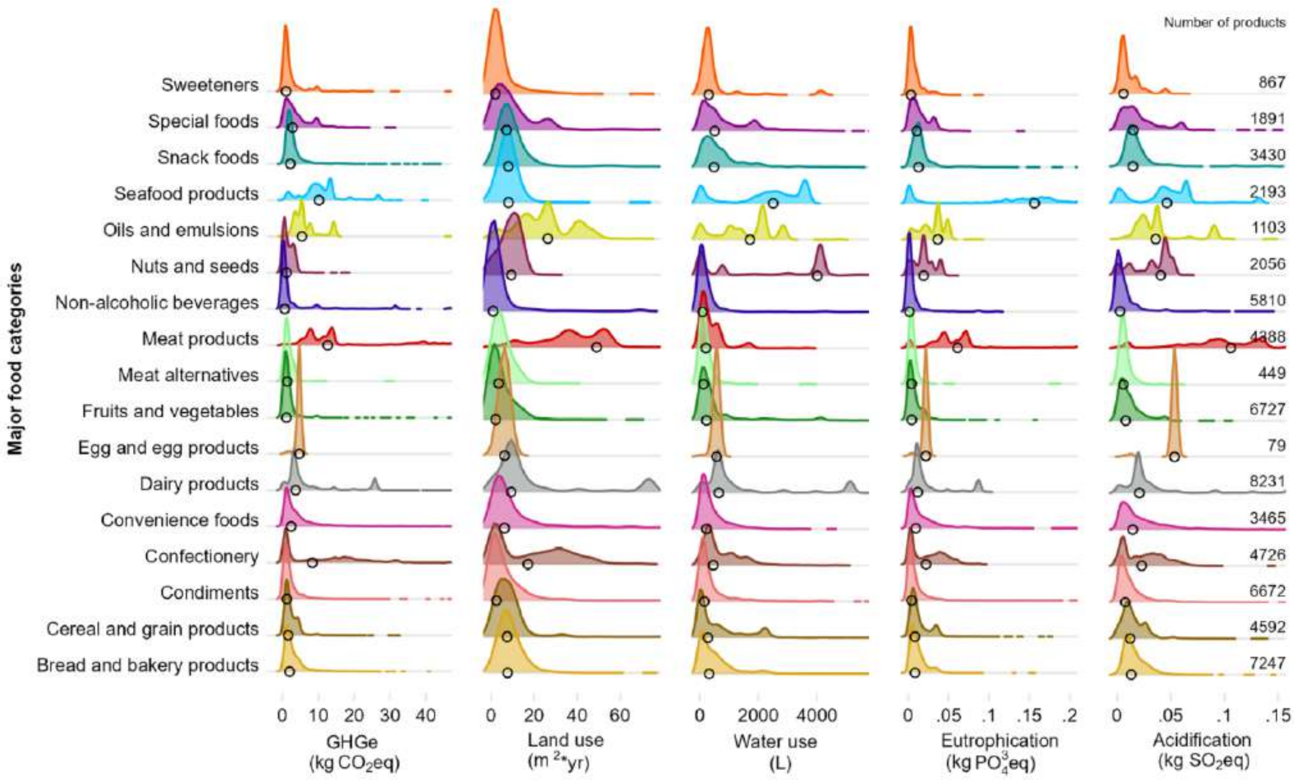

Figure 1: Environmental impacts of major food categories. Each category contains the number of products mentioned in the right corner. All impacts are reported per kilogram of product. The circles show the median of the category.

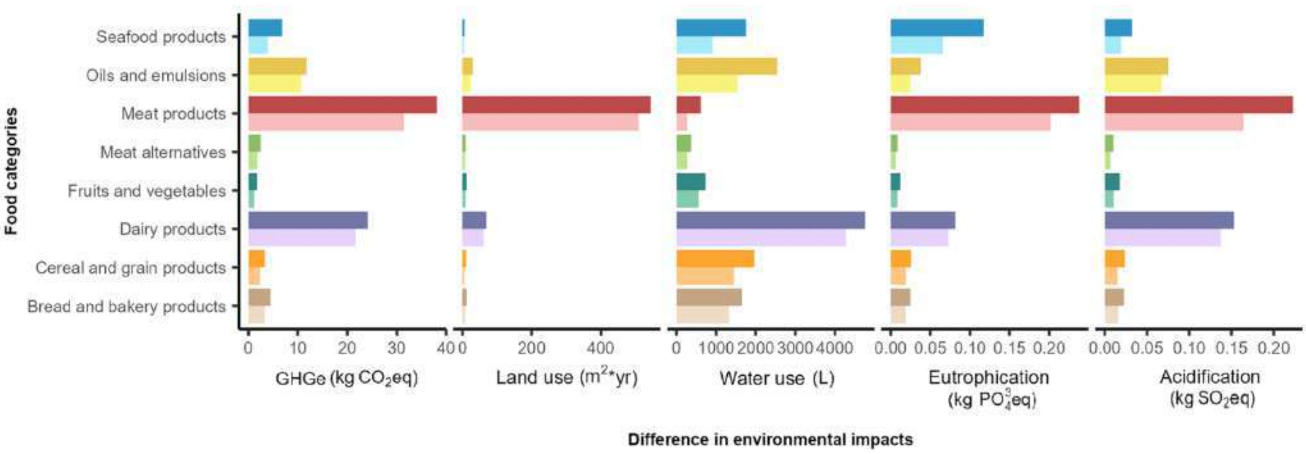

Figure 2: The benefits of swapping within the categories. The darker bars show the difference between the high-impact products (0.90 percentile) and low-impact products (0.10 percentile) of each food category across all the indicators and the lighter bars show

Ecolabeling, time for action; the French case.

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1. INTRODUCTION

France is about to finalise a large-scale ecolabelling scheme, for food and textile to begin with. This program, backed by France's national regulation "Climate and resilience law", meets citizen expectations for more comprehensive and higher-quality environmental information. It occurs within a European context marked by significant developments in private environmental footprinting schemes across almost all sectors (Ecoscore, Earth Foundation, PlanetScore, Clear Fashion, Home Index, etc.). Effectively organizing this information represents both an opportunity and a challenge for policymakers, as evidenced by the European Union's "Green Claim Directive" project. France has assumed the role of a pilot country in this domain, and its experience will benefit other countries and the European Union in the future.
ADEME and the French ministry for Ecological Transition propose an ecolabelling scheme, including environmental database, a calculation method, a tool and a logo, to be implemented on a voluntary basis in 2024, and a perspective to move towards mandatory from 2025.

2. METHOD

The official French eco-labeling program stems from a prolonged phase of experimentation and learning, initiated in 2009 with the "Grenelle de l'Environnement" (environmental policy and stakeholder roundtables). From that moment, a first in-store experimentation occurred between 2011 and 2013, revealing consumer interest alongside the inadequacy of scientific and technical tools at that time. Drawing from these insights, the French Environment and Energy Management Agency (ADEME), along with its partners (such as INRAE, agri-food technical institutes, etc.), made substantial investments. These investments focused on : data production (e.g., the Agribalyse database), enhancements in methodologies, improvements in communication and training for food companies and other stakeholders (including digital platforms such as Yuka). Additionally, the Product Environmental Footprint (PEF) framework facilitated greater recognition of Life Cycle Assessment (LCA) at the European level. Following the publication of Agribalyse v3.0 in 2020, a new series of experiments involved 19 food-related companies. A dedicated scientific committee was established, overseeing both field and laboratory experiments (e.g., analyzing 550 "real-market" products), alongside the development of the Ecobalyse tool—an open-source utility for testing eco-labeling. Specific working groups addressed key topics such as biodiversity, ecosystem services, and seafood products. The eco-labeling scheme proposed today is the outcome of this important scientific and political process.

3. RESULTS AND DISCUSSION

The eco-labeling approach is grounded in Life Cycle Analysis (LCA) and the European Product Environmental Footprint (PEF) framework, as the most robust theoretical method for product assessment. However, various challenges within the current PEF framework necessitate adjustments, leading to the development of a "PEF-wise" method for French eco-labeling. These modifications primarily address methodology and indicators. Within the LCA framework, enhancements are made to Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA) modelling, particularly regarding eco- and human toxicities, with increased weighting in the single score. Additionally, an "ecosystem services module" is introduced to complement the LCA framework, addressing key elements such as field and landscape biodiversity—issues currently underserved by traditional LCA methodologies. Completing LCA where significant gaps are identified is imperative for consumer eco-labeling, both in terms of relevance and acceptability. As of early 2024, final political decisions and validation are pending for the public release of the French eco-labeling scheme.

4. CONCLUSIONS

Significantly enhanced environmental information compared to the current status quo is at reach. The impact of French eco-labeling will depend on its large-scale implementation, the comprehension of companies and consumers, and its integration into decision-making processes—be it in production or consumption stages.

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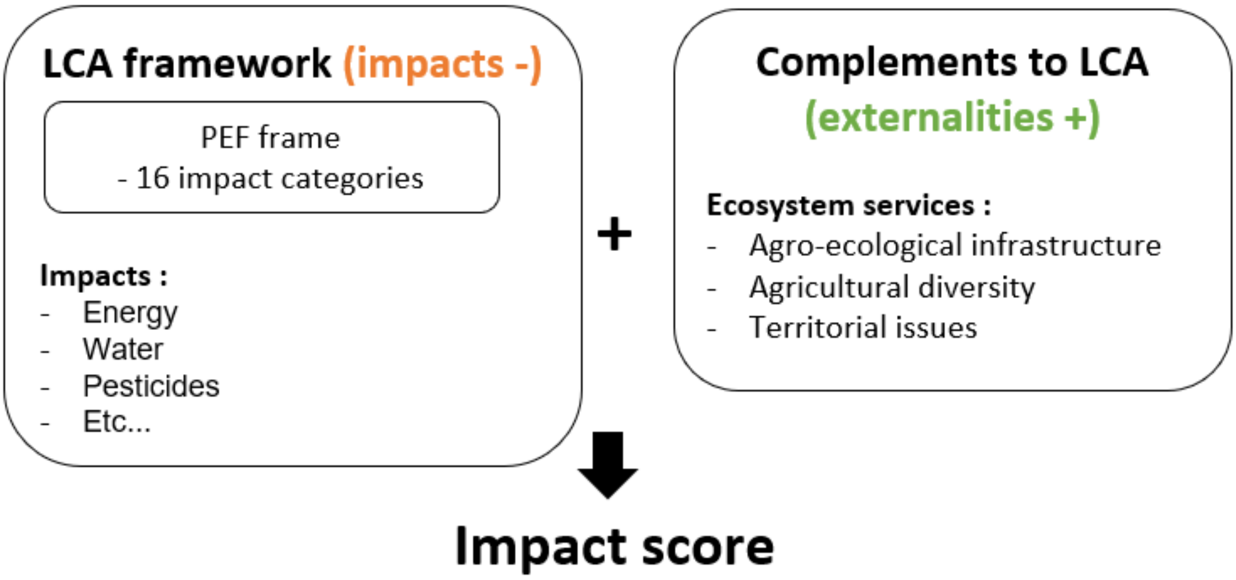

Figure 1 : Assesment framework for French food ecolabelling

Communication of LCA results and integration of ESG criteria into business

From gut feeling to data driven decisions in Michelin starred restaurants

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1. INTRODUCTION

Beyond delivering delicious food, the hospitality sector plays a pivotal role in the food value chain. Alongside culinary fineness, Michelin star restaurants RIJKS and Wils are committed to take charge of their overall environmental impact, by focusing on ingredient origin, waste reduction, and the use of unconventional meat cuts. Head chef Joris Bijdendijk felt the executive decisions he was making were right but lacked the scientific data to back up his 'gut feeling'. With an intrinsic motivation to understand and address their footprint, RIJKS and Wils collaborated with Deloitte Netherlands and PRé to develop a framework to both quantify their impacts and support future decision making. Wanting to look beyond carbon with a holistic approach, this work presents the developed methodology and outcome, which leverages LCA results to provide valuable insights that are already inspiring change within the restaurants.

2. METHODS

To calculate the environmental impact of the restaurants, Deloitte's Strategic Impact Assessment framework (SIA) was employed, which draws from Life Cycle Assessment (LCA) results to quantify the overall value chain impact of products. Primary data of ingredients procured, and on-site utilities usage was collected based on 2022 activities. The individual ingredients (>6000) sourced by the restaurants were mapped to 135 high-level categories, each represented by a secondary Life Cycle Inventory (LCI) dataset to approximate the environmental impact.. Together with Joris, the indicators from ReCiPe 2016 selected in scope were CO_2 eq., other air emissions (SO_2, NO_x eq., $PM_{2.5}$eq.), water consumption, water pollution (Peq., Neq.) and land use. For each, the corresponding 'societal cost' was calculated using monetization factors sourced from the Environmental Protection Agency Environmental Protection Agency (EPA) (2022) for CO_2eq. and from CE Delft (de Bruyn et al. 2023) for the remainder. Also, we benchmarked their chicken supplier against an average secondary dataset to showcase the importance in using primary data to reflect the benefits of sustainable sourcing.

3. RESULTS AND DISCUSSION

The results show that for both RIJKS and Wils, the monetized impacts of the utilities of the restaurant (electricity, water etc.) are significantly smaller than those caused by the ingredients (responsible for 97%-98%). An immediate insight which can be seen in the visualisation on ingredients hotspots (an excerpt shown in Figure 1) is how animal products dominate the impact (notably beef, pork and chicken). Water consumption shows a slightly different story, where almonds and mushrooms also contribute considerably. Unexpectedly, a greater environmental impact was attributed to other air emissions from certain ingredients (notably beef, pork, and butter), than to carbon emissions. Benchmarking showed the restaurants' chicken has 48% lower carbon footprint than secondary data, emphasizing smart sourcing benefits and the necessity of refining data for reality-based decisions, not industry averages.

This narrative has been well received by restaurant staff and the wider community, assisted by several techniques, such as the following. 1) Visual complexity to match model complexity. A simplified non-granular visualization which doesn't focus on exact figures gets the core message across reducing the risk of variance due to model uncertainty and sensitivities. 2) Societal cost proves to be an understandable metric for the general public. Monetizing impacts shifts environmental impacts from ambiguity to relevance, showcasing that environmental impacts have an actual cost they can understand.

4. CONCLUSIONS

While these findings confirmed some of the restaurants' initial assumptions, they also brought attention to additional hotspots that warrant consideration in future decision-making. This work showcases how impact monetization and effective visualisation can help reach wider audiences and drive targeted data-driven decisions, meanwhile respecting the model limitations and data granularity. Also, identification of the real impact coming from suppliers helps to enable sector transformation through dissemination of best practices. We hope these valuable and practical insights can motivate others to be creative when communicating LCA results to inspire positive change.

5. ACKNOWLEDGEMENTS

Joris Bijdendijk from RIJKs and Wils and Johan Leenders from Oranjehoen

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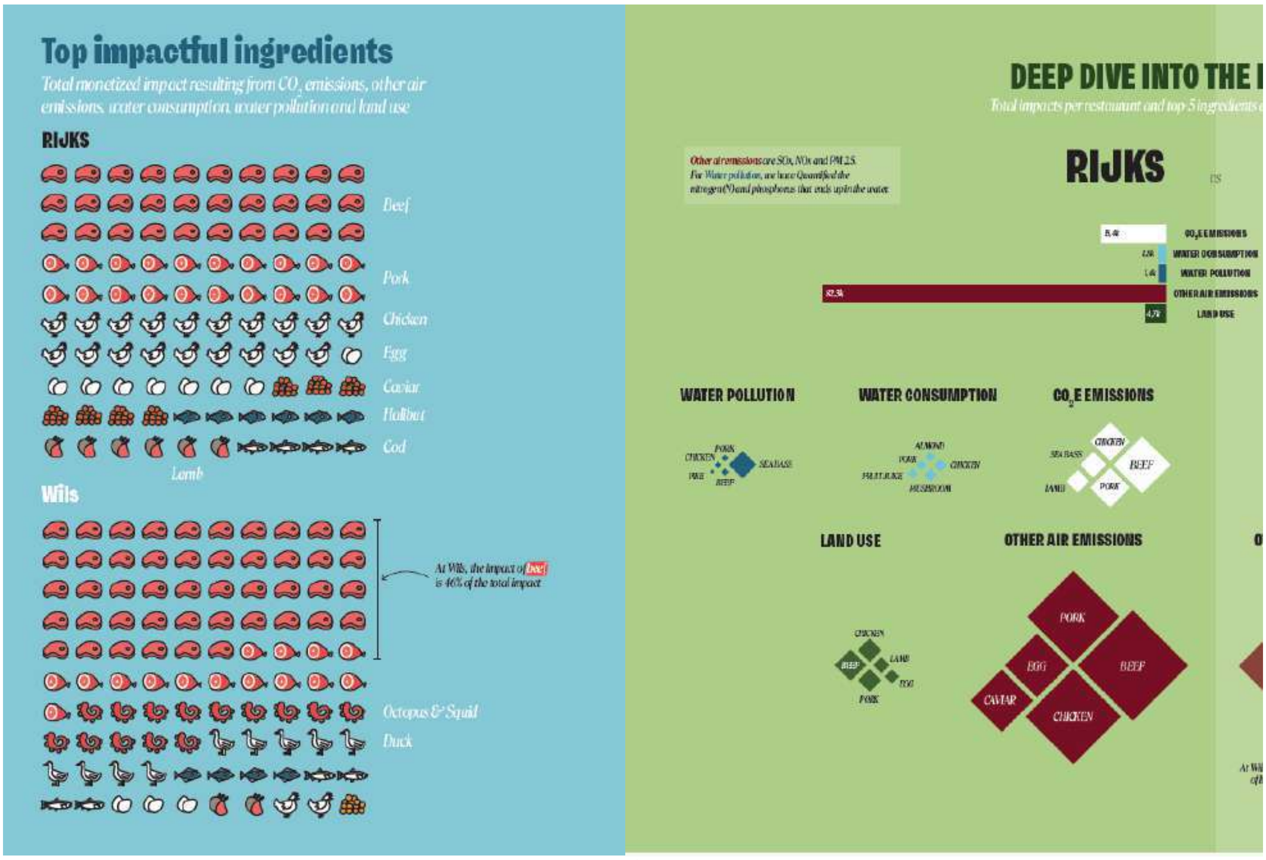

Figure 1. Excerpt of visualisation displayed at a dinner showcasing the results

From LCA to on-the-ground impact- a case study with Californian cotton

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1. INTRODUCTION

In the realm of regenerative cotton production, whether it's major companies supporting claims or farmers improving their practices based on insights, the reliance on LCA results extends beyond quantifying environmental impacts. In this Californian cotton case study, the environmental impacts under regenerative, conventional, and organic farming are compared. Our analysis challenges the farmer's notion that higher pesticide quantities alone lead to impacts, revealing lesser-known culprits- characterisation factors of active ingredients, pesticide application methods and the importance of emissions to specific sub-compartments. Communicating the findings involved navigating technicalities and breaking down complex concepts (i.e., impact assessment methods, characterisation factors, and PestLCI (Dijkman et al., 2012) model to estimate emissions from pesticides). This research explores the best-practice consultant-to-client communication, and the benefits of bi-directional information flow in producing realistic LCA results.

2. METHODS

The LCA covers cradle-to-ginning-gate production, with a functional unit of 1 kg of cotton fiber, using the EF 3.1 impact assessment method, and following the land sector and removals guidance (World Resource Institute and World Business Council for Sustainable Development 2022) (LSRG) or the Draft Flori-PEFCR (Broekema et al. 2023). To communicate the findings, we used a pyramid and a reverse pyramid approach (**¡Error! No se encuentra el origen de la referencia.**). Starting with a broader LCA perspective, we presented the results and key takeaways. The impact assessment method to quantify the environmental impacts was explained, before taking a deeper dive into emissions modelling shaping the results. To connect LCA results with the farm-level, we provided context about the role of data, and used a visualization to highlight the main culprit driving the impact. To bridge the gap from LCA findings to on-farm implementation, we discussed how these findings can inform on-farm strategies.

3. RESULTS AND DISCUSSION

The presentation of results sparked a broader discussion, moving beyond the initial interpretation. In this context, it was communicated that the farmers had been focusing on a horizontal reduction in pesticide quantities, thus the study commissioner urged a closer look at the active ingredients and application methods. Considering the imperative to meet yield demands for the financial sustainability of the cotton-producing farms, a complete elimination of pesticides is currently unfeasible. Based on the farmers' input, we constructed two scenarios (i.e., the "dream" scenario with full elimination of pesticides, and the "dimmed dream" scenario with substitution of harsh chemistry by organic pesticides). The scenario analysis results show that methodically eliminating primary contributors and a broad reduction strategy yield advantages of comparable magnitude compared to the baseline scenario.

3. CONCLUSIONS

The outcome of the study testifies to the complexity of pesticide management on-farm and reinforces the conclusion derived from the results which underlines the trade-offs between a broad reduction approach in total pesticide quantities and the adoption of a targeted elimination strategy focusing on specific active ingredients known to be highly hazardous. The transparent and bi-directional communication style regarding technical aspects and nitty-gritty LCA details facilitated a profound understanding of key drivers, leading to a strategic shift in on-farm practices. This also showcases the reliance LCA practitioners have on farmers to construct realistic scenarios. The project insights allow for an easier on-ground implementation by the farmers, but also promise significant rewards in terms of minimizing environmental impacts, with lower potential risks for their yield quotas.

4. ACKNOWLEDGEMENTS

Rebecca Burgess from Fibershed for coordinating the communication with the farmers.

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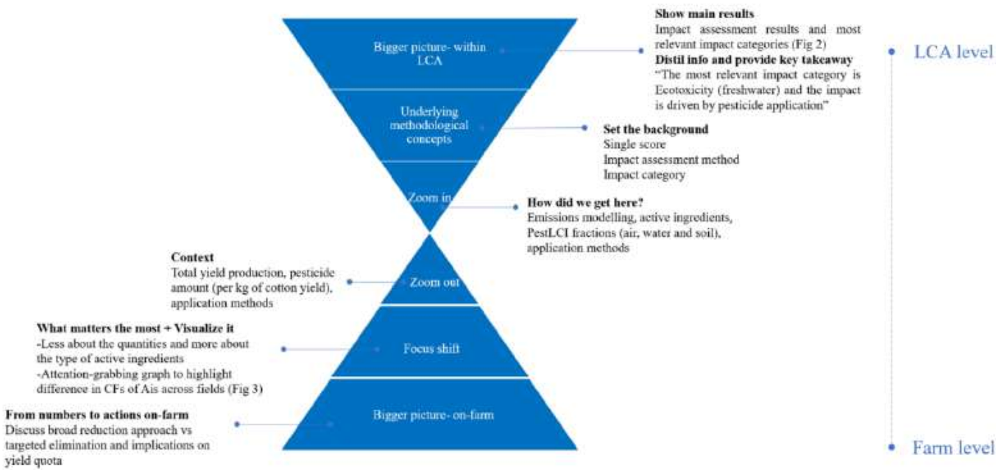

Figure 1. Pyramid and reverse pyramid communication approach

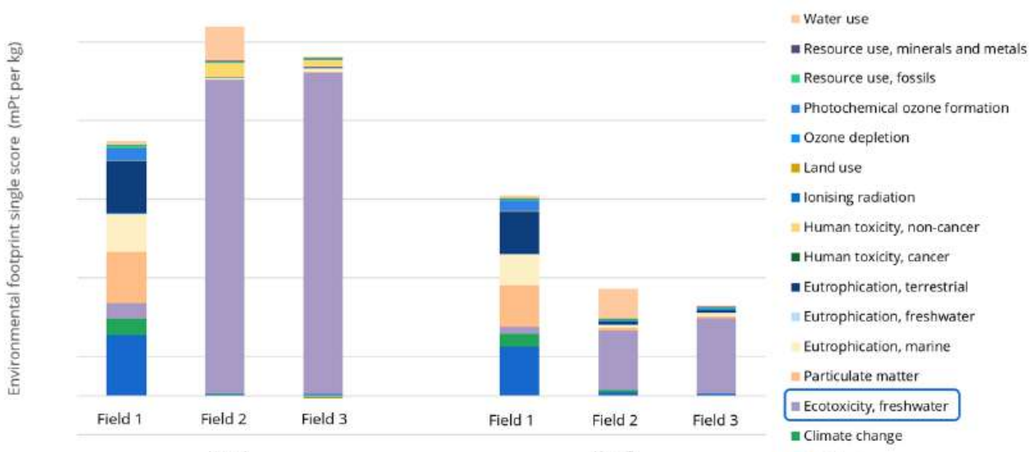

Figure 2. Impact assessment results, identification of the most relevant impact categories across fields. Numerical values have been deliberately removed.

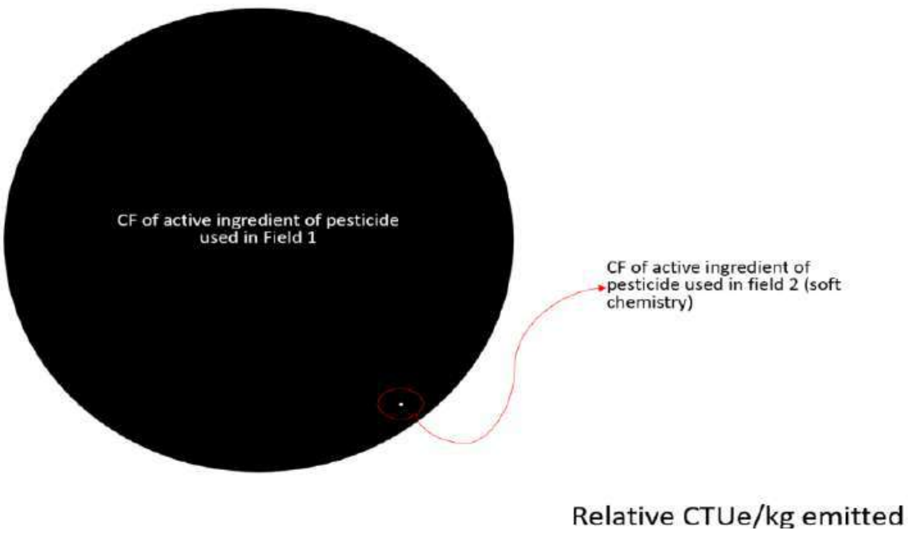

Figure 3. Relative magnitude of characterization factors (CF) of different active ingredients used in pesticides across fields.

Accounting for Overfishing in Environment Labelling – Comparing LCA and Fishery Science Methods

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1. INTRODUCTION

In context of French consumer information, stakeholders (industry, government, NGOs, academia) acknowledge the need for including fishing impacts on biodiversity. To date, the most recent LCA-based method assessing this impact is Hélias et al. (2023), using statistical data of biomass and catches and biological reference points. On the other hand, fishery science has long used Maximum Sustainable Yield (MSY) as the optimal for catches; the latter approach is applied for the fishing pressure indicator assessed within EU market standards developed by the STECF (STECF, 2020). This study, commissioned by ADEME (French EPA) for a stakeholder working group, tests both methods on 70 case studies representing the diversity of French consumption, defined with data likely to be available at consumer level: fished species, and fishing area. Suitability for inclusion in consumer information is discussed.

2. METHODS

Both methods require the same data, which are optimally published by Regional Fisheries Management Organizations (RFMOs). When not available, modelled data were used for LCIA method and System 1 method for STECF. For our study, data from ICES (ICES, 2023) and GFCM (FAO and GFCM, 2023) were used for fishing areas managed by European organizations; precise data could not be mobilized for the other zones, where default data were used. Details on data management are displayed in Table 1.

3. RESULTS AND DISCUSSION

Figure 1 displays a comparison of results using both methods. The two indicators don't address the same questions and only a weak correlation between them can be identified. LCIA method assesses the loss for the fish stock and the time required for filling this loss whereas STECF assesses stocks' fishing sustainability. Peruvian anchovy (*Engraulis ringens*) in Southeast Pacific (FAO 87), is the largest stock assessed in this study; it has the lowest impact for LCIA (CF = 1,12 PDF.year/kg) and displays the second worst grade according to STECF (E).

STECF indicator is suited to environmental market standards, but it doesn't reflect impacts in an additive way. Only LCIA method is currently straightforwardly suited for environmental labelling, allowing consistent aggregation for mass units and across other impact pathways. Value choices in both methods are different as discussed in GLAM 1: STECF's approach is analogous to an "ecosystem services" approach (single service provided by fish: "food provision"), considering that stocks at or above MSY are sustainably managed, and therefore display "no impact" (Grade = "A"). Conversely, LCIA method assumes that as soon as human activities modify the natural ecosystem (e.g. fish populations size), this must be reflected in the impact calculation, thus adopting an "intrinsic" approach of "ecosystem quality".

4. CONCLUSIONS

Including impacts of fishing pressure on biodiversity in environmental labelling is possible. Policy makers need to be aware of the value choice between an anthropocentric vs intrinsic approach. The LCA-based method developed by Hélias et al. (2023) is straightforward to include. The current STECF indicator lacks additivity that prevents it from being used, as is, in the ecolabelling initiative.

5. ACKNOWLEDGEMENTS

We thank members of the French Seafood WG for their valuable insights throughout the work.

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Table 1. Numbers of pairs covered and uncovered for each studied method; covered pairs are split between precise and default method.

Studied method	Optimal data source	Number of pairs covered by precise method	Default data management	Number of pairs covered by default method	Number of pairs not covered
Hélias et al. (2023)	RFMO	13	C-MSY	51	0
STECF, (2020)	RFMO	36	System 1	15	19

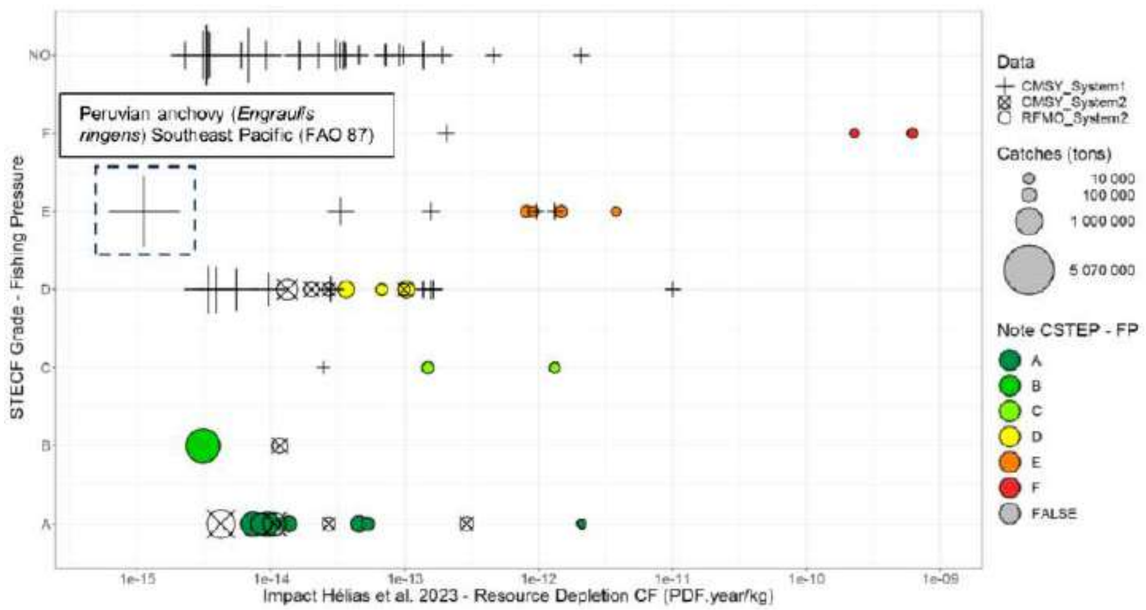

Figure 1. Comparison of results from i) STECF – Fishing Pressure (Y-Axis) with System 2 (et ⊠) and System 1 (+) data and ii) Hélias et al. 2023 – Resource depletion (X-Axis) with RFMO data ( ), and data from C-MSY (⊠ et +). Colors relate to STECF grade, point size is linked to annual catches of the stock, in tons.

Scaling LCA capabilities within companies

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1. INTRODUCTION

In today's sustainability-driven business environment, Life Cycle Assessment (LCA) has emerged as a key tool for companies to understand and manage their environmental impact. However, effectively scaling LCA capabilities within organizations remains a significant challenge. This **oral presentation** explores the strategies and practices that can enable companies to expand their LCA capabilities, transforming them from isolated initiatives into comprehensive, company-wide programs. By examining the barriers to scaling LCA and presenting effective solutions, the presentation aims to provide a roadmap for companies seeking to integrate LCA into their core business practices. Through this integration, companies can not only meet their compliance obligations but also drive innovation, enhance their reputation, and gain a competitive advantage in the market.

2. METHODS

We would like to present an overall process mapping and a few real-life case studies of our clients: analysing these examples of businesses that have successfully scaled and integrated LCA into their core business practices.

3. RESULTS AND DISCUSSION

Scaling LCA capabilities within companies can face several barriers:

3.1 Lack of Expertise and Awareness:

Implementing Life Cycle Assessment (LCA) is a sophisticated process, necessitating a comprehensive grasp of the product lifecycle and environmental impact evaluation. The absence of in-house expertise can pose a significant obstacle to the expansion of LCA capabilities. However, it's not just a lack of knowledge that creates challenges. Often, a lack of awareness about the significance of LCA across all stakeholder levels can lead to bottlenecks, misunderstandings, and a lack of prioritization. This is evident in departments such as production or procurement, where the importance of LCA may not be fully recognized or understood.

3.2 Data Quality and Tool selection:

LCA requires detailed and accurate data about every stage of a product's lifecycle. However, obtaining such data can be challenging, especially for upstream and downstream stages.

3.3 Integration Challenges:

Incorporating Life Cycle Assessment (LCA) into existing business operations and decision-making frameworks can present a challenge. Companies might find it difficult to align LCA with their strategic goals or embed it into their routine operations. This difficulty often stems from the challenge people face when trying to visualize multi-criteria decisions. In this context, the Product Environmental Footprint (PEF) can help by normalizing these complex decisions into a more comprehensible 'eco-score'.

4. CONCLUSIONS

In conclusion, scaling LCA capabilities within companies is a complex yet crucial task in today's sustainability-conscious business environment. While there are numerous barriers to this process, ranging from a lack of knowledge and expertise to resource constraints, data availability issues, integration challenges, tool selection difficulties, and lack of management support, these challenges are not insurmountable. By understanding these barriers and developing effective strategies to overcome them, companies can successfully expand their LCA capabilities. This transformation from isolated initiatives to comprehensive, company-wide programs can enable companies to not only meet their compliance obligations but also drive innovation, enhance their reputation, and gain a competitive advantage in the market. As we continue to navigate a business landscape increasingly focused on sustainability, the ability to effectively scale LCA capabilities will become an invaluable asset for forward-thinking organizations.

5. ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all our colleagues at BrightWolves and Digit Mint for their invaluable work and expertise. We also thank our clients who have allowed us to share these insights with you at LCA Food 2024.

12:30-12:45 Assessing impacts on biodiversity on an Aquaculture porfolio.

Anne Asselin. SAYARI.

Biodiversity footprint for food products: a research agenda

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1. INTRODUCTION

Biodiversity footprint for food products is increasingly seen as an essential element to compare environmental performance of products and inform consumers, e.g. via labels. However, current approaches to assess biodiversity in life cycle assessment are considered in need of substantial improvement to capture the complexity of burden and benefits associated to food supply chains, including for what concerns the capacity to adequately consider impacts at field scale. The current study aims at defining a research agenda for improving biodiversity footprint of food products, building on the evidences gathered over time by the Joint Research Centre of the European Commission and the extensive exchange with stakeholders on the topic.

2. METHODS

The research agenda builds on the results of specific studies addressing: a) available methods for biodiversity footprint within and beyond the LCA domain, to unveil where gaps exist between current coverage of biodiversity loss drivers and models to address the drivers and the related impacts (Damiani et al., 2023); b) a critical mapping of elementary flows of existing operational models for LCA based biodiversity footprint to enable a comparison of results across methods (Sanyé-Mengual et al., 2022); c. a systematic comparison of results to assess the discriminating power of methods, and unveil convergent and divergent results and underpinning causes (Sanyé-Mengual et al., 2023); an analysis of available studies comparing organic and conventional agricultural production, aiming at unveiling the extent to which organic production related practices were dealt with in LCA comparative studies (Boschiero et al., 2023). The findings from these studies were complemented by discussion with stakeholders in the context of different working groups and efforts, e.g. for food labelling, for improving agricultural modelling among others, resulting in the identification of key research gaps.

3. RESULTS AND DISCUSSION

There are a number of key research gaps to be addressed to improve biodiversity footprint of food products. The research agenda covers knowledge gaps at different levels: from data availability and inventory modelling, to impact assessment (in terms of impact categories, completeness of coverage, for example). The main challenges are related to: availability of data at field scale and adequate models to include them in the evaluations; expansion of modelling of agroecological practices to reflect them in the final comparison across products; harmonization of metrics across endpoint impact categories to be able to sum the contribution of the different drivers into a meaningful and comparable biodiversity footprint single score; approaches to integrate ecosystem services evaluation and natural capital accounting methods in LCA.

The final aim is to explore and prioritize future research efforts towards improving the discriminating power of biodiversity footprint methods, namely enhancing the capacity to rank food products capturing at best the most important burden and benefits associated to food supply chains.

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Novel foods and protein diversification (I)

Greenhouse gas emissions from cultivation and three conservation methods of the green alga Ulva *fenestrate*

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1. INTRODUCTION

Seaweed holds great potential to serve as a plant-based seafood alternative as well as a sustainable raw material within industries such as biorefinery and pharmaceutics. This study assesses the production performed by a seaweed farming company operating on the Swedish Westcoast. Initially, the company produced solely the kelp *Saccharina latissima* (hereafter sugar kelp), but recently also the green alga *Ulva fenestrata* (hereafter Ulva). The sugar kelp production of the company has previously been assessed with LCA, but due to the diversity and constant development of farming technologies and post-harvest processing, they saw a need to evaluate also the recently established Ulva production. The goal of this study was to assess the greenhouse gas (GHG) emissions of the Ulva farming operations and subsequent processing steps, to identify hotspots and enable optimisation actions.

2. METHODS

Three functional units (FU) were assessed, all representing Ulva in bulk packaging at the processing factory gate: 1 kg of *dried* Ulva, 1 kg of *blanched and frozen* Ulva, and 1 kg of *salted* Ulva. To further investigate the primary production system, two intermittent FU were assessed: 1 *km of seeded line from hatchery* at harbour and 1 *ton of fresh Ulva* at landing harbour.

The scope covered production from cradle to factory gate. All steps needed to produce fresh Ulva (hatchery, grow out), subsequent processing (processing, packaging) and required transports were included. Building infrastructure use was excluded but the use of machinery and equipment during all stages of the production chain was included. Primary data was collected during the growing season of 2022/2023. Background data was taken from Ecoinvent 3 (version 3.9) and the GHG emissions were calculated using the IPCC 2021 GWP100 method. No allocation was required. A sensitivity analysis was done to explore different production scenarios, including variable yield, different material choices, reduced distance between carrying lines and long-term storage.

3. RESULTS AND DISCUSSION

The carbon footprint of the three products spans a range of 0.4 and 2.9 CO_2 eq./kg product. Electricity use during processing is of highest importance for dried Ulva, representing about 20% of the total footprint. Dried Ulva has a footprint more than seven times that of the "wet" products, aligning with assessments of kelp that identifies drying as a hotspot (Thomas et al. 2021, Nilsson et al. 2022). However, as the water content is highly variable between the products, a recalculation on dry matter basis was done, resulting in a more evenly distributed footprint (2.4–2.9 kg CO_2 eq./kg DW product).

The carbon footprint of hatchery operations is 55.1 kg CO_2 eq./km seeded line and hotspots include material use and transports during the pre-cultivation process. At landing, the footprint of FW Ulva is 0.3 kg CO_2 eq./kg. The most important contributors at landing are use of grow out infrastructure, energy and fuel use during harvesting and hatchery operations. In comparison, the carbon footprint of sugar kelp, also farmed on the Swedish west coast, has been calculated to 0.06 kg CO_2 eq./kg FW sugar kelp (Thomas et al. 2021). The difference is mainly due to the fact that the more recently established Ulva cultivation is comparably less optimized. It is also possible to grow ability to grow larger volumes of sugar kelp per longline, which enables larger yields.

4. CONCLUSIONS

The assessment reveals findings that can aid a broader understanding and improvement within seaweed aquaculture. Along the production chain, it is often processes directly or indirectly connected to consumption of fossil fuels (transport, boat operations) that represent a large share of the carbon emissions. Measures to target these processes include reducing required transport distances, improving efficiency of boating operations and/or increasing yields. Switching from fossil fuel driven boats to alternative fuels or motors like ammonia or electric is another opportunity, however requiring substantial investments in infrastructure.

5. ACKNOWLEDGEMENTS

We extend our gratitude to Nordic SeaFarm for their collaboration and valuable insights, which have significantly contributed to the depth and relevance of the findings.

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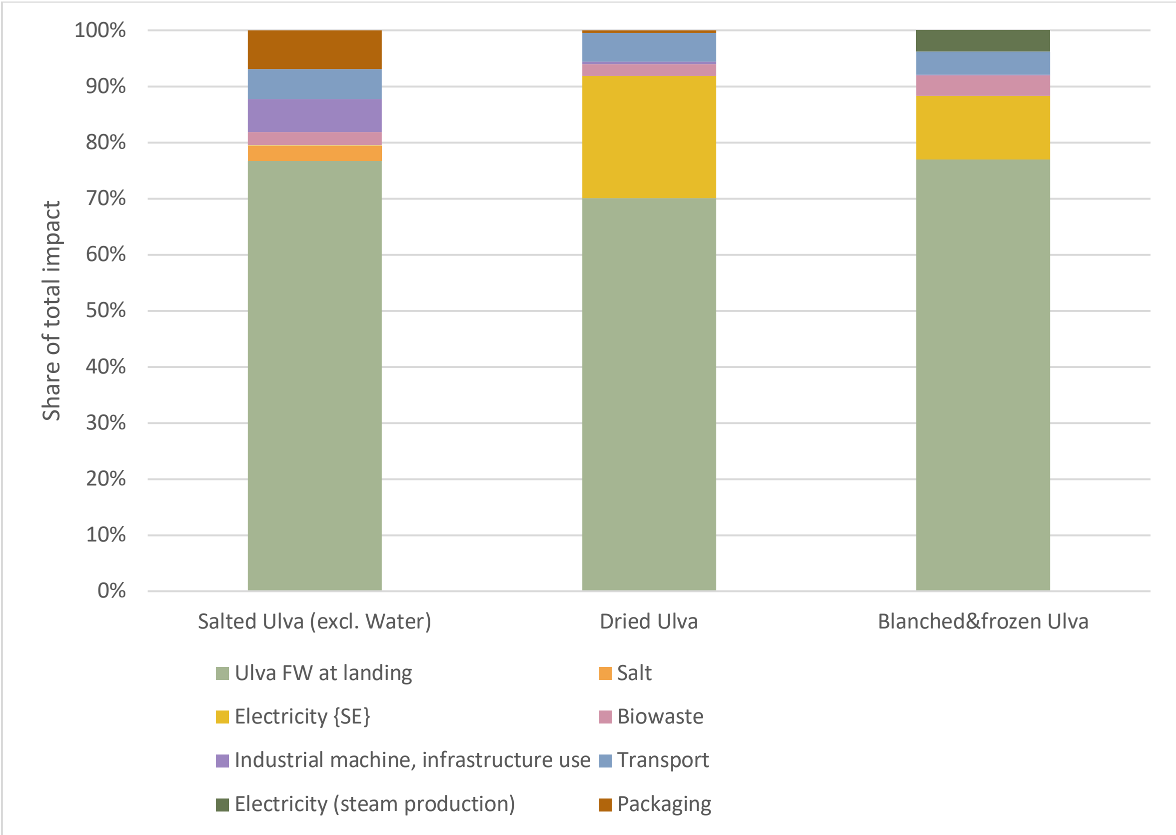

Figure 1. Relative contribution of key life cycle stages to the total environmental impact of the assessed seaweed products

Life Cycle Assessment of microalgae production for food and feed: from light to dark

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1. INTRODUCTION

Current food systems are not sustainable. Two system level problems of modern food systems are associated with overproduction (and high levels of food waste generated) and overconcentration. Both issues can be mitigated with the development of decentralized food waste treatment technologies oriented towards production of biomass for food and feed (Smetana et al., 2017). Production of microalgae can be one of such technologies with potential to be transportable, relying on various carbon sources and producing alternative type of protein sources. Therefore, a systematic assessment of the microalgae application to produce alternative proteins is needed. This research presenting the results of Life Cycle Assessments (LCA) performed within EU Funded projects ClimAqua and GiantLeaps is aimed to provide a few highlights on the sustainability potential of different microalgae production technologies.

2. METHODS

The study presents a comparative analysis of a few published (5) and not published (1) yet LCA studies of microalgae production relying on modular mobiles designs potentially applicable for food waste treatment and production of single cell proteins (e.g., *Galdieria sulphuraria, Chlorella vulgaris*) as a source of proteins for food and feed. They followed cradle-to-gate approach and relied on IMPACT 2002+ but also on Environmental Footprint 3.1 methods. Two cultivation tropic routes are considered in the study, autotrophic (relies on photosynthesis using light and carbon dioxide) and heterotrophic (cultivation uses organic carbon sources in the absence of light). Results calculated for a few functional units (FU) to represent the function of waste treatment (FU1 – 1 ton of food waste treated), production efficiency (FU2 – 1 kg of produced dry matter), and protein supply (FU3 – 1 kg of proteins produced). Only the last two functional units are presented in the abstract, no specific standardization was carried out for comparison, and all the results are presented separately.

3. RESULTS AND DISCUSSION

The cultivation of microalgae in limited space (mobile units) relying on agri-food waste resulted in relatively high environmental impacts (Table 1). Heterotrophic microalgae cultivation had lower environmental impacts than autotropic cultivation in most categories, however in some categories like Eutrophication, Land use and Water use the differences are minimal and do not comply with the requirements of the uncertainty analysis. Heterotrophic microalgae in some cases had comparatively low impact in the category of Climate change fitting in the range of plant protein sources (Poore & Nemecek, 2018). Heterotrophic cultivation also demonstrated to have much lower environmental impact when amount of food waste treated is considered. Technologically autotrophic cultivation is also much more demanding in terms of being suitable for the mobile units, which poses additional risks for the implementation.

4. CONCLUSIONS

Utilisation of microalgae for the return of nutrients from food waste to the food chains is a promising technology from environmental impact. Despite challenges associated with the downscaling of microalgae cultivation technologies for the mobile waste transformation units, heterotrophic microalgae cultivation can be recommended for further research and development.

5. ACKNOWLEDGEMENTS

The study received funding from the European Union's HORIZON EUROPE research and innovation programme under grant agreement No 101059632 (project GiantLeaps). It has also been partially funded by the German Federal Ministry of Education and Research (BMBF) in the framework of the Era-Net Cofund “FOSC-ERA” (Project ClimAqua 2821ERA12) Programs.

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Table 1.
Results of environmental impact of microalgae production technologies (cultivation on organic wastes and side-streams) in selected impact categories (DM – dry matter content, 1 kg of protein) (EF- Environmental Footprint 3.1)

Impact category	Unit	Autotrophic		Heterotrophic		Methodology
		1 kg DM	1 kg protein	1 kg DM	1 kg protein	
Climate change	kg CO2 eq	6.53-189.4	21.77-473.5	2.43-19.68	8.73-12.49	EF 3.1
Climate change - Fossil	kg CO2 eq	6.48	21.6	5.40	9.0-16.9	EF 3.1
Eutrophication, marine	kg N eq	0.0068	0.017-0.023	0.0062	0.01-0.019	EF 3.1
Eutrophication, freshwater	kg P eq	0.0022	0.006-0.007	0.0019	0.003-0.006	EF 3.1
Eutrophication, terrestrial	mol N eq	0.071	0.18-0.24	0.067	0.112-0.209	EF 3.1
Land use	Pt	23.22	58.1-77.4	22.86	36.87-70.34	EF 3.1
Land use	m2org.arable	n/a	n/a	0.07-0.09	0.25-0.32	IMPACT 2002+
Resource use, fossils	MJ	89.49	223.73-298.3	68.13	109.9-212.9	EF 3.1
Non-renewable energy use	MJ	n/a	n/a	56.5-69.2	202.8-248.5	IMPACT 2002+
Water use	m3 depriv.	3.39	8.48-8.5	2.33	3.76-7.28	EF 3.1

Life Cycle Assessment of Oatly products compared to dairy equivalents for Oatly's key global markets

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1. INTRODUCTION

Blonk Consultants was commissioned by Oatly for the execution of multiple life cycle assessments (LCAs) of five of its products sold in seven countries. Oatly's motivation for these assessments was to identify hotspots and opportunities to improve the environmental performance of their products, and compare them to each other and to their dairy equivalents.

2. METHODS

The LCAs were executed in line with the ISO 14040:2006 and 14044:2006 standards and the guidance established by the European Commission in the Product Environmental Footprint (PEF) project. The LCA software used was SimaPro 9.5 and secondary data was derived from Agri-Footprint (AFP) 6 and Ecoinvent 3.6 databases.
Products in scope include Oatly Barista, Original, Oat Drink, Unsweetened, Super Basic, "No" Sugars, and Creamy Oat, and their dairy equivalents, and consider various fat contents, storage conditions, and packaging sizes. The function was defined as "provision of cow's milk based or oat based products, to be added to food and beverage for taste and texture", and the functional unit was 1 liter of Oatly product or dairy equivalent at point of sale, including packaging (manufacturing and end of life). The locally produced cow's milk used as reference for the dairy equivalents was modelled following international guidelines from PEFCR for Dairy, IPCC (2006) and European Environmental Agency (2016)) using AFP data and literature, and was differentiated by storage conditions. A review by independent experts following ISO/TS 14071:2014 took place.
The results were reported for the 10 most relevant environmental impact categories for food products from the ReCiPe 2016 impact assessment method, selected for its global applicability as products in scope originate both from Europe and North America. The ReCiPe impact categories were selected based on their similarity to those mentioned in the available PEFCRs for food and beverage products. Emissions from land use change and peat oxidation are included in the climate change impact category.

3. RESULTS AND DISCUSSION

Figure 1 shows the climate change impact for all Oatly products in scope, including the relative reduction in comparison to their dairy equivalent which ranges from -44 to -80%. The dominant life cycle stage for most products is the raw material phase, caused by production of oats and rapeseed in the case of Oatly products, and by enteric fermentation, manure management and feed cultivation in the case of the dairy equivalents. Only for US products, the processing and distribution stages are top contributors as well, respectively due to natural gas use and longer transport distances. Although the climate change impact of Oatly's products is consistently lower than their dairy equivalents, there is a large variation amongst the products, ranging from 0.34 to 0.84 kg CO_2 eq./L, mainly caused by variation in raw material and processing impacts.

The relative impact of Oatly's products in comparison to their dairy equivalents for all impact categories is shown in Table 1. For most impact categories, Oatly's products show a significantly lower (-17% to -93%) impact than their dairy equivalents. This was not always the case for land use and land occupation (which is related to yields of oat, rapeseed and feed crops, but also to the characterisation method of the land use impact category), mineral resource scarcity (partially due to the use of metals for renewable energy production and the use of aluminium in packaging), fossil resource scarcity (linked to fossil fuel use in distribution) and, in three cases, water consumption (linked to hydropower used in Oatly's Vlissingen factory).

4. CONCLUSIONS

The assessed products from Oatly show significant impact reduction in comparison to their dairy equivalents in most of the impact categories in scope. For each of the impact hotspots, opportunities for impact reduction were identified.

Sensitivity analyses on the functional unit (nutritional value, chilled vs ambient products and different fat contents), allocation method, LCIA methodology, system boundaries (inclusion of use phase), milk modelling and packaging assumptions, as well as single and paired uncertainty analyses confirmed the robustness of the results. These detailed LCA studies can provide guidance for further methodological development of similar products, like a (shadow) PEFCR and provide much needed publicly available data on the impacts of plant-based alternatives – a research area of LCAs which is still quite limited.

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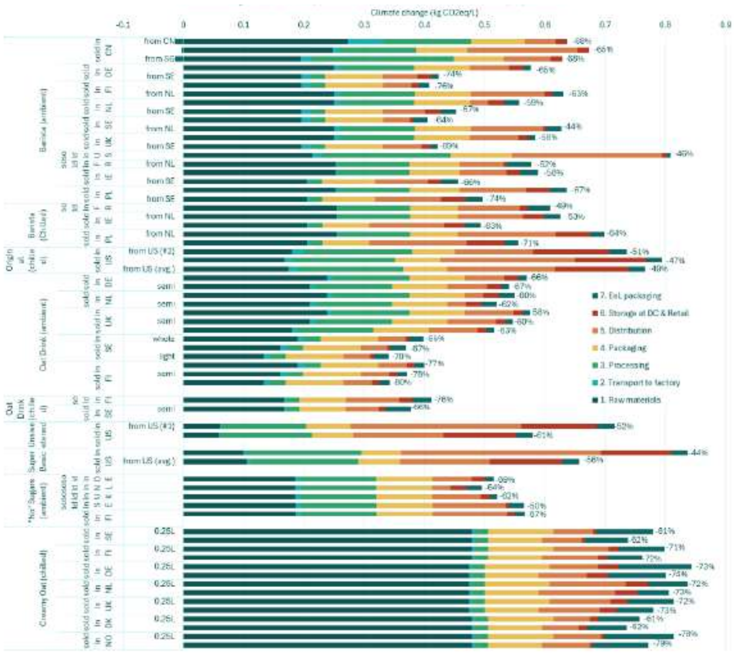

Figure 1. Climate change impact of Oatly products produced and sold in different geographies (abbreviated). % refers to the relative difference between Oatly product and its dairy equivalent, produced locally.

Product	Sold in	From	GWP	PM	AP,terr	EP, fresh	EP, marine	LU	LOcc	Min RS	Foss RS	Water
Barista (ambient)	CN	Ma'anshan (CN)	-68%	-86%	-91%	-60%	-61%	-17%	-26%	-50%	-46%	-78%
		Singapore (SIN)	-68%	-81%	-81%	-55%	-91%	26%	8%	-49%	-33%	-25%
	DE	Vlissingen, NL	-65%	-88%	-75%	-57%	-72%	-25%	-47%	-4%	3%	-15%
		Landskrona, SE	-74%	-88%	-75%	-57%	-72%	-30%	-50%	2%	-44%	-51%
	FI	Landskrona, SE	-76%	-68%	-78%	-47%	-67%	-48%	-54%	-5%	-49%	-48%
		Vlissingen, NL	-63%	-62%	-75%	-44%	-66%	-45%	-52%	-9%	17%	-11%
	NL	Vlissingen, NL	-59%	-92%	-70%	-50%	-60%	7%	-15%	43%	-6%	-26%
		Landskrona, SE	-67%	-91%	-67%	-48%	-62%	1%	-19%	55%	-43%	-56%
	SE	Landskrona, SE	-64%	-60%	-75%	-44%	-61%	-41%	-46%	15%	-42%	-46%
		Vlissingen, NL	-44%	-52%	-71%	-40%	-60%	-37%	-43%	10%	39%	-6%
	UK	Vlissingen, NL	-58%	-86%	-64%	-45%	-63%	-19%	-35%	32%	-3%	-13%
		Landskrona, SE	-69%	-86%	-63%	-46%	-64%	-24%	-38%	40%	-48%	-50%
	US	Ogden, Utah, US	-46%	-67%	-75%	-25%	-41%	6%	-8%	-14%	27%	-71%
	FR	Vlissingen, NL	-52%	-77%	-68%	-49%	-66%	-40%	-52%	-5%	25%	-83%
	IE	Vlissingen, NL	-56%	-79%	-40%	-51%	-71%	-11%	-30%	41%	-7%	-57%
		Landskrona, SE	-66%	-78%	-31%	-55%	-72%	-11%	-30%	34%	-43%	-65%
	PL	Vlissingen, NL	-67%	-84%	-80%	-75%	-70%	-69%	-71%	-34%	-24%	-71%
		Landskrona, SE	-74%	-85%	-79%	-76%	-71%	-70%	-71%	-37%	-52%	-75%
Barista (chilled)	FR	Vlissingen, NL	-49%	-77%	-68%	-51%	-66%	-39%	-52%	-23%	23%	-83%
	IE	Vlissingen, NL	-53%	-78%	-38%	-52%	-71%	-10%	-29%	20%	-6%	-56%
		Landskrona, SE	-63%	-76%	-28%	-56%	-72%	-11%	-30%	15%	-39%	-64%
	PL	Vlissingen, NL	-71%	-84%	-78%	-74%	-71%	-69%	-70%	-48%	-49%	-73%
		Landskrona, SE	-64%	-84%	-79%	-74%	-70%	-69%	-70%	-46%	-22%	-69%
Original (chilled)	US	Millville/Cumberland, US	-51%	-71%	-78%	-17%	-43%	-1%	-9%	-37%	-1%	-81%
		Ogden, US	-47%	-70%	-79%	-22%	-47%	-7%	-15%	-30%	8%	-79%
"No" Sugars (ambient)	DE	Vlissingen, NL	-69%	-89%	-79%	-61%	-79%	-42%	-58%	-4%	-3%	-14%
	NL	Vlissingen, NL	-64%	-93%	-75%	-55%	-71%	-17%	-32%	43%	-12%	-25%
	UK	Vlissingen, NL	-62%	-88%	-69%	-50%	-73%	-37%	-48%	33%	-8%	-12%
	SE	Vlissingen, NL	-50%	-56%	-75%	-47%	-70%	-51%	-55%	10%	31%	-5%
	FI	Vlissingen, NL	-67%	-65%	-78%	-49%	-75%	-57%	-61%	-9%	11%	-10%
Oat drink (ambient)	DE	Vlissingen, NL, whole	-66%	-88%	-76%	-57%	-73%	-28%	-49%	2%	3%	-15%
		Vlissingen, NL, semi	-67%	-89%	-78%	-60%	-77%	-36%	-54%	-1%	0%	-15%
	NL	Vlissingen, NL, whole	-60%	-92%	-71%	-50%	-62%	4%	-18%	53%	-6%	-26%
		Vlissingen, NL, semi	-62%	-92%	-74%	-53%	-68%	-8%	-26%	48%	-9%	-26%
	UK	Vlissingen, NL, whole	-58%	-87%	-64%	-45%	-65%	-22%	-36%	41%	-3%	-13%
		Vlissingen, NL, semi	-60%	-87%	-68%	-48%	-70%	-31%	-43%	36%	-6%	-14%
		Vlissingen, NL, light	-63%	-88%	-70%	-51%	-75%	-39%	-49%	31%	-9%	-15%
	SE	Landskrona, SE, whole	-65%	-60%	-75%	-45%	-63%	-43%	-48%	22%	-43%	-46%
		Landskrona, SE, semi	-67%	-63%	-77%	-49%	-69%	-50%	-54%	18%	-46%	-46%
		Landskrona, SE, light	-70%	-65%	-80%	-52%	-74%	-57%	-59%	13%	-49%	-47%
	FI	Landskrona, SE, whole	-77%	-68%	-78%	-48%	-68%	-50%	-55%	1%	-50%	-48%
		Landskrona, SE, semi	-78%	-70%	-80%	-51%	-73%	-56%	-60%	-2%	-52%	-49%
		Landskrona, SE, light	-80%	-72%	-82%	-53%	-78%	-62%	-65%	-6%	-55%	-49%
Oat drink (chilled)	FI	Landskrona, SE, semi	-76%	-70%	-80%	-56%	-74%	-55%	-57%	-30%	-46%	-63%
	SE	Landskrona, SE, semi	-66%	-67%	-79%	-50%	-69%	-49%	-50%	-18%	-47%	-60%
Oatly Unsweetened	US	Ogden, US	-52%	-70%	-82%	-52%	-77%	-63%	-57%	-40%	13%	-85%
		Millville/ Ogden, US	-61%	-78%	-87%	-54%	-77%	-64%	-58%	-43%	-11%	-85%
Oatly Super Basic	US	Millville, US	-44%	-64%	-78%	-37%	-61%	-35%	-34%	-32%	37%	-82%
		Millville/ Ogden, US	-56%	-74%	-83%	-39%	-60%	-32%	-32%	-38%	0%	-81%
Creamy Oats (chilled)	SE	Landskrona, SE	-61%	-59%	-72%	-35%	-54%	-38%	-42%	-20%	-30%	-61%
	FI	Landskrona, SE	-71%	-63%	-73%	-40%	-57%	-40%	-45%	-28%	-33%	-62%
	DE	Landskrona, SE	-73%	-87%	-73%	-53%	-68%	-30%	-47%	-15%	-33%	-63%
	NL	Landskrona, SE	-72%	-93%	-72%	-57%	-64%	-18%	-29%	-14%	-45%	-79%
	UK	Landskrona, SE	-72%	-88%	-65%	-41%	-66%	-36%	-47%	31%	-43%	-70%
	DK	Landskrona, SE	-61%	-53%	-61%	-45%	-36%	-8%	-15%	6%	-26%	-65%
	NO	Landskrona, SE	-78%	-70%	-84%	-73%	-79%	-75%	-73%	-37%	-38%	-78%

Table 1. Environmental impact of Oatly products produced and sold in different geographies in comparison to their dairy equivalents produced locally. Red cells = >10% difference favouring the dairy equivalent; green = >10% difference favouring the Oatly product; yellow = <10% difference, indicating similar performance.

Life cycle assessment of Beefy-9 and Beefy-R serum-free culture media for cell-cultivated beef production

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1. INTRODUCTION

Cell-cultivated meat has the potential to become a commercial scale, novel source of protein for the global population in the future. To produce cell-cultivated meat, cells are fed with culture media, which has been reported as a major contributor to the overall environmental impacts and cost of cell-cultivated meat production. Media should be formulated from low impact, animal-free ingredients to promote sustainability. Stout et al. (2022) developed Beefy-9, a serum-free culture medium formulated with recombinant albumin as an essential part of the fetal bovine serum-free medium. However, recombinant albumin is expensive. Therefore, Stout et al. (2023) introduced rapeseed protein isolates (RPI) as a replacement for the functionality of albumin for serum-free, cost-effective bovine satellite cell production. While Beefy-R can reduce costs relative to Beefy-9, its effect on environmental impacts is unknown. The goal of this study was to estimate the environmental impacts of both culture media and identify hotspots in their production using life cycle assessment (LCA).

2. METHODS

The systems were modelled as theoretical, commercial scale Beefy-R and Beefy-9 production systems using currently available technologies and inputs. The functional unit for this LCA was chosen as one liter of sterilized culture media. The system boundary is cradle-to-factory gate, including raw materials production, protein isolation, and sterilization of the culture media, and excluding final packaging and transportation of the product. Production of commercial-scale recombinant growth factors were modeled by Sinke et al. (2023). For Beefy R, RPI is produced from rapeseed cake using alkali extraction, isoelectric precipitation, centrifugation, and filtration to generate a concentrated protein solution (50 mg/mL). ReCiPe Midpoint (H) 2016 was used for impact assessment. Uncertainty was assessed through sensitivity and scenario analyses, as well as Monte Carlo simulation and paired t-tests.

3. RESULTS AND DISCUSSION

The results demonstrated that Beefy-R has significantly lower environmental impacts compared to Beefy-9 in 11 out of 18 evaluated impact categories. For instance, the global warming potential (GWP) for Beefy-R and Beefy-9 production are 0.08 and 0.39 kgCO_2eq per liter, respectively (Table 1). RPI has less than a three percent contribution to thirteen of the eighteen assessed impact categories in terms of environmental impact. Nonetheless, RPI constituted 21.3% of the land use in the production of Beefy-R culture media.

In Beefy-R, despite the absence of recombinant albumin, recombinant proteins and growth factors were the primary hotspot, leading to 41%, 6%, and 12% of GWP, land use, and water consumption for the formulation, respectively (Figure 1). Although Beefy-R is relatively more sustainable compared to Beefy-9, the environmental impact could still be significant in the context of overall environmental impact of cell-cultivated meat systems. For example, the GWP of the production of culture media requirements for production of one kg of cell-cultivated meat with Beefy-9 and Beefy-R was 16.8 and 3.5 and kg CO_2 eq, respectively, assuming 43 kg of culture media is required to produce one kg of cell-cultivated meat.

Impact category	Unit	Quantity	
		Beefy-9	Beefy-R
Climate change *	kg CO_2 eq	0.39	0.08
Terrestrial acidification	kg SO_2 eq	1.40×10^{-3}	3.52×10^{-4}
Freshwater eutrophication *	kg P eq	4.34×10^{-5}	2.54×10^{-5}
Marine eutrophication *	kg N eq	1.30×10^{-5}	1.21×10^{-5}
Terrestrial ecotoxicity	kg 1,4-DCB	0.18	0.19
Freshwater ecotoxicity	kg 1,4-DCB	2.29×10^{-3}	2.36×10^{-3}
Human carcinogenic toxicity	kg 1,4-DCB	2.77×10^{-3}	2.73×10^{-3}
Human non-carcinogenic toxicity	kg 1,4-DCB	4.33×10^{-2}	4.34×10^{-2}
Land use *	m^2a crop eq	1.20×10^{-2}	8.85×10^{-3}
Water consumption *	m^3	2.78×10^{-3}	1.59×10^{-3}

4. CONCLUSIONS

This study confirms that RPI can be a more sustainable substitute for recombinant albumin in serum-free media for bovine cell culture. However, there remains room for improvement of the overall environmental impacts of Beefy-R through valorization of the by-products of protein isolation. Additional research is also required to identify low-impact alternatives for other recombinant proteins and growth factors in culture media.

5. ACKNOWLEDGEMENTS

Funding provided by the U.S. Department of Agriculture NIFA AFRI Sustainable Agricultural Systems program (grant #2021-699012-35978).

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Table 2. Select environmental impacts of Beefy-R culture media production (FU = I liter of culture medium).*Indicates a statistically significant difference (95% confidence) between products.*

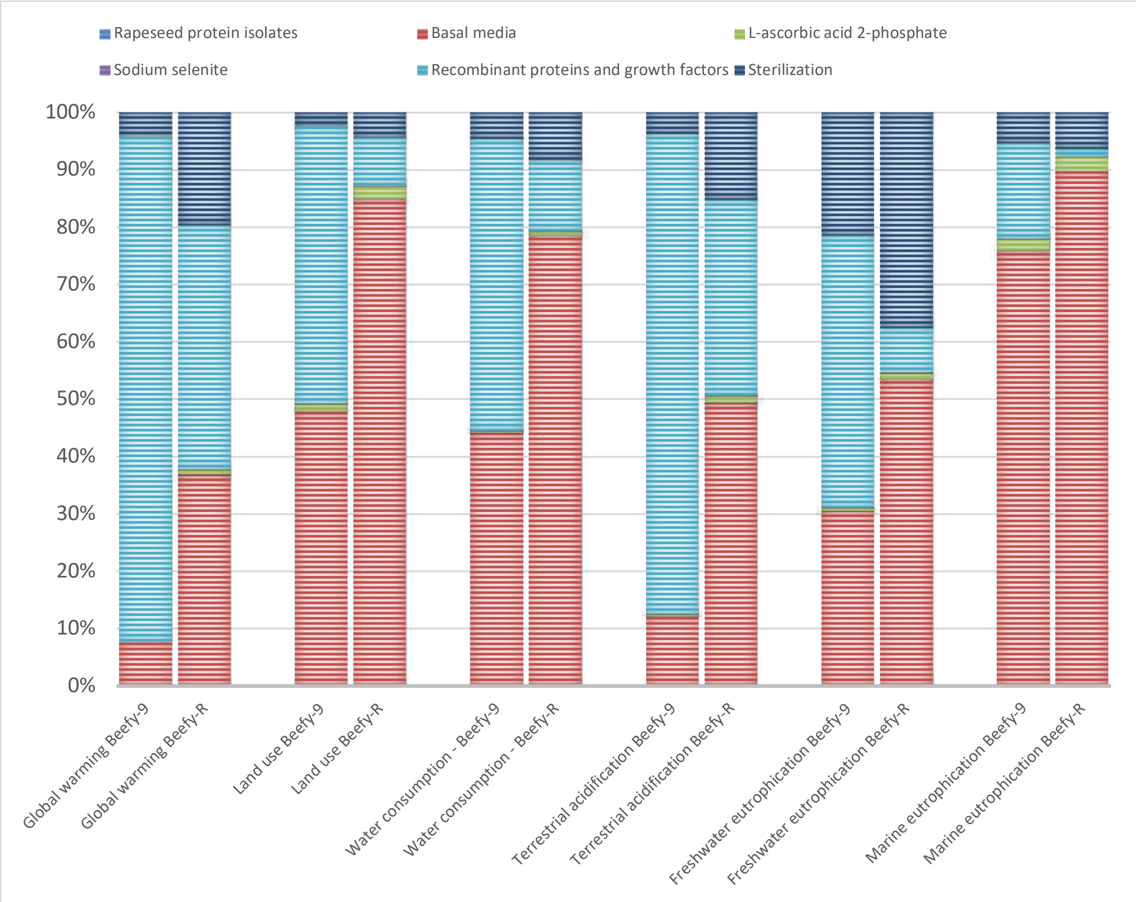

Figure 2. Contribution of inputs to select environmental impacts of Beefy-9 and Beefy-R production

Life Cycle Assessment of Recombinant Growth Factor Production for Cultivated Meat Through Molecular Farming

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1. INTRODUCTION

Cultured meat (CM) emerges as an environmentally sustainable alternative, demanding animal-free and eco-friendly production for market viability (Santos et al., 2023). The use of fetal bovine serum (FBS) in CM production faces ethical and environmental challenges, prompting the development of FBS-free culture media using growth factors from microbes (Kolkmann et al., 2022). Several culture media are developed for the aim of eliminating the FBS inputs (Skrivergaard et al., 2023) by using growth factors synthesized by microbes. However, the costs of growth factors produced by microbes are high. As an alternative to production of growth factors through microbes, the use of plants to synthesize the molecules have been developed called molecular farming which is cheaper in price. This study aims to evaluate the environmental impacts of insulin-like growth factor (IGF) production through molecular farming in plant systems in comparison to microbial IGF production (Trinidad et al., 2023) production using an attributional life cycle assessment (LCA) method. Using an LCA allows for the analysis of trade-offs bet ween various impact categories and measures the environmental impact of IGF production from MF.

2. METHOD

We applied an attributional LCA approach with a cradle-to-protein gate system boundary, based on current data gathered and estimated from a functioning production-scale pilot in Iceland. The environmental analysis of insulin-like growth factor IGF production was modelled with the aid of the OpenLCA v 2.1 software using the ecoinvent v.3.6 database. We used the ReCiPe 2016 midpoint (H) method to calculate the global warming (kg CO2 eq.), terrestrial acidification (kg SO2-eq.), freshwater Eutrophication (kg N eq.), land use (m2a), ozone depletion (kg CFC-11 eq.), cumulative energy demand (MJ eq). Water scarcity was assessed using the AWARE method.

3. RESULTS

Figure 1 illustrates the environmental impact of IGF production per mg of protein, along with the contribution of each process across four different scenarios: (1) Iceland (greenhouse GH)-baseline, (2) Iceland/Canada (infield) (3) Canada (infield) (4) Microbial GF production (Literature data). These scenarios utilize electricity mix from both Iceland (hydro 71% and geothermal 29%) and Canada (hydro 60.8%), chosen to reflect different carbon intensity levels of country electricity in both EU and the North America. The study's modified null hypothesis significance testing (NHST) led to the rejection of the null hypothesis for all alternatives and impact categories, indicating significant differences between GF produced through MF and microbial method. The results show that GF produced through infield generally has lower environmental impacts for most impact categories compared to the baseline GH cultivation method in Iceland. In comparison with microbial method of production, both infield and GH production platform showed higher environmental impacts, however. The micro/macro nutrient and electricity input used in tissue culture and green factory (GH) respectively were identified as the main contributor to the environmental burdens, ranging between 1% and 196% . This impact was offset through a large environmental saving from the wastewater treatment system.

4. CONCLUSIONS

GF from molecular farming provided promising environmental benefits compared to microbial GF. LCA was employed to assess potential enhancements to the baseline case by addressing identified hot-spots. The other notable sensitivity of the results was due to the assumptions relating to the potential use of the waste product from purified barley used. The genetically modified barley biomass is not yet approved in the EU for use; it was thus considered as biowaste in the main scenarios at this stage. This is likely to change in the future since other by-products from the food and beverage industry are currently used as feed.

5. ACKNOWLEDGEMENTS

This work was part of the ‘Transforming agriculture with agroecological symbiosis combined with cellular agriculture— environmental impacts and perceptions of farmers and consumers’ project funded by the Finnish Cultural Foundation.

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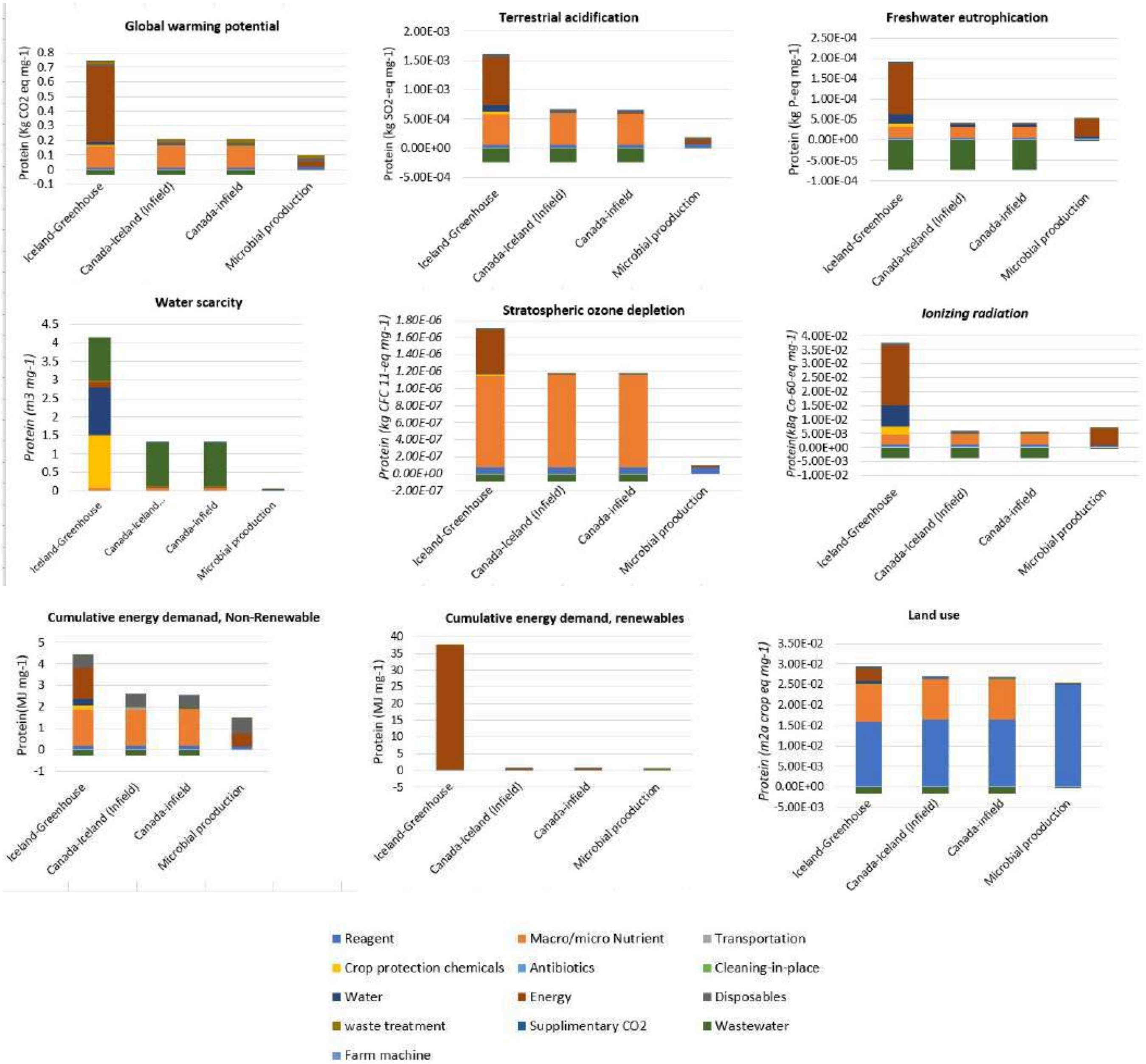

Figure 1. Environmental impact of GF through MF production per scenario. Deterministic results and process contributions in IS , CAN and The USA (Trinidad et al 2023) per mg of IGF product.

Looking forward to a sustainable insect meal value-chain: a LCA study on yellow mealworm meal production

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1. INTRODUCTION

Among the novel and future sustainable foods, edible insects can play a relevant role in providing alternative and low-impact proteins [1, 2]. Their exploitation is of particular interest given their ability to convert agricultural and food waste into products of high nutritional and economic value [3]. With the scope of designing a sustainable and circular insect meals value chain, a preliminary Life Cycle Assessment (LCA) study was carried out to explore the environmental implications of a yellow mealworm (YM) *Tenebrio molitor* experimental farm. This beetle is one of the main insect species reared for food and feed purposes. The main product of the mass rearing is fresh mature larvae that could be processed into raw meal or further fractionated into defatted meal and fat of equivalent economic value. Defatting is required to have a more stable and industrially processable product (e.g. by extrusion process).

2. METHODS

The LCA focuses on an experimental-scale case study, and complete cradle-to-gate inventories up to the gate of defatted insect meal were considered. Primary data about YM mass rearing and YM meal processing were collected in CNR – Institute of BioEconomy and Porto Conte Ricerche srl laboratories, respectively, in 2017. The modelling was conducted using SimaPro Analyst 9.3.0.3 software with the ecoinvent 3.9 database. Impact assessment was based on the EF 3.0 Method (adapted) V1.02. Environmental impacts of YM reared on two different insect diets were compared considering a complete cycle, from ovipositing adults to mature larvae (about 3 months): the first used durum wheat bran (WB) and fresh vegetable discards (FVDs, used as a source of water) with a 49:51 mass ratio; the second was composed of a mix of WB (6% of the whole mass administered), dried brewer spent grain (BSG) (31%) and FVDs (63%). FVDs were modelled as 50% leafy vegetables (mainly lettuce), 25% fruiting vegetables (mainly cucumbers and zucchinis), and 25% fruits (mainly apples). For dried BSG, LCA's modelling of the whole brewing process was carried out using primary data, as they were not available in ecoinvent. The study employed a 1% cut-off for data inclusion, and economic allocations were used for insect products (larvae/frass) and beer/BSG production, while mass allocations were applied for insect meal processing. Two functional units (FUs) were set: 1 kg of fresh YM larvae, and 1 kg of defatted YM meal with a content of 65% and 5% of protein and lipid, respectively.

3. RESULTS AND DISCUSSION

Considering the fresh larvae FU (Fig. 1), relevant differences between the two diets environmental profiles were found in four impact categories: Photochemical Ozone formation, Climate Change, Resource Use fossil, and Water Use. Insects reared on WB showed lower impacts for all these categories, except Water Use, than insects reared on BSG, which was mainly tied to feed crop cultivation (allocated to BSG, to a little extent, being a subproduct of beer brewing). The rearing phase represented the most impacting process for the main impact categories, except for Photochemical Ozone Formation, where the defatting phase, due to ethanol use emissions for fat extraction, was the predominant one (Fig. 2). The environmental performance of the rearing phase was driven by insects' diet, that represented from 39% to 88% and from 32% to 96% of the main impact categories for BSG for WB, respectively. Difficulties in comparing our results with the small number of cases described in the literature due to differences in technological conditions and methodological approaches. Considering the environmental performances of alternative protein sources (fishmeal and soybean meal), resulted in larger impacts due to differences in process scale and modelling parameters. According to that, a more comprehensive analysis shall consider a protein-based FU and circularity indicators.

4. CONCLUSIONS

This LCA study showed that insect diet plays a key role in the environmental profile of the YM meal, suggesting large room for improvement and opportunity for repurposing agricultural by-products, discards and waste in a circular economy perspective. Looking forward to an upscaling of the YM meal production process under study, a more in-depth environmental investigation will be carried out using site-specific data for all feed inputs as well as additional performance indicators. In particular, we will address nutritional aspects (n-LCA) and delve further into the circularity of YM meal production.

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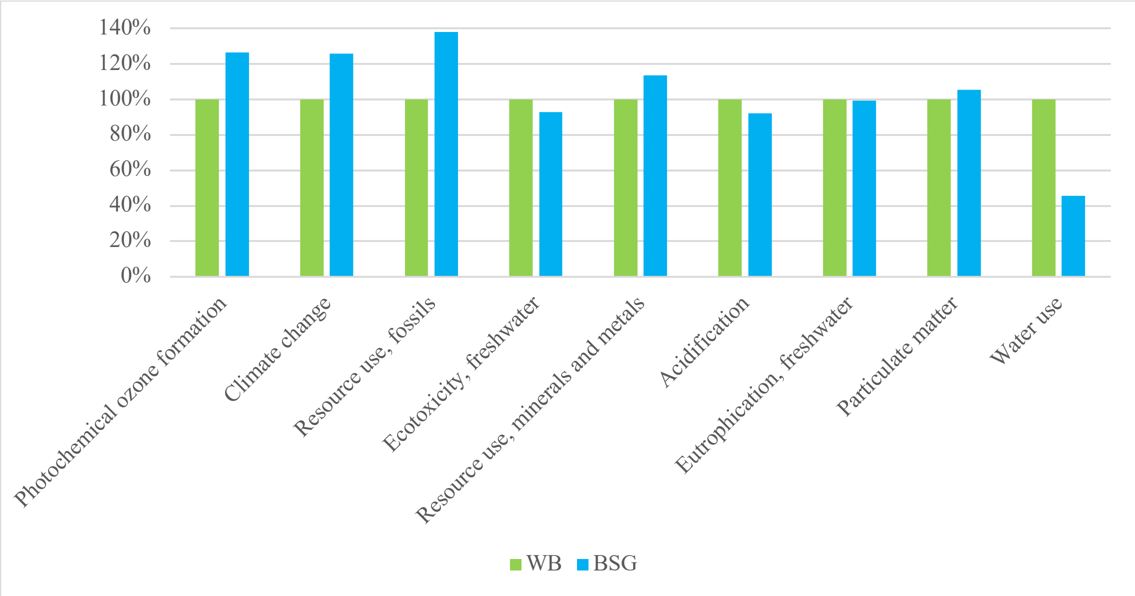

Figure 1. Environmental profile of Yellow Mealworm (YM) rearing. Evaluation method EF 3.0, only the impact categories that accounted for at least 90% of the single score are shown. Functional unit:1 kg of YM larvae. WB = wheat bran, BSG = brewery spent grain.

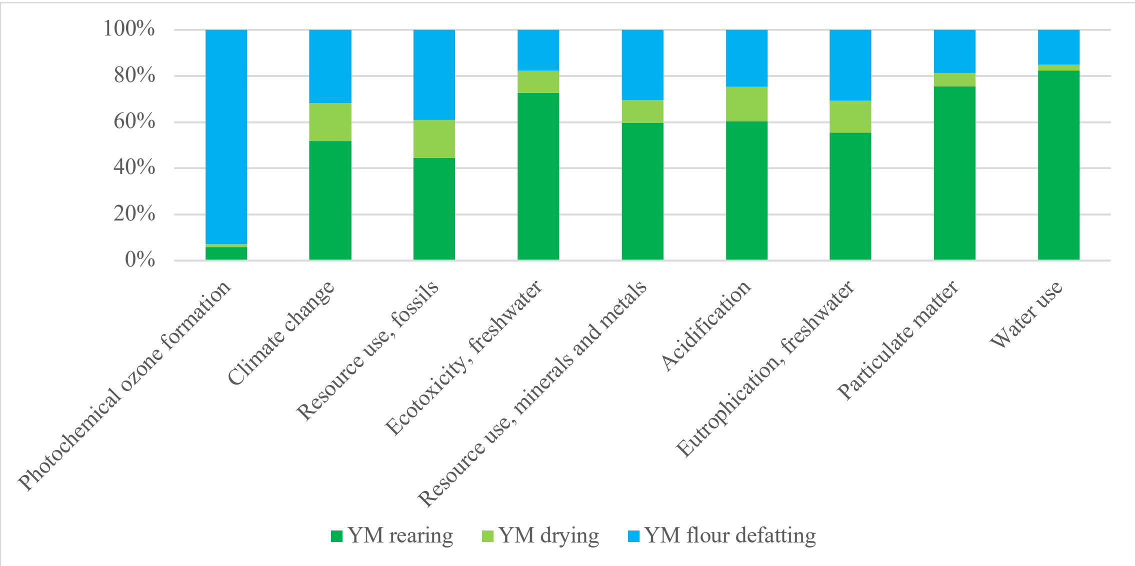

Figure 2. Percentage contribution of the three main Yellow Mealworm (YM) meal (barley spent grain) production phases. Evaluation method EF 3.0, only the impact categories that accounted for at least 90% of the single score were selected. Functional unit:1 kg of defatted YM meal.

Novel foods and protein diversification (II)

The nutritional and environmental consequences of replacing meat and dairy products with market-ready alternatives in recommended and average Swiss diets

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1. INTRODUCTION

Animal foods are rich in nutrients such as high-quality proteins, minerals (calcium, iron, iodine) and vitamins (B1, B2, B6, B12) with high availability due to matrix effects. However, the contribution of animal foods to environmental impacts and health issues has reached the spotlight of discussion (Poore and Nemecek, 2018). In recent years, increasing numbers of alternative products have been introduced to the market, partially with the idea to substitute meat and dairy products in the diet. This raises questions of whether these substitutes can effectively replace meat and dairy products in terms of nutrition and contribute to reducing diet-related environmental impacts. Hence, this study seeks to explore the nutritional and environmental consequences of replacing meat and dairy products with currently available alternatives in recommended and average Swiss diets.

2. METHODS

The study focuses on the Swiss context as a proxy for high-income countries with markets allowing for early adoption of nutritional trends. The environmental impacts of the food items were computed using SimaPro based on life cycle inventories (LCI) taken from different databases (Agribalyse, WFLDB, ecoinvent and SALCA) for better data availability and accuracy. The data was harmonized to represent Swiss conditions, including local production and imports. Nutrient information was taken from the EuroFIR (European Food Information Resource) database for all food items, as it standardizes nutrient content data from different countries into a comprehensive and unified database. The nutritional information for alternative products was aggregated based on inputs from seven European countries (FR, GR, PT, CH, SI, ES, GB) to ensure data availability, while for all other food items in the diet nutritional data was based on Swiss data. We defined two reference diets, one describing Swiss diet habits as per 2014 (=average diet) (BLV, 2015) and the other reflecting Swiss dietary recommendations (=recommended diet) (SGE, 2020). Per reference diet, two alternative diets were defined assuming either the replacement of meat or the replacement of both meat and dairy products with the aforementioned alternatives. We assumed that within the alternative diets the meat and dairy products are replaced 1:1 with respect to weight, the most straightforward interpretation of a “replacement” from the consumers’ perspective.

3. RESULTS AND DISCUSSION

Substituting meat products in the average and recommended diet can reduce the environmental impact across all categories (Table 1). Meanwhile, the replacement of both meat and dairy products, further decreased the global warming potential, acidification potential and land occupation, but increased the water scarcity and eutrophication potential, mainly through almond- and oat-based milk alternatives as well as cheese alternatives based on coconut oil. While the nutritional value of the diets increased for many nutrients when meat and dairy products were replaced, certain essential nutrients such as calcium and vitamin B12 decreased (Table 2). The high salt content of the alternatives can further lead to an increased sodium concentration in the alternative diets. Iodine intake remains low across all diets, a known issue in Switzerland (BLV, 2021). Supplementation with critical micronutrients could help to improve the quality of alternative products and therefore diets based on them. Furthermore, the bioavailability and quality of nutrients are relevant aspects to consider when comparing animal products to their alternatives and still require extensive research.

4. CONCLUSIONS

Alternative products offer a valuable opportunity to lower the environmental impacts of the two proposed diets, while simultaneously providing consumers with high quantities of nutrients. However, they can be insufficient for some essential nutrients and will require further improvement from a nutritional perspective to allow an adequate substitution of animal products. Moreover, a careful selection of the raw materials during the production of the alternatives could ensure benefits across all impact categories.

5. ACKNOWLEDGEMENTS

We thank the Foundation for Technology Assessment TA-SWISS for funding this project.

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Table 1. Exemplary results of the environmental assessment of the diets. The impacts of the average Swiss diet were taken as reference. For the other diets the results for the respective impacts are shown in comparison to the reference diet.

Impact category \ Diet	Average (ref. diet)	Average -no meat	Average -no meat -no dairy	Recomm.	Recomm. -no meat	Recomm. - no meat - no dairy
Land occupation	= 100%	< 80%	< 70%	< 90%	< 80%	< 60%
Water scarcity	= 100%	< 100%	> 100%	< 90%	< 90%	< 100%
Global warming potential	= 100%	< 80%	< 60%	< 80%	< 70%	<50%
Acidification potential	= 100%	< 70%	<50%	< 80%	< 70%	<50%
Eutrophication potential	= 100%	< 90%	= 100%	< 90%	< 80%	< 100%

> 100%	= 100%	< 100%	< 90%	< 80%	< 70%	< 60%	<50%

Table 2. Exemplary results of the nutritional analysis of the diets. The colours highlight the compliance with the dietary reference intakes (DRI) of the individual nutrients.

Nutrient \ Diet	Average	Average -no meat	Average -no meat -no dairy	Recomm.	Recomm. -no meat	Recomm. -no meat -no dairy
Protein	Complies with DRI	Complies with DRI	Complies with DRI	Complies with DRI	Complies with DRI	Complies with DRI
Calcium	Does not comply with DRI	Partially complies with DRI	Does not comply with DRI	Complies with DRI	Complies with DRI	Does not comply with DRI
Iron	Partially complies with DRI	Partially complies with DRI	Partially complies with DRI	Complies with DRI	Complies with DRI	Complies with DRI
Iodine	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI
Vitamin B12	Complies with DRI	Partially complies with DRI	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI
Sodium	Partially complies with DRI	Partially complies with DRI	Partially complies with DRI	Complies with DRI	Complies with DRI	Partially complies with DRI
Added Sugar	Does not comply with DRI	Does not comply with DRI	Does not comply with DRI	Complies with DRI	Complies with DRI	Complies with DRI

Does not comply with DRI	Partially complies with DRI	Complies with DRI

The sustainability and nutritional profile of alternative protein sources - Avoiding fallacy by including protein quality and nutrient density in LCIA of novel foods

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1. INTRODUCTION

Alternative protein sources offer the potential to be a sustainable food source for a growing global population. Although initial assessments of the environmental and health potential of dairy and meat alternatives exist, research regarding the inclusion of the nutritional composition and bioavailability in environmental impact assessments of food is lacking (Silva & Smetana, 2022, Green et al., 2021). Since mass-based comparisons of food items neglect the nutritional composition, they are in many cases not adequate to generate meaningful results (McLaren, 2021). Nutritional LCAs (nLCA) target these challenges by developing nutritional functional units (nFU). However, these are mostly limited to single nutrients (e.g., impact per 100g protein), single environmental impacts or disregard differences in protein quality. This study demonstrates that the FU in LCA studies of food should be carefully adjusted to avoid engendering misleading conclusions. Further, it is shown that the nutrient composition and protein quality are important aspects to consider when developing sustainability recommendations for the food sector. Therefore, the environmental and nutritional footprints of 25 food items in the context of alternative proteins are calculated, contextualized, and compared.

2. METHODS

Data about the nutritional profile and the environmental performance was gathered, adjusted, and calculated. Nutrient profiling was achieved by adapting the Nutrient Rich Food (NRF) metric, one of the most used and established nutrient indices to rank food items according to their nutrient content (Green et al., 2021). Eleven encouraging nutrients were selected based on potentially critical nutritional supply in vegan diets. The environmental impacts considered include global warming potential (GWP), biodiversity loss, land use, water scarcity, energy use and eutrophication. To evaluate and integrate the bioavailability and quality of proteins the Digestible Indispensable Amino Acid Score (DIAAS) (FAO, 2013) was incorporated in the analysis. The environmental impacts were related to different FUs including NRF and DIAAS.

3. RESULTS AND DISCUSSION

Six different FUs for eight environmental impact categories and 25 food items were calculated to demonstrate how the inclusion of the nutritional profile and the protein quality affect the environmental and health performance (Figure 1 to 3). Results showed that the FU had a great influence on the ranking although not changing the general conclusion that most animal-based proteins (beef, lamb and pork) led to higher GHG emissions than alternative protein sources. The GWP of protein sources which are usually available as powders or have a high energy density (e.g., spirulina, nuts, seeds) decreases when switching from mass-based to energy-based FU (Figure 1). Protein quality strongly affects the ranking especially for almonds and cereals (Figure 2). Using a protein-based FU, lamb and beef lead to higher GWP than plant-based drinks (PBD) although PBD are low in protein (<5g protein/100g). In comparison to cow's milk, oat-based drink performs worse. However, when taking nutrient composition into account all PBD outperform cow's milk in terms of GHG-emissions. Results are similar for other environmental impacts except for water scarcity and biodiversity footprint of nuts and seeds.

4. CONCLUSIONS

The FU plays a crucial role when comparing the environmental performance of food items. The inclusion of nutrient composition and protein quality in environmental impact assessments provide a clearer picture for the development of sustainability-related dietary recommendations than using only mass-based FUs. Especially in the context of alternative proteins, where nutrient quality and bioavailability appear to invigorate the sustainability debate of non-animal compared to animal-based protein sources, the selection of appropriate FUs is crucial to avoid misleading recommendations. Including nutrient composition and bioavailability in environmental impact assessments of food is of particular importance when comparing diverse food items (e.g., for food labelling) or developing food based dietary guidelines. However, data gaps lead to uncertainties. Further research is needed, especially in context of novel foods.

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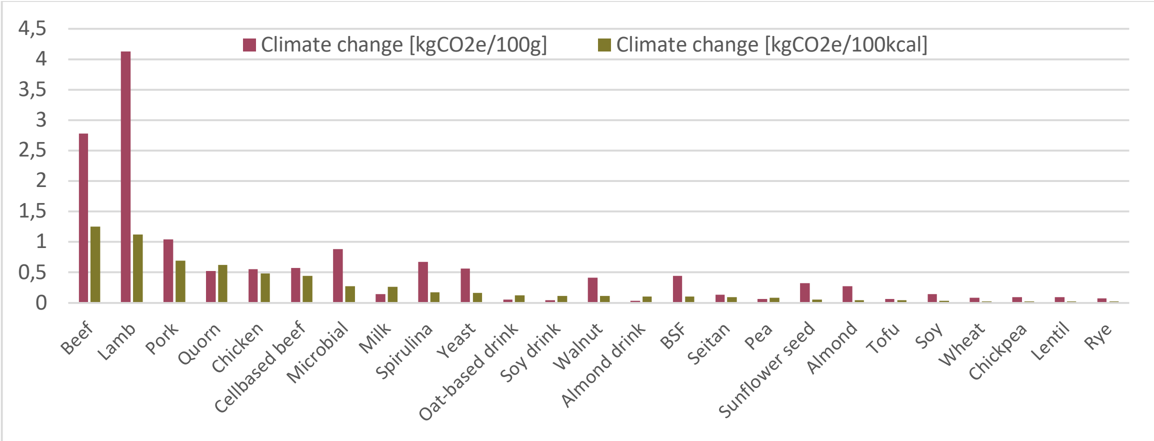

Figure 1: GWP of protein sources (average) with mass and calorific energy as FUs

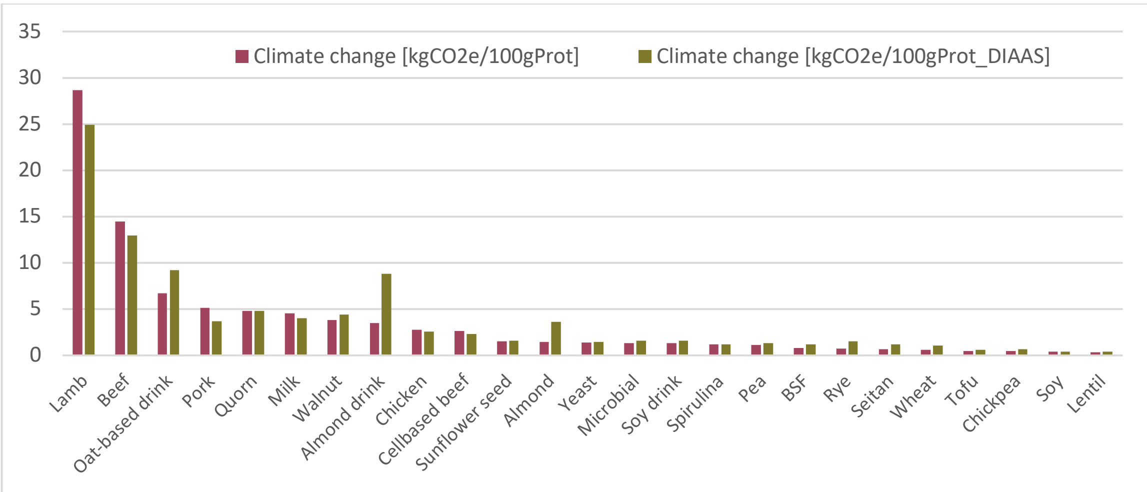

Figure 2: GWP of protein sources with protein content and DIAAS adjusted protein content as FUs

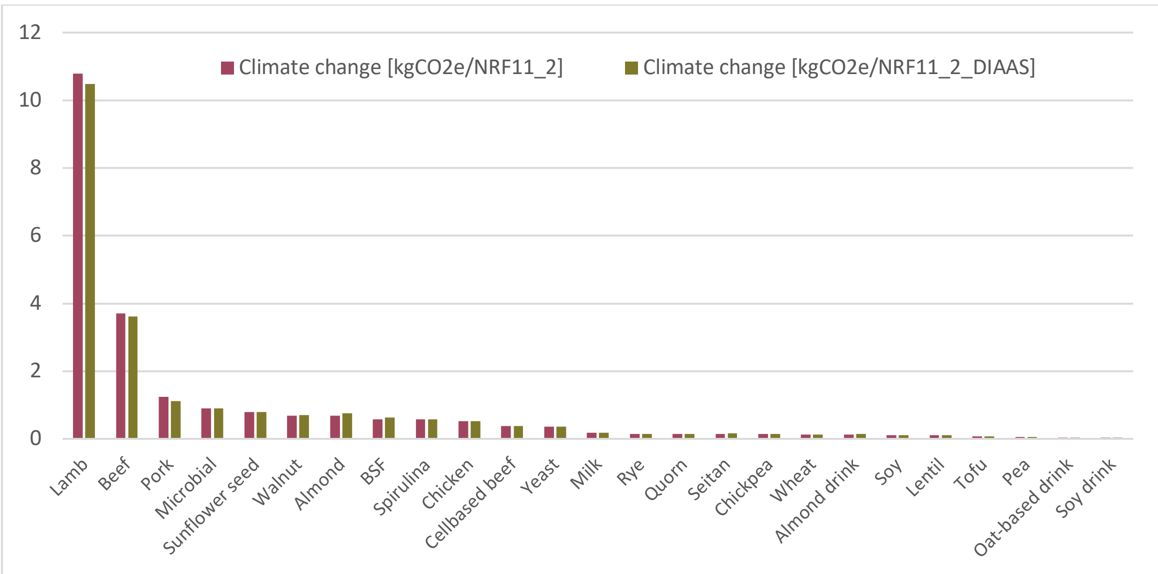

Figure 3: GWP of protein sources weighted with NRF and DIAAS-adjusted NRF

A novel nutrient quality index for life cycle assessment of protein-rich foods

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1. INTRODUCTION

Alternative protein sources (APSs) have emerged as a potentially healthy and, presumably, sustainable solution for meeting future food demand. Even though numerous investigations have assessed the environmental implications of these products through the application of life cycle assessment (LCA), most ignore the function of other essential nutrients and do not reflect the actual bioavailability and digestibility of the protein. Therefore, the objective of this contribution is the development of a complex nutrient quality model that meets the needs outlined above and to test it in the LCA of emerging APSs and their animal-based counterparts.

2. METHODS

The characteristics and properties of the model were based on those of the Spanish Nutrient Rich Food 9.2 (sNRF9.2) index (Fernández-Ríos et al., under review). 11 positive nutrients – fiber, protein, vitamins A, B9, B12, D and E, Zn, Mg, Ca and Fe – and 2 negative nutrients – saturated fatty acids and Na – were included. A protein quality scoring system was considered by means of the Digestible Indispensable Amino Acid Score (DIAAS). The integration of all the components gave rise to the quality Nutrient Rich Food 1.10.2 (qNRF1.10.2) model, whose algorithm is shown in Eq. (1).

$$qNRF1.10.2 = \left[\frac{protein \cdot DIAAS}{DRI_p} + \sum_{i=10}\left(\frac{nutrient_i}{DRI_i}\right) + \sum_{j=2}\left(\frac{L_j}{MRI_j}\right)\right]/ED \qquad \text{Eq. (1)}$$

where protein is the protein content in 100g of food, DIAAS the DIAA score (%), DRI_p the daily recommended intake for protein, $nutrient_i$ the amount of nutrient i (positive) in 100g of food, DRI_i the daily recommended intake for nutrient i, L_j the amount of nutrient j (negative) in 100g of food, and MRI_j the maximum recommended intake for nutrient j.

The model was applied to a range of conventional animal foods and APSs. Environmental impacts of most of the products were compiled from the Agribalyse database or collected from literature. The outcomes were subjected to eight impact categories related to the resources use and ecosystems and human damage.

3. RESULTS AND DISCUSSION

Results revealed that animal-based products do not always have the worst environmental performance when compared to other protein-rich foods (Figure 1). Although for all indicators this food group was located at the bottom of the ranking, some emerging APSs presented significantly higher burdens in specific indicators. Spirulina was attributed with 35% and 57% more of the fossil and mineral resources consumption respectively than meat (on average). There were even conventional foods that consume considerably more water than animal products; cereals entailed a water deprivation of almost 16m^3/FU (vs. 4.8m^3). However, despite being critical in some specific emissions or resources, the performance of emerging APSs is offset by their nearly neutral impact in other categories. The performance of nuts, seeds and legumes was pretty acceptable, which generally achieved positions from first to third, as well as of vegetable food mixtures. On the other hand, cereals were frequently situated at the middle of the ranking, generally penalized for some foods such as rice or corn.

4. CONCLUSIONS

The application of the novel index supported the existing statements on the environmental profile of meat products, while showing some weaknesses of emerging APSs, probably due to their nascent production and commercialization. This research led to the conclusion that there must be a trade-off in the consumption of conventional and emerging foodstuffs to achieve healthier and more environmentally sustainable dietary patterns.

5. ACKNOWLEDGEMENTS

This work was supported by the Spanish Ministry of Science and Innovation through the KAIROS-BIOCIR project (PID2019-104925RB) (AEO/FEDER, UE). Ana Fernández-Ríos thanks the Ministry of Economy and Competitiveness of Spanish Government for their financial support via the research fellowship RE2020-094029.

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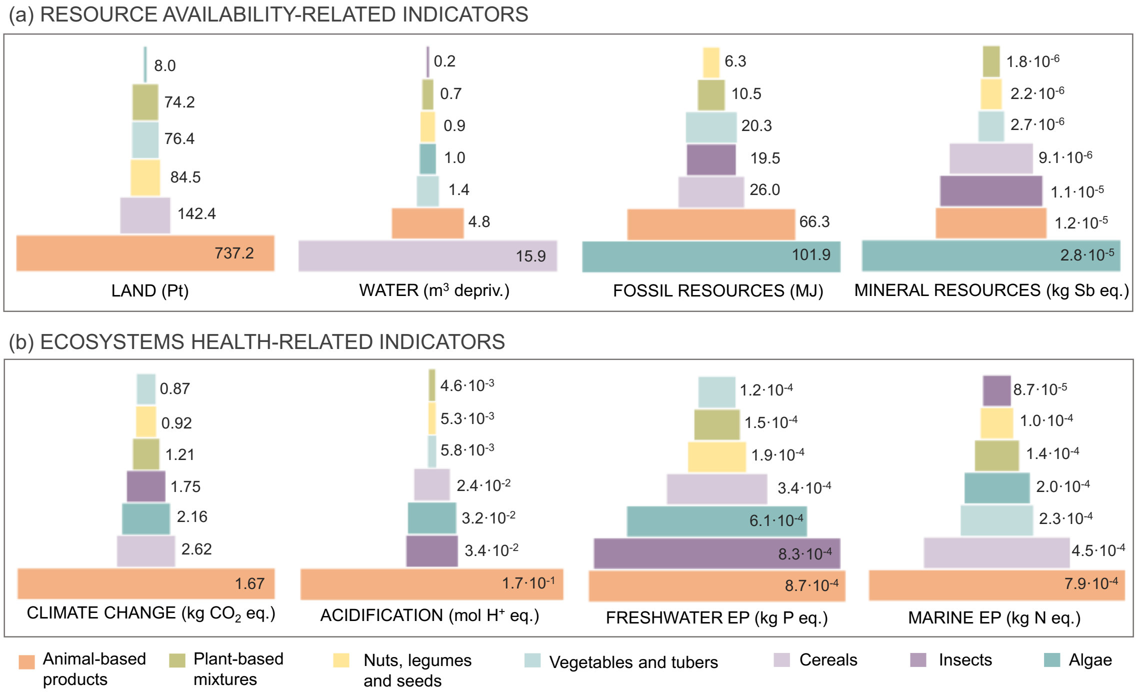

Figure 1. Average environmental impacts associated with resource- and ecosystem- related indicators of animal-based products and APSs. The burdens reported were calculated by the average of the foods of each category using a FU of 1000qNRF1.10.2.

Global environmental impact of replacing livestock with cell-cultured and microbial proteins

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1. INTRODUCTION

Extant studies highlighted the environmental advantage of microbial protein (MP) and cell-cultured recombinant proteins (RP) over livestock proteins when attributional life cycle assessments (LCA) were used (Järviö et al., 2021a; Järviö et al., 2021b). A systemic assessment is needed to assess the impact of replacing traditional livestock with cellular agriculture given the interdependencies between the livestock sector and other sectors in the food system. Here, we aim to assess the environmental changes on the global food system given the transition towards MP and cell-cultured RP powered by green energy, i.e., wind and solar PV to replace livestock proteins (i.e., pork, goat, beef, poultry, milk, cheese, and eggs).

2. METHODS

This work incorporates system dynamics (SD) modelling and LCA to allow a comprehensive assessment of the current and future environmental situation between 2020 and 2050, where we quantify the greenhouse gas (GHG) emissions, agricultural land use, and energy demand under different replacement scenarios $(ScnX)$ replacing $0, 20, 40, 60, 80, and\ 100\%$ of livestock protein (El Wali et al., 2024). We also examine the availability of critical materials needed for this transition (Figure 1). The SD model is driven by the growing population and per capita demand for food, while the LCA was carried out using the ReCiPe 2016 Midpoint (H) method based on the provision of wind and solar energy as the only direct energy sources to quantify global warming, energy demand, and land use per kg protein of MP and cell-cultured RP.

3. RESULTS AND DISCUSSION

The full transition to cellular agriculture requires a maximum 72% and 51% of wind and solar PV capacities by 2050, respectively. The results showed no shortage of most critical materials to fuel the transition, except tellurium, which allowed up to 60% transition (El Wali et al., 2024).

3.1 Environmental impact

The transition to cellular agriculture increases carbon dioxide (CO_2) emissions following the deployment of grid mixes as indirect energy sources, while methane (CH_4) decreases following the replacement of livestock production – largest contributor to CH_4 emissions from the food system. Overall, global GHG emissions from the food system would reduce by up to 52% in 2050 following Scn100, compared to current emissions (Figure 2a) (El Wali et al., 2024). The intensive use of agricultural land decreases by 83% in 2050 following the gradual elimination of livestock commodities (Figure 2b). This is despite the need for additional arable land area to produce starch as glucose source for cell-cultured RP, where 6% of arable land in 2050 will be dedicated to produce maize starch as glucose source following Scn100 (El Wali et al., 2024). The transition to cellular agriculture increased the energy demand for the global food system by 69–83% in 2050 (Figure 2c), where 52–56% of the energy demand came from cellular agriculture food production (El Wali et al., 2024).

4. CONCLUSIONS

The global transition to cellular agriculture reduces greenhouse gas emissions and agriculture land use while increasing demand for critical materials.

5. ACKNOWLEDGEMENTS

This work was supported by the 'InterEarth RESET' project (no. 353328) funded by the Academy of Finland.

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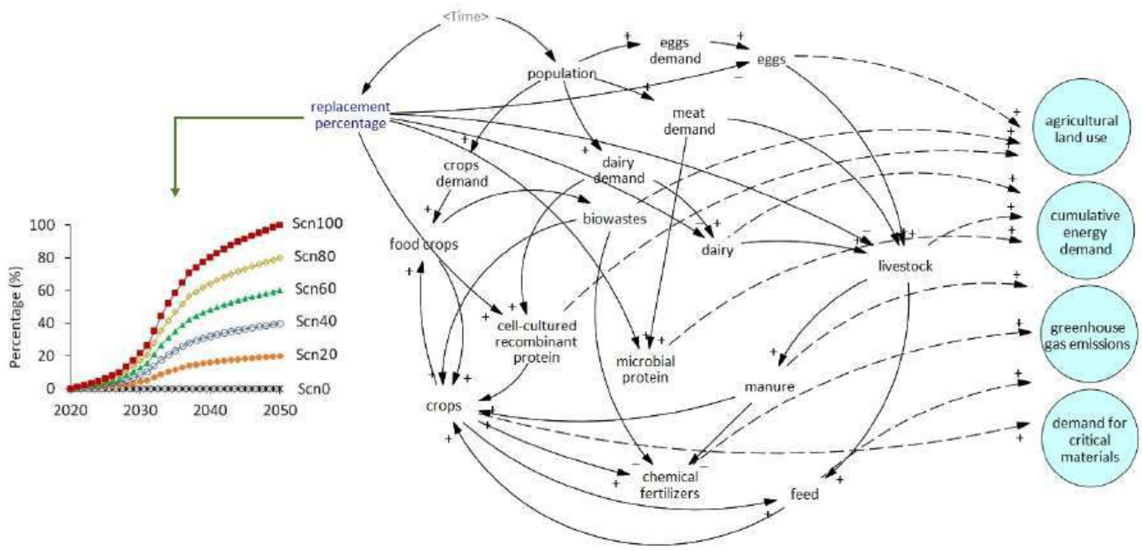

Figure 1. Conceptual framework for the environmental assessment of replacing livestock proteins with microbial and cell-cultured proteins.

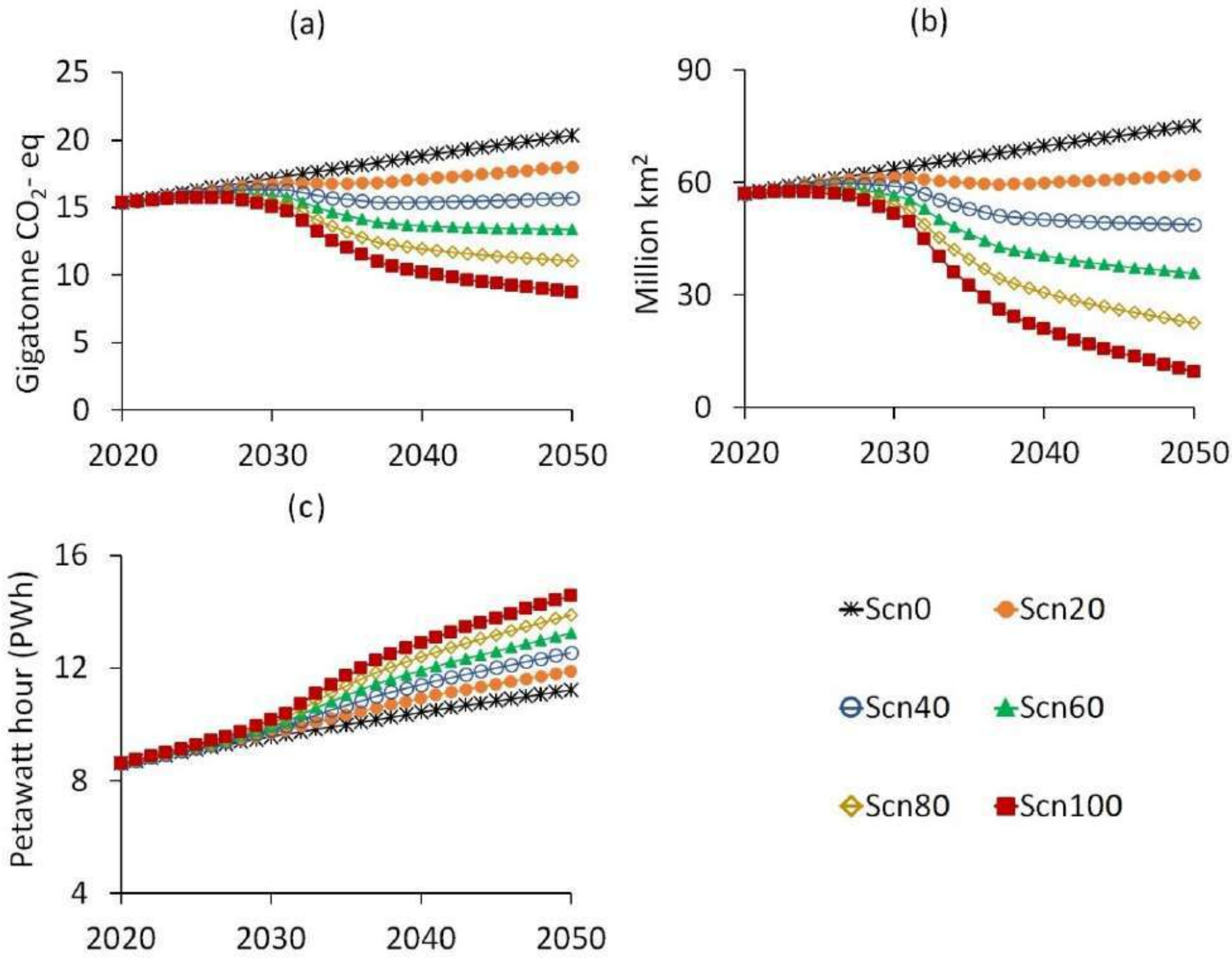

Figure 2. Environmental impact of the global transition to cellular agriculture under different replacement scenarios (Scn0 → Scn100) between 2020 and 2050 from the food system. (a) Annual greenhouse gas (GHG) emissions. (b) Agricultural land use. (c) Cumulative energy demand. Figures reproduced from El Wali et al. (2024).

Comparative Life Cycle Assessment of Innovative Plant-Based and Conventional Meat Products

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1. INTRODUCTION

Transitioning from animal-based to plant-based dietary choices is recognized as a viable approach to establishing sustainable food systems (Willett et al., 2019). Life cycle assessment (LCA) studies comparing the impacts of plant-based and animal-based products (Shanmugam et al., 2023; Rubio et al., 2020) highlight the results' dependency on case-specific scenarios including production technologies and geographical locations. This study focuses on the environmental sustainability of novel plant-based meat substitutes by employing explicit and realistic scenarios for three plant-based and three conventional animal-based meat products.

2. METHODS

This study presents a cradle-to-manufacturing gate LCA of plant and animal-based meat products (Table 1). Marketed portions of plant-based and animal meat products are typically similar and, therefore, consumed at similar masses; for that reason, mass FU was set for this study. The assumed plant-based meat recipes consider the meat extrudate analogue (the main ingredient in terms of protein content, encompassing the agricultural cultivation, fractionation, and extrusion stages), water, canola and coconut oil, wheat gluten, potato starch, and spices mix to obtain a similar macronutrient profile and texture to that of conventional animal-based meat products. The assessed systems are in the Midwest region of the US, where all of the primary feedstocks are cultivated except for yellow peas (assumed to be grown in the Manitoba province of Canada); different crop geographies were explored through a sensitivity analysis.

The LCA software SimaPro 9.5, Ecoinvent 3.9.1 and World Food LCA (WFLDB) databases, and ReCiPe 2016 midpoint (H) method were used due to accessibility, background data requirements, and its wide range of environmental impact categories, respectively. Baseline results were calculated considering mass allocation criteria, while economic allocation was explored in a sensitivity analysis.

3. RESULTS AND DISCUSSION

Plant and animal-based meat systems are examined with a high level of granularity and comparability. Plant-based meat systems show consistently lower impacts than animal-based meat systems across all categories applying both mass and economic allocation (
Figure 1).
For plant-based meat products, the extruded meat analogue is shown as a key driver for global warming impacts and other categories. The other final recipe ingredients (focus on canola and coconut oils, potato starch, and spices mix) show significant impacts on other categories such as land use and water consumption. The hotspots for the extruded meat analogues are the cultivation (upstream fertilizer use and direct field emissions) and fractionation stages (high energy use). For animal-based meat systems, the animal husbandry stage is the main contributor to all impact categories due to its feed consumption and derived emissions. Systems #4 (beef) and #5 (pork) show the highest impacts in all environmental impact categories (
Figure 1).
The sensitivity analysis for the crop geographies shows high increases in water consumption and marine eutrophication when switching to French and German peas. Water consumption and freshwater ecotoxicity increase when using soybeans from Brazil instead of the US.

4. CONCLUSIONS

Plant-based meat alternatives show consistently lower environmental impacts than animal-based meat products regardless of the allocation criteria. Plant-based meat products' impacts are focused on the meat extrudate and the complementary recipe ingredients. The main impact hotspots for the extruded meat analogues are the agricultural and fractionation stages. It is crucial to highlight that these systems are still under development and little data on industrial scale is widely available. There is still much room for optimizing the plant-based processes.

5. ACKNOWLEDGEMENTS

To The Good Food Institute, for commissioning this study, to Nathan Ayer, for facilitating the data collection from companies, and to Tess Konnovitch for her support in data visualization.

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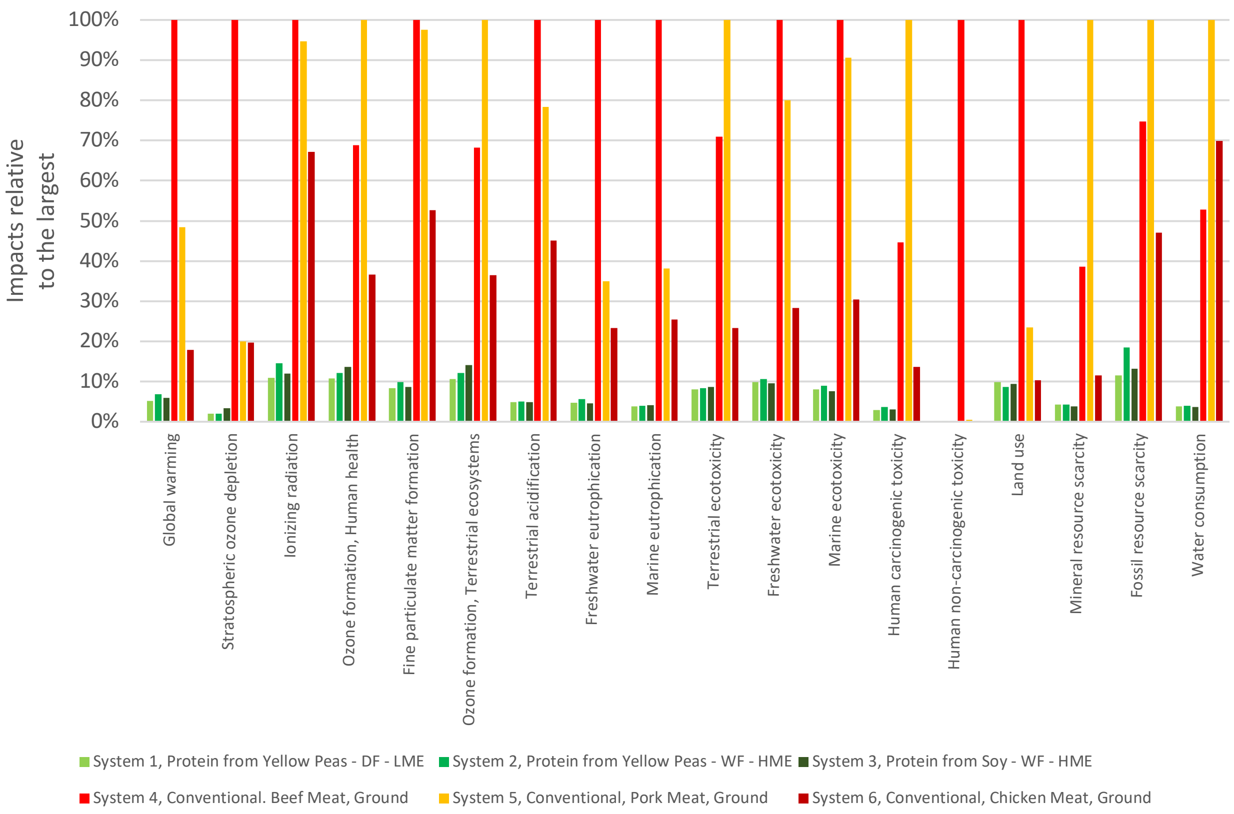
Table 1. List of assessed plant-based and animal-based meat systems.

System	Type of Meat Product	Primary Protein Source	Processing and Product Forming Methods
System #1	Plant-based	Yellow peas	Dry Fractionation (DF) and Low Moisture Extrusion (LME)
System #2	Plant-based	Yellow peas	Wet Fractionation (WF) and High Moisture Extrusion (HME)
System #3	Plant-based	Soybeans	Wet Fractionation (WF) and High Moisture Extrusion (HME)
System #4	Animal-based	Beef	Intensive feedlot and pasture
System #5	Animal-based	Pork	Industrial
System #6	Animal-based	Chicken	Industrial

Figure 1. Baseline results comparison.



Comparative assessment of alternative protein sources for meat substitution

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1. INTRODUCTION

The modern food system is characterized with high environmental impact, which is in many cases associated with increased rates of animal production and overconsumption, but also with the processing rates (Figure 1). The adoption of alternatives to meat proteins (insects, plants, mycoprotein, microalgae, cultured meat, etc.) might potentially influence the environmental impact and human health but could also trigger indirect impacts with higher consumption rates. Current study provides a condensed analysis on potential environmental impacts (greenhouse gases (GHGE), land use (LU), non-renewable energy use (NRE) and water footprint (WF)), resource consumption rates and unintended trade-offs (i.e., nutrient content decrease) associated with integration of alternative proteins in meat substitutes.

2. METHODS

The analysis was conducted using the Google Scholar database based on review of original studies published in scientific journals in English during the last decade (till 2022). Studies were selected by applying the keywords “meat” and “protein” plus “substitute”, “analog”. Such a search yielded around 3800 articles. Further inclusion of terms such as “LCA” or “life cycle assessment” or “environmental impact” or “carbon footprint” further limited the number of studies to 81, further narrowed via analysis to 64 sources, but it also included additional highly referenced studies from older periods (up to 20 years old).

3. RESULTS AND DISCUSSION

The analysis revealed that on a protein basis, animal-based proteins on average had a considerably higher GHGE than proteins incorporated in plant-based meat substitutes: farmed fish (34% higher); poultry meat (43%), pig meat (63%), farmed crustaceans (72%), beef from dairy herds (87%), and beef from beef herds (93%). However, processed plant-based meat substitutes had 1.6-7 times higher environmental impact than less processed plant protein sources (e.g., tofu, pulses, and peas) (Figure 2). For some protein sources like microalgae, the analysis showed that on a weight basis, the GHGE and NRE demand of microalgae can be much higher than those of beef and other plant raw materials, while LU and WF do not demonstrate similar outcomes. When used as meat substitute ingredients, cultured meat and insects also tend to have greater environmental impacts.

The incorporation of raw materials into ready-to-consume products shifted the relative impacts of meat substitutes. Plant-based extrudates (intermediate products) had low GHGE: 7.7-7.9 kg CO_2eq. kg^{-1} having impact in lower range compared to chicken meat protein 7.7-11.3 kg CO_2eq. kg^{-1}. Plant-based meat substitutes at the same time were significantly lower in GHG footprint (2-22.35 kg CO_2eq. kg^{-1} protein) than hypothetical cultured meat (average 56 kg CO_2eq kg^{-1} protein), however cultured meat had a potential to have lower impact than beef and farmed crustaceans. Accounting for the land use change impact could increase the impact of chicken meat to 26.7-46.7 kg CO_2eq for 1 kg of proteins. Similarly, a few-fold improvement potential was observed in several categories (terrestrial eutrophication, acidification, photochemical oxidant formation, particulate matter, ozone depletion) for plant fiber products compared to chicken meat.

4. CONCLUSIONS

Multiple food system analyses currently available do not provide a reliable model for higher-level system modelling. Some studies successfully reflect on indirect environmental, economic, and social factors, as well as resource and environmental impact trade-offs. A further model, based on interaction between the actors of a complex food system and able to define the second and third order impacts (e.g., rebound effects), would be required to predict the influence and role of meat substitutes in future diets and potential shifts with the inclusion of other protein alternatives.

5. ACKNOWLEDGEMENTS

The study has received funding from the European Union's HORIZON EUROPE research and innovation programme under grant agreement No 101059632 (project GiantLeaps). It is also partially funded by the German Federal Ministry of Education and Research (BMBF), grant numbers 031B0934 and Era-Net Cofund FOSC-ERA Program (Project Climaqua 2821ERA12).

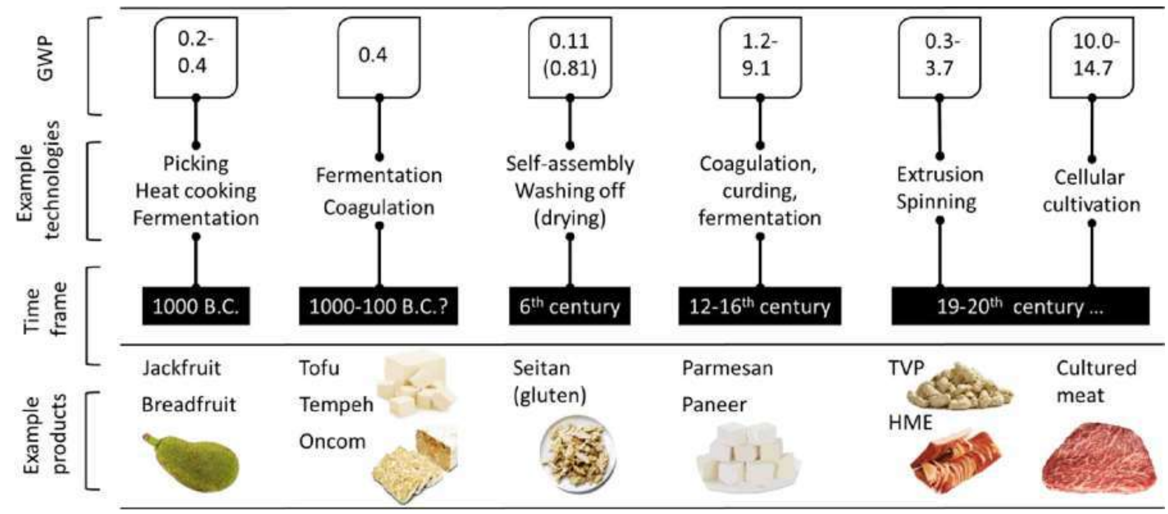

Figure 1. Historical development of meat substitutes and their global warming potential (GWP in kg CO_2eq per 1 kg of product); TVP – texturized vegetable protein; HME – high moisture extrusion (Source: https://doi.org/10.1016/j.resconrec.2022.106831)

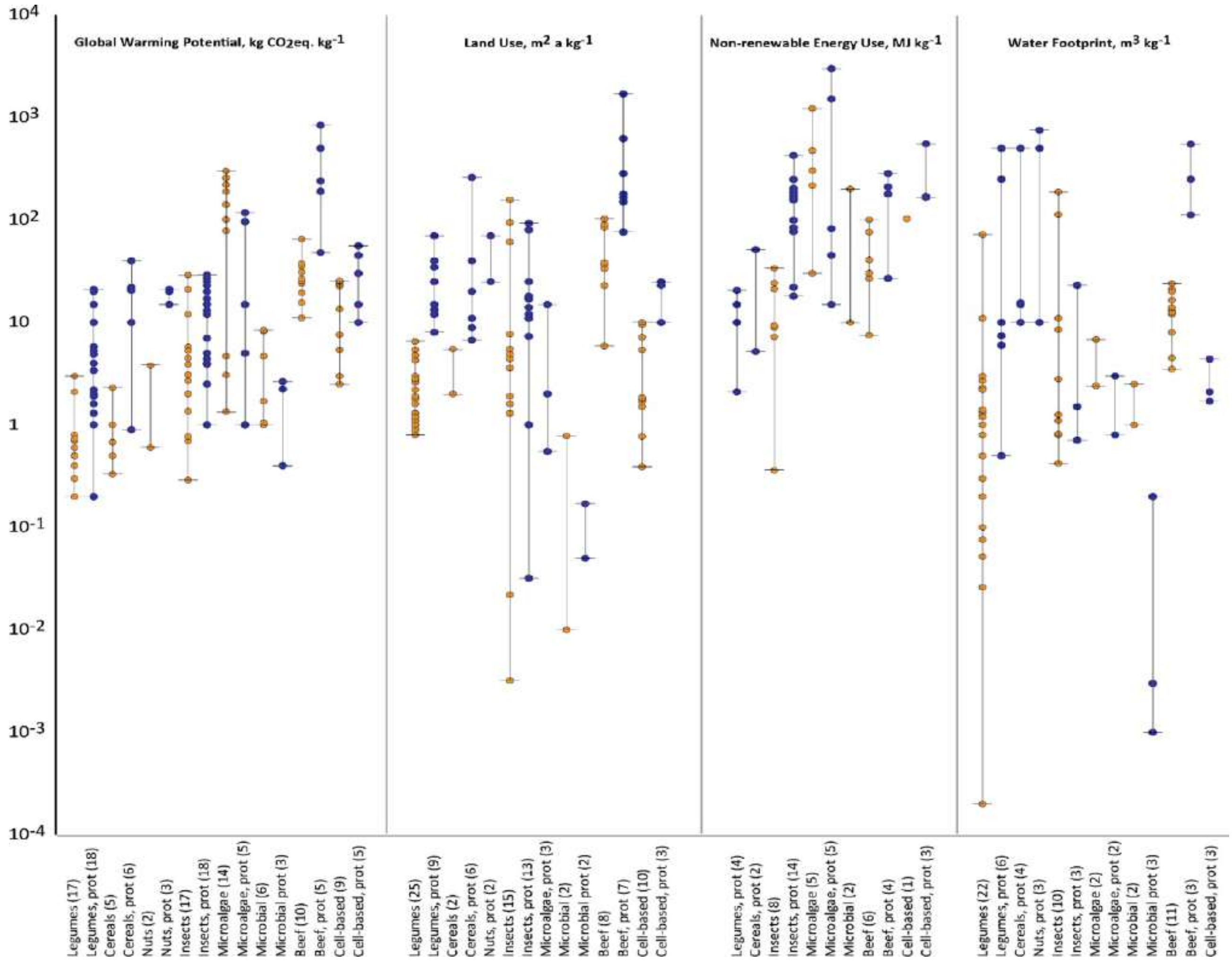

Figure 2. Environmental impact (Global Warming Potential and Water Footprint) and resource demand (Land Use and Non-renewable Energy Use) of raw materials (ingredients) used as matrices of meat substitutes; light dots – impact per kg of product in dry matter; dark dots – impact per kg of proteins; number in the brackets corresponds to the number of data points (Source: https://doi.org/10.1016/j.resconrec.2022.106831)

Sustainable territories and economies

LCA of territorial food supply scenarios: a spatialized and prospective approach

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1. INTRODUCTION

Food is increasingly a central focus of local policies. In order to meet growing environmental challenges, and societal demand for more sustainable food products, prospective scenarios to feed territories are elaborated based on profound changes in upstream (e.g. development of organic farming) and downstream (e.g. short supply chains) practices. Quantitative assessment tools are however needed to evaluate their environmental impacts in a comprehensive and contextualized approach. The objective of this study is therefore to propose methodological developments to apply LCA to contrasted prospective territorial food supply scenarios, taking into account both Life Cycle Inventory (LCI) spatial variability and Life Cycle Impact Assessment regionalisation. A southern French city is used as a proof of concept.

2. METHODS

As a starting point, forty representative products of the French food consumption were selected to model food supply, from agricultural field to delivery to point of sale. The products chosen are those that are consumed the most and have the greatest environmental impact (Notarnicola *et al.*, 2017). The product LCI are based on Agribalyse data and are then adapted by parameterising six food supply chain components, to improve spatial and temporal accuracy. The parameters are i) the nature and quantities of the food products consumed due to different diets within the population, ii) the origins and amounts of agricultural and food product imports, iii) agricultural practices, iv) mineral fertilizer origin mixes, v) transport distances and modes, and vi) composition of the energy mixes (electricity and gas) all along the supply chains. Finally, all elementary flows related to LCI data are mapped to impact assessment spatial units to compute regionalised environmental impacts in both the foreground and background systems according to the approach of Mutel and Hellweg, (2023). The Impact World + method (Bulle *et al.*, 2019) is then used to quantify regionalised midpoint indicators for water scarcity, land occupation & transformation, eutrophication and acidification. All these methodological developments are integrated into a Python environment, allowing for reproducibility. They are then implemented on two contrasted prospective territorial food supply scenarios in 2050. The scenarios are i) “Business as Usual” and ii) “Frugal generation”, whose main characteristics are described in Table 1, based on Barbier *et al.*, (2022).

3. RESULTS AND DISCUSSION

Results for impacts on Ecosystem Quality, Human Health and Mineral and Fossil resources (see Figure 1) show that the prospective scenario "Frugal Generation" scenario diminishes the impacts. It is mainly due to the reduction in the quantities of meat consumed, as well as the change in agricultural practices, compared with the “Business as Usual” scenario.

Furthermore, the comparison of impacts between site-generic and regionalised midpoint indicators reports differences up to 60% (see Figure 2) and can accentuate the differences between the scenarios.

4. CONCLUSION

The methodology developed in this study allows parameterising key components of food supply chains (energy, transport, agricultural practices …) and thus to design regionalised prospective scenarios. The results highlight the interest of improving spatial representativeness of both the inventory and the impact assessment for assessing territorial food supply chain environmental impact. Assessing multiple scenarios will make it possible to identify the main drivers to decrease the environmental impacts of territorial food systems including the proportion of organic production, the proportion of local consumption or the switch to a vegetarian diet, and thus to formulate practical recommendations to local stakeholders.

5. ACKNOWLEDGMENT

Work supported by the French National Research Agency (ANR grant ANR-20-CE03-0006).

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Table 1 : Main parameters of two prospective scenarios for France in 2050

Parameter	S0 : Business as usual	S1 : Frugal generation
Share of organic agriculture	30%	100%
Share of renewable gas	19%	88%
Share of wind+solar electricity	8.4%	81.5%
Foreign food importation level (vs today)	+ 0%	-60% to -90%
Share of vegetarian diet in population	4%	29%

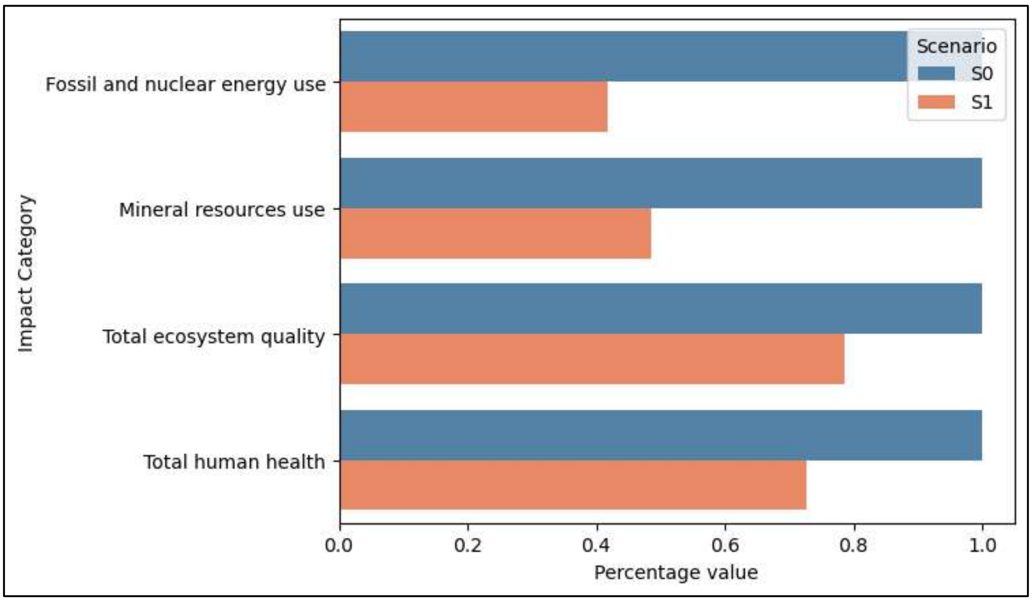

Figure 1: Comparison of the impacts on Ecosystem Quality, Human Health and Mineral and Fossil resources for the scenario "Business as Usual" (S0) and "Frugal Generation" (S1).

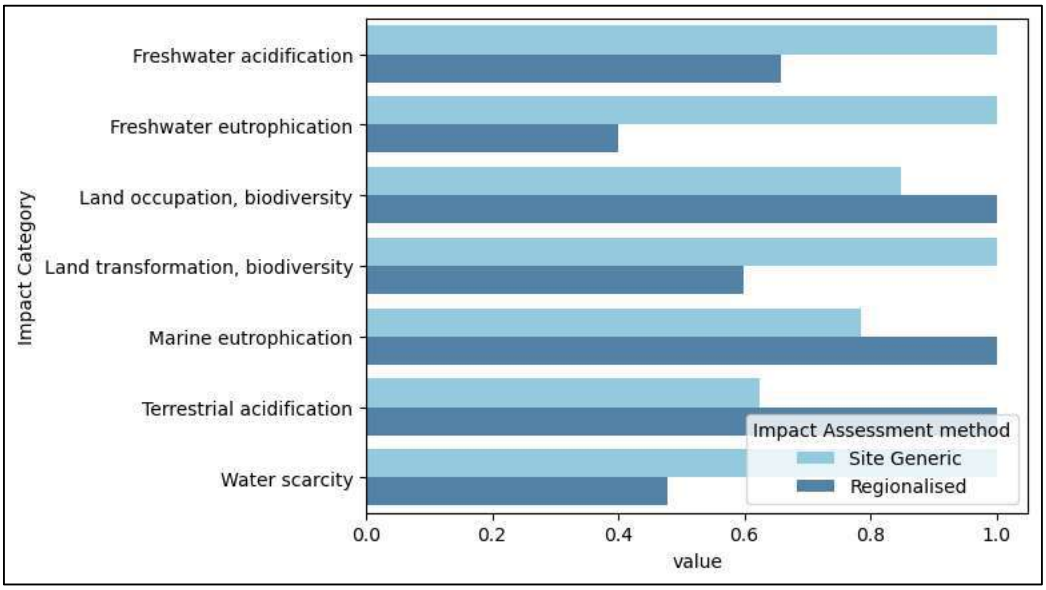

Figure 2: Comparison of the Site Generic and Regionalised midpoint impacts for the scenario "Business as Usual" (S0).

Advancing the sustainability transformation of agriculture under the European Green Deal: An Agent-Based LCA for policymaking support

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1. INTRODUCTION

The sustainability transformation of agriculture is a cornerstone of the European Green Deal (EGD) that encompasses ambitious goals to address numerous and diverse environmental concerns. In sum, agriculture is expected to contribute positively to climate change mitigation and nature preservation while meeting growing societal needs for food, energy, and biomaterials.

Arguably, a need arises for policymaking concerned with the transformation of agriculture to realise synergies and minimise trade-offs among its different components [1].

Delivering comprehensive policy action efficiently requires decision-support tools that can assess the outcomes of interventions across multiple goals. Here, we evaluate the regional implementation of cross-cutting policy instruments by means of Agent-Based (Territorial) Life Cycle Assessment (AB-LCA) of agricultural regions. The following research question guides our study:

- How will the changes in regional structure and production associated to the removal of the VCS influence the transformation of agriculture towards the EGD objectives?

2. METHODS

Our approach allows us to evaluate a policy intervention across the environmental goals of the EGD while considering the role of regional structural dynamics. First, we develop AgriPoliS, an agent-based model of farmers´ decisions, to simulate regional farm structure and agricultural production in the presence and in the absence of a policy intervention, here the removal of the CAP´s Voluntary Coupled Support to livestock (VCS). Then, we use the agent-based simulations as input for a comparative environmental analysis with LCA methods [2]. Lastly, we identify the links between the economic and environmental output of our AB-LCA modelling and a synthesis of the EGD objectives for agriculture (Table 1).

Our analysis considers the Swedish county of Jönköping, a farming region characterised by high livestock density and less productive arable land with high presence of grass (Fig. 1). Our development of AgriPoliS in this work improves the model´s representation of livestock trends.

3. RESULTS AND DISCUSSION

3.1 Structural change and transfer of environmental impacts

Our agent-based simulation results show similar land abandonment and afforestation trends in NO-VCS and BAU, meaning that the removal of the payment does not substantially affect the structural development of the region. Significant food production is lost over time in both simulations, and livestock activities increase at the expense of arable crops.

The loss of agricultural production in JKP leads to a substantial transfer of environmental impacts elsewhere to keep provision levels stable, although overall environmental impacts, including GHG emissions, remain similar (Fig. 2). While this trend is somewhat exacerbated by the removal of the VCS, most of the impact transfer occurs also in BAU.

3.2 Misalignment with biodiversity objectives in the EGD

The reduction in arable land leads to substantial reductions in regional ecotoxicity impacts from pesticide application and N run-off that can have a positive effect on biodiversity. However, the subsequent loss of landscape openness from land abandonment is highly detrimental to a large share of local species that are adapted to mixed-forestry landscapes. In addition, the transfer of environmental impacts can threaten regions with high biodiversity value [3].

4. CONCLUSIONS

As the region faces similar development in BAU and NO-VCS, our results show that the VCS does not substantially contribute to solve regional land abandonment. Removing the payment could unlock the economic resources to target the issue with more efficient policymaking. The benefits of doing so comprise enhancing biodiversity in JKP and preventing the transfer of environmental impacts outside of the region, which are both important aspects under the EGD.

The continuation of this work will include an evaluation of Götalands Södra Slättbygder (GSS), an intensive farming region with contrasting characteristics from JKP.

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#	Policy initiative	Goal	Indicator	Scope	Metric
1	Green Deal	Emission reductions	Overall GHG performance	Global	CO2 eq.
2	Green Deal	Avoid environmental burden shifts	Overall environmental performance	Global	DALY, PDF
3	F2F strategy	Sustainable production	Environmental cost-effective production	In-region	SEK/DALY, SEK/PDF
4	F2F strategy	Sustainable production	N off-field emissions	In-region	kg N
5	F2F strategy	Sustainable production	Environmental impact of pesticides	In-region	CTU
6	RED & Bioeconomy	De-carbonise energy and materials	Additional biomass for energy	In-region	MJ of biomass
7	Soil strategy	Soil Health	SOC levels in agricultural land	In-region	C%
8	Biodiversity strategy	Nature preservation	Abandoned semi-natural pastures	In-region	ha
9	Biodiversity strategy	Nature preservation	Abandoned farm land	In-region	ha

Table 1 – Overview of indicators linking environmental EGD goals for agriculture with our AB-LCA modelling

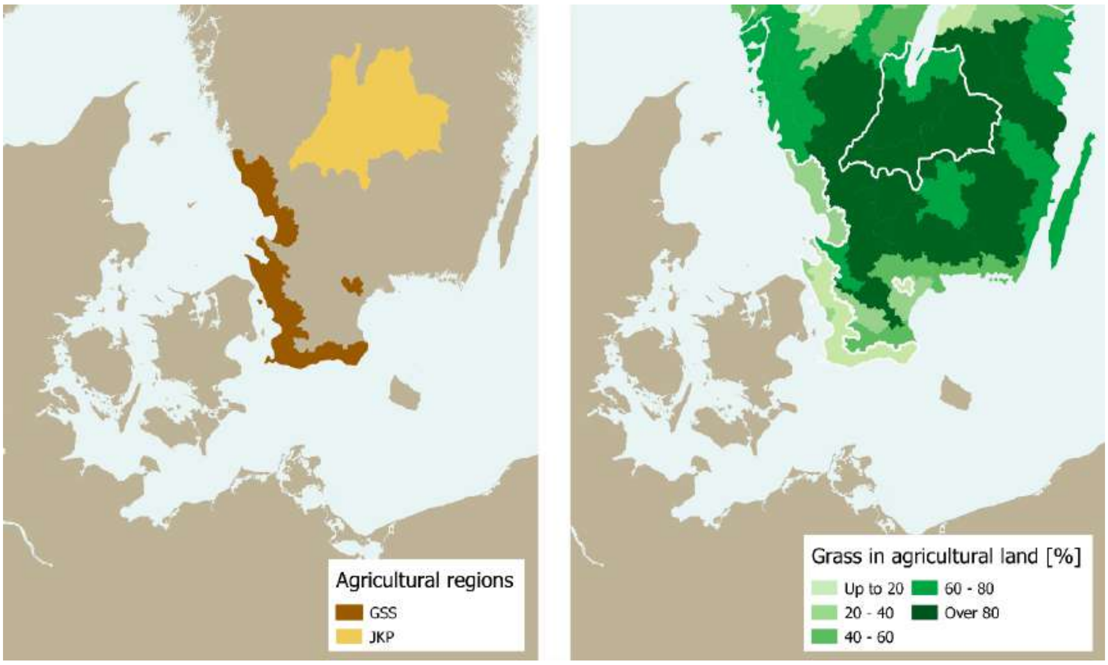

Figure 1 – The agricultural regions of GSS and JKP in southern Sweden (left). Grass coverage of total agricultural land in the yield regions of southern Sweden (right), which is a proxy for farming intensity (the more grass, the less intensive)

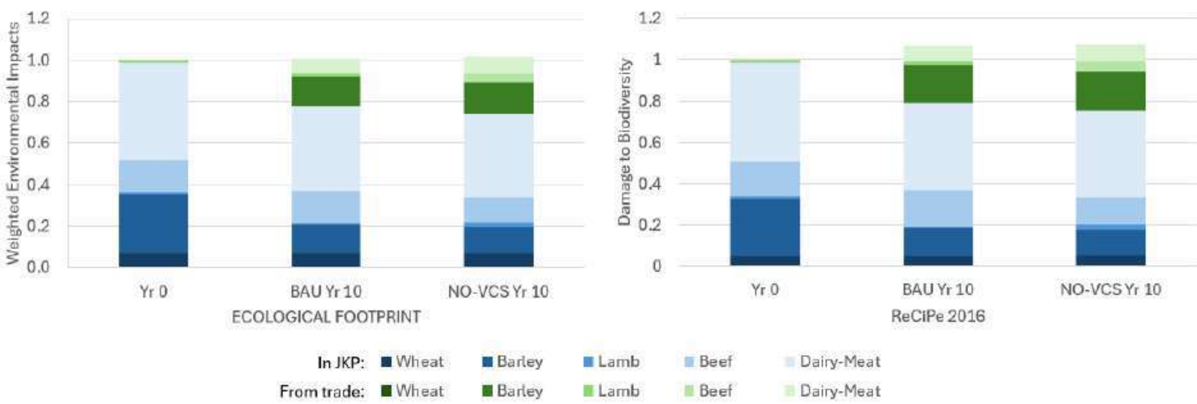

Figure 2 – Damage results for JKP under current situation (Yr 0) and simulated scenarios after 10 years with (BAU) and without VCS payment (NO-VCS) following Ecological Footprint and ReCiPe impact assessment methods.

Comparative assessment of the land footprint and regulating ecosystem services embodied in the EU-27 consumption of vegetable oils: an environmental trade-off analysis among substitutes goods

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1. INTRODUCTION

Global agricultural land-use change (LUC) is one of the main drivers of exceeding Planetary Boundaries[1]. Despite contributing to global food security, trade of agricultural products displaces environmental impacts, spatially decoupled from consumption choices at local level[2]. The European Union (EU) leads trade and consumption of so-called forest risk commodities (FRCs)[2]. Among them, soybeans and oil palm fruits are key. By imposing due diligence for operators placing palm and soy oil within the EU market, the EU Regulation on deforestation-free products (EUDR) could cause consumption trade-offs among the main vegetable oils and associated impacts. This study estimates, through different methods, environmental trade-offs linked to the EU consumption of palm, soybean, rapeseed, and sunflower oil.

2. METHODS

We assessed the EU trade networks of the four targeted vegetable oils, their relative primary products, and oil cakes between 2000 and 2020, by computing networks' centrality measures[3]. Through a physical model[4] (PM) we quantified the land footprint (LF) of the EU consumption of the targeted commodities. Finally, we performed an environmental trade-off analysis between oil yield and three ecological conservation targets (i.e., biodiversity - B, carbon - C, and water – W) impacted by primary production in the EU suppliers. Data to perform the PM were retrieved from Faostat[5]. For the spatial analysis, B, C, and W regulation maps[6] were overlayed with the country's crops agricultural areas[7]. A mean conservation score covering the three ecological conservation targets (BCW) was estimated for agricultural terrestrial units (TUs) supplying the EU.

3. RESULTS AND DISCUSSION

Our results identify the main trade corridors, their weight, and specific function in linking primary production of targeted vegetable oils to EU consumption. According to our PM, the EU consumed 6.7 Million ha (Mha)/year of soybean (i.e., 15.1% of the global LF), 4.3 Mha/year of rapeseed (16.5%), 4.0 Mha/year of sunflower (22.6%), and 1.2 Mha/year of oil palm plantations (6.2%). The leading suppliers varied among products and consumption countries (Table 1). The BCW associated with TUs producing oil palm fruits was considerably higher than the alternatives (Table 2). Figure 1 shows the negative correlation between the oils LF and the BCW by country and product: on average, countries with a lower LF displaces more ecological impacts.

4. CONCLUSIONS

Our analysis shows different trade and consumption patterns associated with key vegetable oils and highlights the different responsibilities in terms of land use displacement by the EU-27. By linking the consumption of alternative products to specific environmental impacts located within and outside the EU, our research can bridge different EU policies: those aimed to protect and restore domestic biodiversity - e.g., the EU Nature Restoration Law and those aimed at halting environmental degradation embodied in global trade (e.g., EUDR). Indeed, fostering these policies' connection could avoid controversial outcomes (e.g., the increase of ecological indices in the EU and a corresponding decrease globally).

5. ACKNOWLEDGEMENTS

This research was carried out thanks to the Collaborative Doctoral Partnership between the European Commission and the University of Padova.

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Table 1: Land use displacement (%) by primary product of the top five EU27 cosnuming countries and the rest of the EU27 (ROEU27) within producing countries sourcing at least 1% of their apparent

Soybeans	Producing countries (%)															
Top five EU27 + ROEU27	BRA	ARG	USA	PRY	UKR	IND	ITA	CAN	RUS	URY	FRA	BOL				
1. FRA	65.8	15.0	4.9	3.0		5.4		1.0	1.0		1.4					
2. SPA	33.1	48.3	10.9	4.7												
4. ITA	21.8	52.4	5.1	7.9	2.4		6.3	1.1								
3. DEU	54.2	16.3	16.6	5.1		1.0		2.2		1.9						
5. POL	20.5	50.2	7.9	8.6	7.5				2.1			1.0				
6. ROEU27	47.2	30.5	10.4	4.2		1.1		1.6								
Rapeseed	Producing countries (%)															
Top five EU27 + ROEU27	FRA	POL	DEU	AUS	UKR	CAN	ROM	RUS	CZE	HUN	UK	BGR	LTU	SVK		
1. DEU	12.9	6.8	33.8	10.8	6.5	4.5	3.3	1.2	5.2	4.0	2.4	1.2	1.6			
2. FRA	54.7		5.1	9.8	8.7	8.9	2.6	1.5			2.3	1.5				
3. POL		74.9	1.5		8.8		1.4		4.3	1.8				2.1		
4. BEL	21.2	1.6	10.1	26.3	13.4	3.9	6.8	1.2		1.6	3.6	3.3	2.0			
5. NED	14.3	3.3	24.2	17.6	11.5	3.4	5.8	2.2	2.2	2.4	3.4	2.0	1.9			
6. ROEU27	9.4	7.5	9.9	5.6	7.4	6.0	3.7	11.8	5.0	5.4	2.6	1.7	3.1			
Sunflower seed	Producing countries (%)															
Top five EU27 + ROEU27	UKR	ROM	FRA	SPA	HUN	ARG	RUS	BGR	MDA	ITA	SVK	USA	SRB	CHN	CZE	AUT
1. SPA	23.5	4.5	7.0	47.5		3.6	5.7	2.8	1.4			1.2				
2. ITA	34.5	6.8	1.7		8.4	3.4	19.3	2.4	4.4	14.9			1.1			
3. FRA	28.6	7.1	34.4	3.3	2.4	12.4	3.9	3.9								
4. ROM	1.7	77.4			5.7			4.6	9.1							
5. DEU	18.2	8.2	9.7	1.8	24.5	11.3	6.6	6.1	1.2		3.3	2.0		1.4	1.3	1.1
6. ROEU27	28.8	10.3	7.9	3.1	11.2	13.6	7.7	6.8	1.8		2.2	1.0	1.9			
Oil palm fruit	Producing countries (%)															
Top five EU27 + ROEU27	IDN	MYS	PNG	GTM	HND	COL	ECU	THA	CIV	BRA	GHA					
1. ITA	64.2	23.5	5.7	1.7	2.9	1.1		1.4								
2. SPA	61.6	14.2	7.6	4.3		4.3	1.2		1.6							
3. DEU	44.6	26.7	9.7	3.7	4.5	3.7	1.2	1.7	1.5	1.0						
4. BEL	37.3	37.1	9.2	4.1	4.3	3.3					1.0					
5. FRA	48.1	33.0	4.9	3.1	3.5	2.4										
6. ROEU27	37.9	38.7	6.5	4.5	4.7	3.4	1.1									

Countries' names follow Alpha-3 codes ISO 3166-1

Table 2: Mean environmental conservation score - i.e., a value ranging between 1 (max) and 100 (min) - by primary crop considering: 100% global TUs producing the crop, only those with intensive coverage (High intensity, HI), and lower coverage (Low intensity LI).

Conservation target	Oil palm fruits	Soybeans	Rapeseed	Sunflower seed	Mean
BCW	**28.90** (100%) 32.30 (HI) 27.74 (LI)	**45.60** (100%) 51.49 (HI) 43.64 (LI)	**39.71** (100%) 45.75 (HI) 37.70 (LI)	**45.70** (100%) 51.55 (HI) 43.75 (LI)	**39,98 (100%)** 45,27 (HI) 38,21(LI)

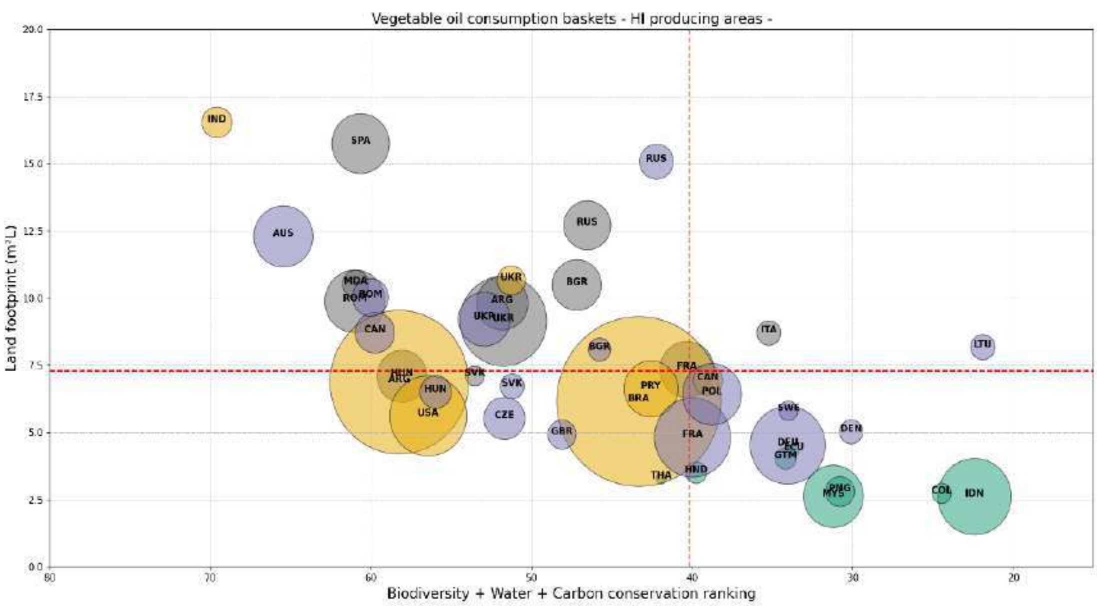

Figure 1: Trade-offs between oil yield (m^2/l) – y axes - and mean BCW conservation ranking ((x-axis) dimensionless) for the HI distribution. The BCW ranking is flipped, with the low values on the right (high conservation priority) and the high values on the left (low conservation priority). The size of the bubbles is the mean annual proportion of EU LF by producing country and primary product (green = oil palm fruits, yellow = soybeans, grey = sunflower seed, violet = rapeseed). The dashed horizontal and vertical lines represent the mean LF across countries and products (y = 7.3 m^2/l), and the mean BCW conservation ranking across countries and products (x = 40.2).

Mapping Deforestation Embodied in EU Bio-based Imports

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1. INTRODUCTION

Forests play a crucial role in mitigating climate change and supporting biodiversity by acting as vital carbon sinks and habitats for countless species. However, deforestation and forest degradation, primarily driven by agriculture and agroforestry expansion, threaten these essential functions. The European Union (EU) Regulation on Deforestation-free Supply Chains (EUDR) aims to curb global deforestation and forest degradation, thereby reducing greenhouse gas emissions and biodiversity loss. By requiring that selected bio-based products imported into the EU market be sourced from deforestation-free land since 31 December 2020 (the cut-off date), the EUDR seeks to address the environmental impacts of trade for products related with cattle, timber, cocoa, soy, palm oil, coffee, and rubber. Our study (1) assesses the EU's land footprint of those imported bio-based products, (2) quantifies the embodied deforestation and associated forest biomass loss of EU imports, and (3) discusses the implications of the EUDR for deforestation responsibility linked to trade networks. We use agricultural statistics and trade flow data, alongside remote sensing products on deforestation, as inputs for a physically based land footprint model and a land use balance model. Our findings highlight substantial contributions to deforestation-related impacts, particularly attributed to imports of soy, cattle, and palm oil, emphasizing the pressing need for sustainable practices within global supply chains. Furthermore, it is imperative to recognize the distinct roles of each country, as their varying shares of responsibility in embodied deforestation through trade differ significantly. This underscores the necessity for collective efforts, with the EU setting the stage as others must actively engage to address this global challenge effectively.

2. METHODS

2.1 EU's Land Footprint of imported bio-based products

The calculation of the land embedded in imported bio-based products is based on the Land Footprint model developed within the JRC (De Laurentiis et al 2022 and Cuypers et al. 2013) and is refined for the seven commodities considered in the EUDR. The model allows for the conversion of a quantity of processed product into an equivalent quantity of its primary product (PCE) that would be used to produce the processed product. The PCE is then converted into cropland and grassland. A reallocation method (based on Kastner et al 2011) was implemented to account for re-exports and it is based on the production and bilateral shares of the traded equivalent quantities. This allows reallocating import quantities to the original country of production of a commodity. Input data and the methodology are shown in Figure 1.

2.2 Embodied deforestation and biomass impact of EU imports

The attribution of deforestation to agricultural production and trade is based on a modified version of the Land Use Balance Model developed by Pendrill et al., (2019a,b). The model relies on the land footprint (from 2.1), on FAO (Food and Agriculture Organization) statistics on production, trade, and land use change, and on remote sensing deforestation products and biomass maps. The modelling approach attributes forest loss in a country proportionally to the expansion of cropland, pasture, and forest plantations, capped at the total estimated forest loss (Bourgoin et al, 2023, Global Forest Watch, 2014) in the region. We consider a time lag of five years between deforestation and the establishment of crop fields. By using the European Space Agency Climate Change Initiative biomass maps (Santoro et al, 2021) we then calculate the biomass associated to the deforested areas and calculate the forest biomass losses embodied in trade.

3. RESULTS AND DISCUSSION

The EU plays a significant role in the import of coffee and cocoa beans, palm oil, and soybean cake. The share of the EU land footprint relative to the sum of those products is higher for soy-based products (40%), followed by cocoa (35%), palm oil fruit (11%) and coffee-based products (10%). On average, the highest amount of cropland from the EU imported soy-based products is from Brazil (Fig. 2a), but the share of the associated responsibility for the EU is less than 15%, whereas China accounts for more than 50% of it (Fig. 2b). The embodied land of equivalent quantities imported of EUDR bio-based products is unequally distributed, thus calling for the necessity of collective efforts across worldwide countries (Fig. 2b). Our evaluation reveals that the EU imports of the EUDR commodities impact mostly in South America (through the soybean and cattle supply chain), central western Africa (through the cocoa supply chain), and Southeast Asia (where palm oil is produced) (Fig. 2c).

4. CONCLUSIONS

Our study quantifies significantly deforestation footprint embedded within the EU's imports of bio-based products listed in the EUDR, while also stresses the potential disproportionate contribution to deforestation burdens. This research demonstrates the critical role of regulations like the EUDR in driving systemic transformations towards sustainable supply chains and mitigating deforestation. Further work is needed on the social and economic implications of EUDR to producer countries.

5. ACKNOWLEDGEMENTS

This work is partially funded by Directorate-General for Environment (DG ENV F.3) under AA JRC N 35920 NFP.

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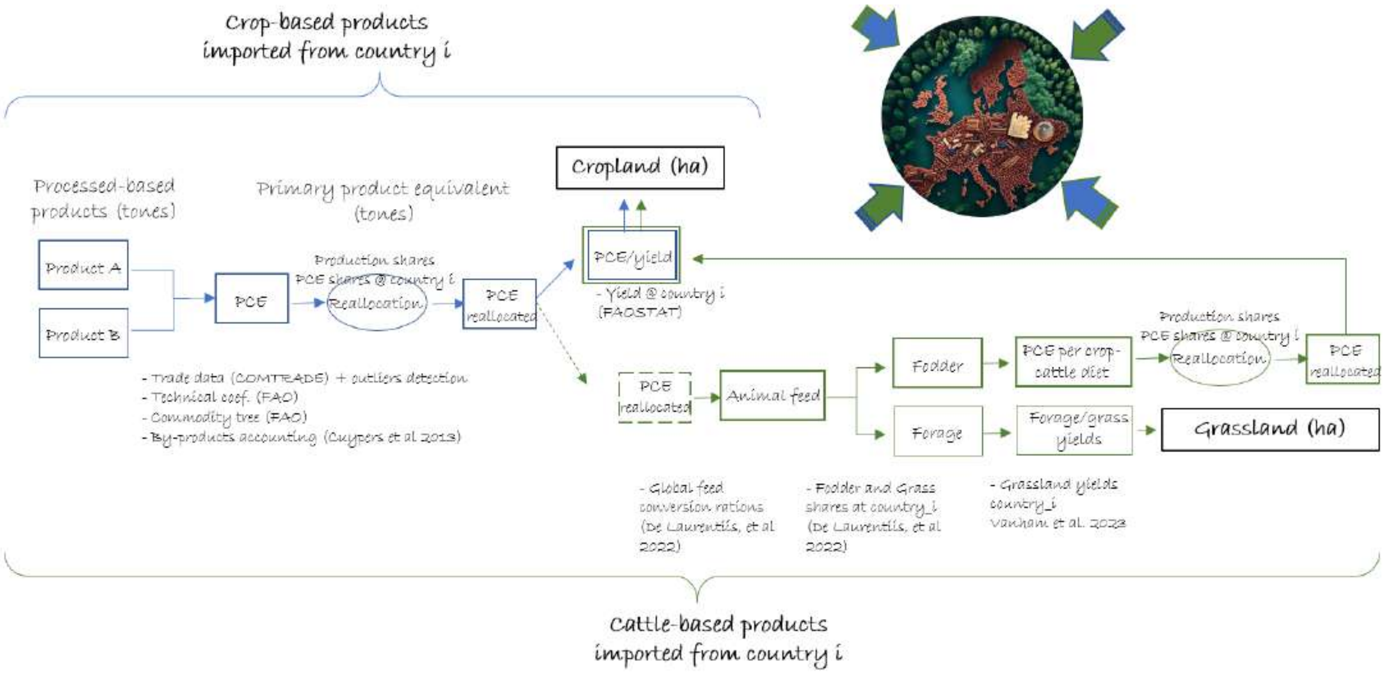

Figure 1 – Methodology for calculating the land footprint of imported processed crops and cattle products, i.e. cropland and grassland (based on De Laurentiis, et al 2022).

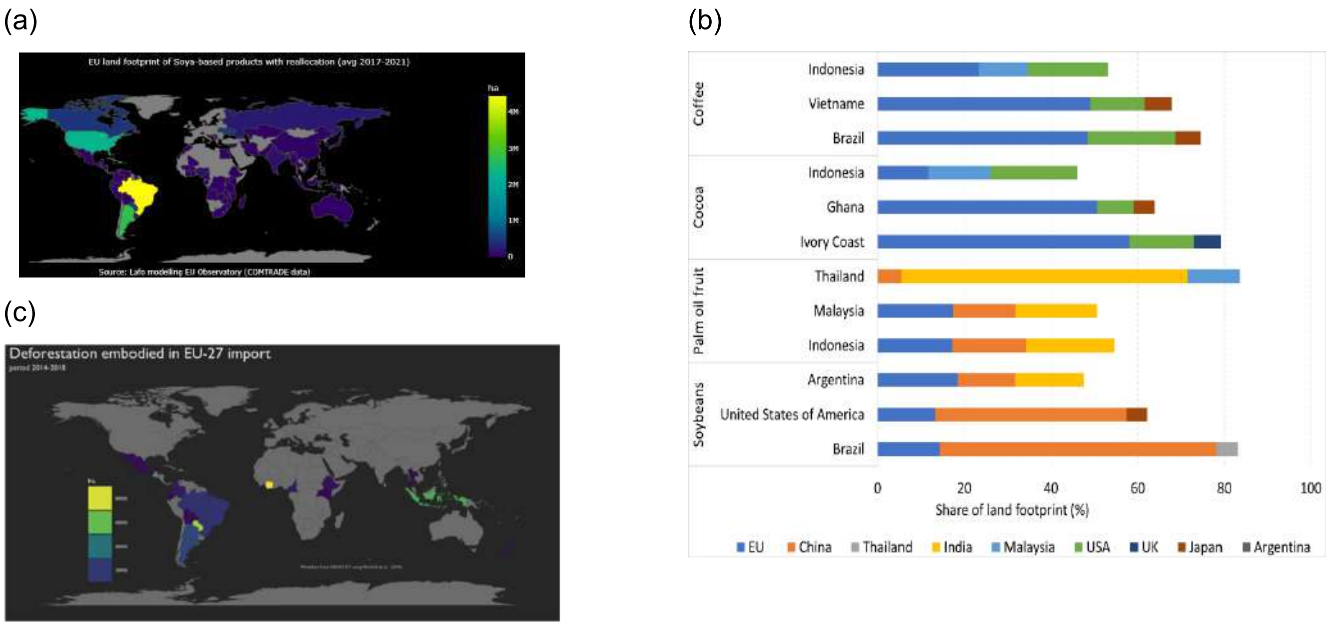

Figure 2 – (a) EU land footprint (Mha) per crop-based commodity averaged 2017-2021; (b) Schematic view of the unequal shares of embodied land of the imported EUDR crop-based products across producers. Data is shown for the three top world producers of each primary crop. (c) Deforestation embodied (expressed in hectares per year) in the EU-27 imports of cocoa, coffee, cattle, palm oil and soybeans products.

Carbon and Biodiversity Footprints of the Swiss food consumption

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1. INTRODUCTION

Over recent decades, global levels of food production have experienced unprecedented growth rates. This progress has come at high environmental costs. Soil degradation, water scarcity, and loss of biodiversity endanger the flossuture fertility of our planet (United Nations, 2019).
The Swiss biodiversity footprint has risen at a rate of 8% between 2000 and 2018. 70% of it is due to imported goods. A total reduction of 74% is needed to be within the planetary boundaries[1]. At present, there is no study at product level, analysing land use related biodiversity loss of food consumed in Switzerland.

2. METHODS

The "ShopHero" project follows a novel, scalable and tailored approach for consumers to track and monitor the sustainability of their groceries and food waste, and therefore, to change their behaviour. With the introduction of the General Data Protection Regulation (GDPR), European customers have the right to access their loyalty card data, which can be used as a data source for research. The biodiversity loss and global warming potential of 45 raw food products were modelled. The origin of the imported products was identified with trade data from import and export statistics. Specific land use biodiversity impacts were added, using country-level characterisation factors by Chaudhary & Brooks (2018)[2], indicating potential damaged fraction of global species loss (PDF) from land use. The global warming potential was calculated according to IPCC 2021[3], using the Agribalyse and Ecoinvent databases and own calculations.

3. RESULTS AND DISCUSSION

Out of all 45 modelled food products, cocoa, olive oil, coffee and pepper have the highest biodiversity loss per kg. In terms of quantity consumed in Switzerland, the biodiversity footprint is dominated by 3 products: cocoa, coffee and animal products account for 72% of the total biodiversity footprint (see Figure 1).

A reduction in consumption of cocoa, coffee, and meat by 50% each could reduce biodiversity loss by 32%. Even though basic food such as potatoes or cereals are consumed in greater quantities, their relative impact to biodiversity loss is smaller than 1%.

Country-specific differences are striking: Due to the large differences between the country-specific characterisation factors, the origin of the products has a decisive influence on biodiversity loss. One option to reduce the biodiversity footprint is to source products from countries and ecoregions with low or lower biodiversity impact. There is need for further development of biodiversity characterization factors that better reflect differences between monoculture and agroforestry production systems that both are particularly important for imported products such as cocoa and coffee. A comparison of the global warming potential and the biodiversity impact shows no direct correlation (see Figure 2).

4. CONCLUSIONS

The study shows that with small adjustments in the origin and type of purchased food, substantial reductions in both, the biodiversity and carbon footprint of individual food baskets can be achieved. A renunciation, consumption reduction or change of origin of just cocoa and coffee, which are luxury products with only small nutritional benefit, can reduce the total biodiversity impact significantly. To reach the biggest impact, the focus should be on reducing products with both, a high global warming potential and biodiversity loss (e.g. beef, pork, coffee), marked in the orange box of Figure 2. Products with both low greenhouse gas emissions and low PDF should be favoured (e.g. beans, peas, corn). Communication measurements on a general as well as a specific level could incentivise consumers to adjust their shopping behaviour to a more sustainable nutrition.

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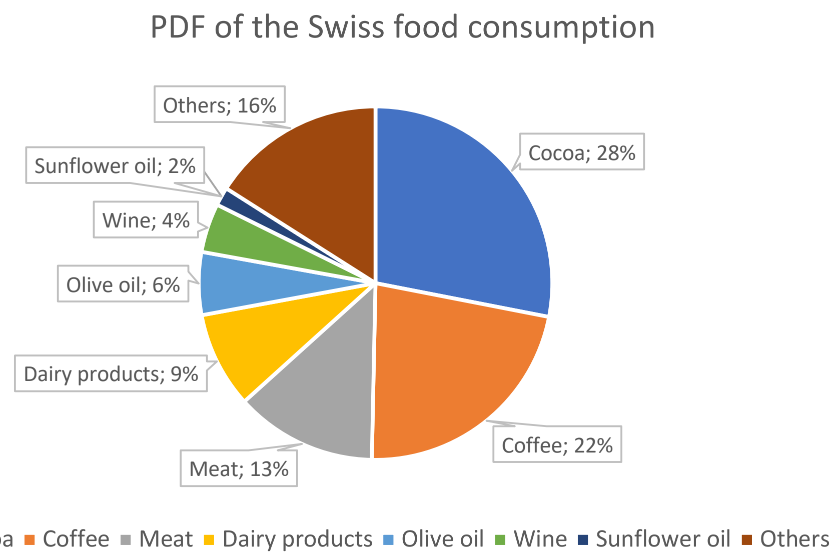

Figure 1 Consumption based potential disappeared fraction of global species (PDF), calculated with characterization factors from Chaudhary & Brooks (2018).

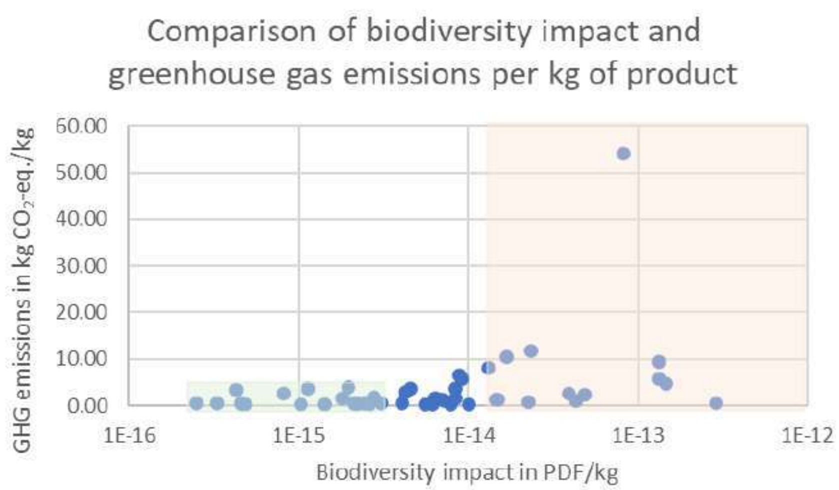

Figure 2 Comparison of the life cycle greenhouse gas (GHG) emissions and the biodiversity loss per kg of product. GHG (x-axis) was calculated using the IPCC 2021 method, biodiversity loss (y-axis) was calculated with the method of Chaudhary & Brooks (2018). Note: the x-axis is log-scaled.

Land-related biodiversity impacts in global agri-food supply chains – a spatially-resolved assessment from 1995 to 2022

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1. INTRODUCTION

We evaluate the spatial distribution of biodiversity impacts due to land-use change from 1995 to 2022, and pinpoint the factors driving these changes within the global agri-food supply chain.

2. METHODS

We merge the Land-Use Harmonization 2 (LUH2) dataset[1], which offers global land-use change data spanning from 1995 to 2022, with ecoregion-specific global potential species loss factors sourced from UNEP-SETAC[2,3]. This methodology enables us to analyze the global potential species loss (PSL_{glo}) resulting from human-induced land-use change at a detailed spatial level (15-minute arc resolution). To pinpoint the influencers and focal points of biodiversity fluctuations within global agri-food supply chains, we incorporate this regionalized impact assessment into Resolved EXIOBASE (REX3). REX3 is a detailed multi-regional input-output (MRIO) database that includes production and bilateral trade data of agricultural commodities across 189 countries and 163 sectors from 1995 to 2022.

3. RESULTS AND DISCUSSION

3.1 Hotspots of global biodiversity impacts from land-use change

Figure 1 offers a summary of the overall biodiversity changes resulting from land-use change from 1995 to 2022. Positive values indicate biodiversity declines (e.g., due to deforestation), while negative values signify biodiversity improvements (e.g., through reforestation). Our analysis highlights a substantial rise in biodiversity loss primarily in tropical regions, driven by deforestation and the transformation of natural landscapes. Conversely, in the temperate and arid regions of the Northern Hemisphere, biodiversity has shown positive trends due to reforestation, abandonment of agricultural land and conversion of cropland to rangeland. Considering both losses and gains, the net global impact on biodiversity due to land-use change increased by 1.4 % PSL_{glo} from 1995 to 2022.

3.2 Drivers of biodiversity impacts in the global supply chain

The connection to the REX3 databases uncovers that the escalation in impacts on tropical biodiversity hotspots is primarily driven by the production of agricultural commodities for exports. Latin America, Africa, and Southeast

Asia + Pacific (excluding China and India) emerge as key producers of exported agri-food products, while major consumers of traded commodities include China, the Middle East, the USA, and Europe (Figure 2). In aggregate, the biodiversity impacts associated with international trade have doubled since 1995, now constituting half of the global biodiversity impacts in 2022.

4. CONCLUSIONS

Our research highlights that domestic biodiversity improvements in Europe, the USA, China, and the Middle East have been achieved through the outsourcing of agri-food supply chains to tropical biodiversity hotspots. This has resulted in a global biodiversity deficit that exceeds the gains by a factor of ten. Furthermore, the net biodiversity impact stemming from land-use change (1.4 % PSL_{glo} from 1995 to 2022) surpasses the current biodiversity target by almost 50 times. Hence, concerted global endeavors should prioritize substantial reductions in the biodiversity impacts of land-use change. This would also mitigate associated climate impacts, as land-use change contributes to over 10 % of global climate effects.

5. ACKNOWLEDGEMENTS

We thank Prof. Dr. Louise Parsons Chini from the University of Maryland for providing valuable explanation on the LUH2 dataset as well as land-use time series from 2016 to 2022.

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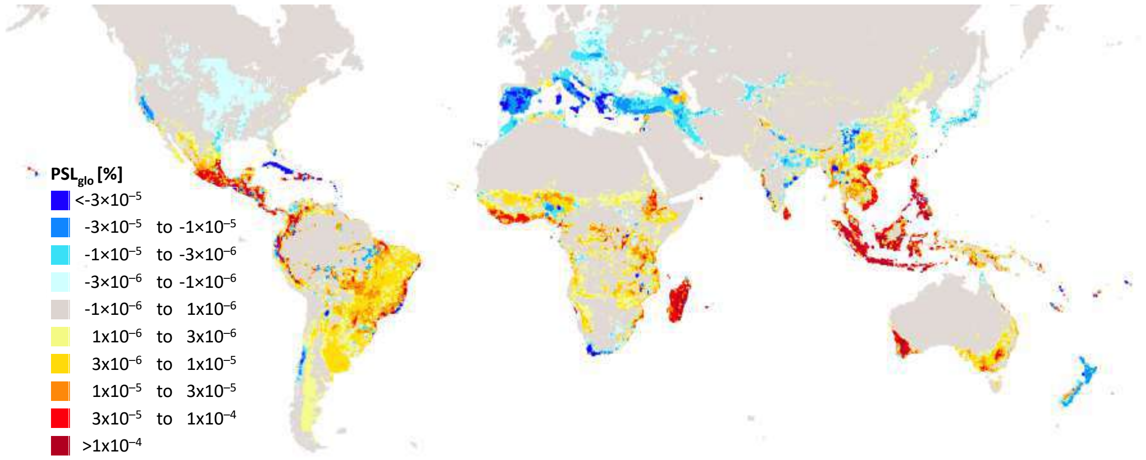

Figure 1. Biodiversity impacts of land-use change from 1995 to 2022. Positive percentages refer to biodiversity losses, while negative values refer to biodiversity gains.

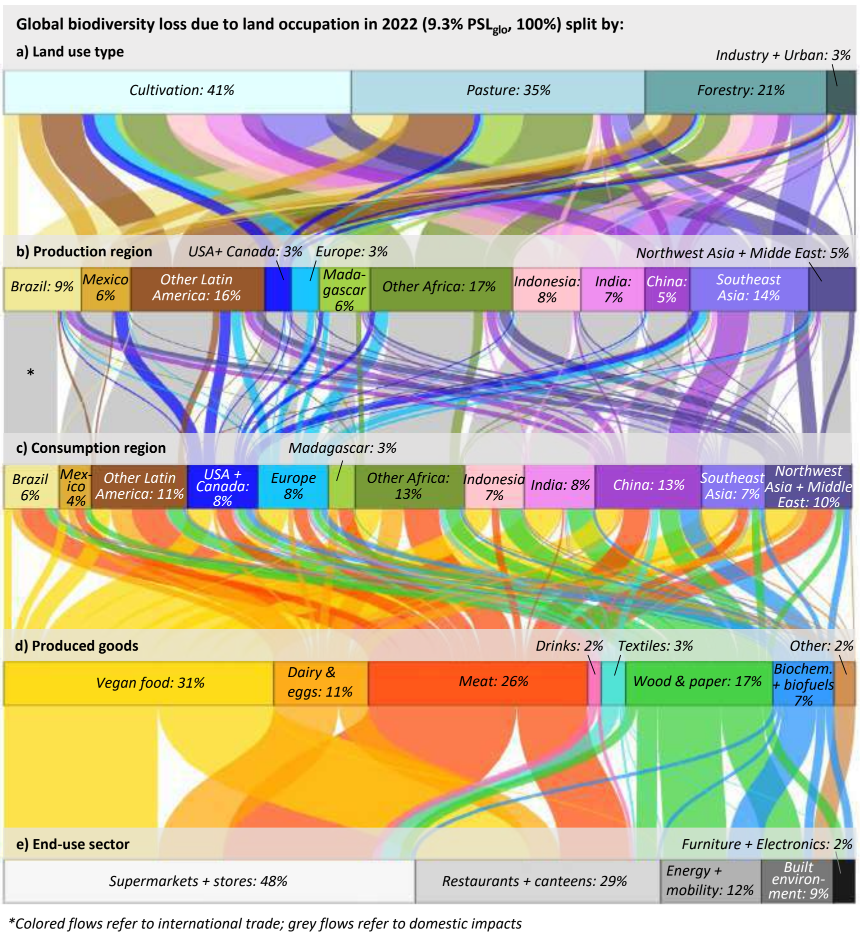

Figure 2. Global biodiversity loss of land use in 2022 divided by a) land use type, b) production region, c) consumption region, d) produced goods and e) end-use sector.

Sustainability of food systems in developing and emerging economies

Some environments aspects of Brazilian typical meal preparation in restaurants

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1. INTRODUCTION

Food is the basic of human life and food production has major implications for the use and alteration of natural resources. Feeding a population of 7.6 billion requires the use of land, energy, water and has serious implications for the environment. Given that eating outside of the home has become increasingly significant, the project in which this abstract takes part focuses on evaluating the preparation efficiency of the basic Brazilian dish in restaurants, consisting of rice, beans, red meat steak, and salad. In this paper, some of the environmental aspects of the composition of this meal are presented and discussed. The completed project will be published subsequently.

2. METHODS

Data related to the preparation of the basic Brazilian dish were collected in São Paulo city during visits to nine restaurants which together prepare a total of 1880 meals daily. The food preparation processes on industrial-scale stoves were surveyed for cooking rice and beans, frying red meat steak and cleaning and sanitizing lettuce. The boundaries of this study included the agricultural, processing, and transportation stages to the meal preparation sites. Data inventory of the upstream chains of restaurants was extracted from the scientific literature. The study was modelled using the Gabi Professional software.

3. RESULTS AND DISCUSSION

The inventories of the food components were combined to simulate the typical Brazilian meal (used as a functional unit). The average weight of 442 grams, composed of 39% cooked rice, 19% cooked beans, 14% grilled steak, and 27% lettuce salad washed and sanitized according to the Food Guide for the Brazilian Population (Brazil, 2014).

The analysis of the contribution of components (Table 1) on the average meal reveals that the consumption of beef steak is a major contributor to the main impacts measured, contributing to practically 91% of the impact of climate change (CC), 86% of blue water use (BWU), 84% of land use (LU) and 47% of primary energy demand (PED). The portion of cooked rice is almost twice the size of the portion of cooked beans, which due to the specifics of its production processes, make their contributions to be respectively about 28% and 10% of PED, and 10% and 5% in LU. The lettuce serving also consumes around 16% of PED and 4% of BWU. As shown in previous work (Santillo and Mourad, 2023) about 77% of blue water consumption comes from the sanitization process, due to the high consumption of water when washing vegetables under running tap water.

4. CONCLUSIONS

The analysis of the contribution of the components of the average meal prepared in restaurants shows that the consumption of beef steak is the major contributor to the main impacts measured, being responsible for practically 91% of the impact of climate change, 86% of the consumption of blue water, 84 % of land use and 47% of primary energy demand. The great impact that meat consumption has on the environment is well known around the world and for these reasons there are several studies to develop foods that offer substantial amounts of proteins to nourish the needs of living beings, but at the same time having lower environmental costs. In reality, Brazilians have a huge range of foods available, made up of varieties of vegetables, fruits and other meats. Although their meals are made up of several items, this research focused on the data regarding the typical Brazilian meal.

5. ACKNOWLEDGEMENTS

The authors are grateful to the restaurant partners for the infrastructure, to ITAL for offering the master program, and to CNPq - National Council for Scientific and Technological Development (Process 440170 / 2019-2) for the financial support.

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Table 1. Contribution analysis of the components of the basic Brazilian meal.

Parameter	lettuce	rice	beans	beef
	Relative contribution (%)			
Primary energy demand (MJ/meal)	16.6	27.9	8.7	46.8
Blue water use (kg/meal)	4.2	3.4	6.3	86.0
Land use (m^2a/meal)	0.8	10.2	4.8	84.2
Climate change (kg CO_2 eq./meal)	0.4	7.7	0.3	91.0

Environmental and socio-economic analysis of the Ivorian market vegetables suburban systems

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1. INTRODUCTION

Vegetable production in Ivory Coast is dominated by small farms that supply the local market with diverse produce. This activity generates income for producers and provides them with financial autonomy (AGRA, 2021; Silue, 2016), yet, the sector faces several challenges, including the appearance of diseases and pests, depletion of soil fertility, and limited access to high quality seeds (De Bon et al., 2019). A generalised decrease in soil fertility in the country has been caused by mineral fertilisation and repeated use of soils, combined with reduced fallow durations (Oula, 2021).

There is growing interest in agroecology as a means of moving towards more sustainable farming and food systems, including in the context of the African and Ivorian market vegetables production (AFSA, 2016). However, evidence of the contribution of agroecology to sustainability remains fragmented due to heterogeneity of methods and data, different scales and timeframes, and gaps in knowledge.

This work focuses on the environmental assessment of the Ivorian market vegetables production in a context of an incipient agroecological transition, complemented by preliminary socio-economic assessment aiming, among other objectives, to understand the rationales of adoption or agroecological practices. The main goal of this work is thus to identify potential differences in environmental impact intensity explainable by the different strategies adopted by Ivorian market vegetable producers, with focus on agroecological practices, mostly at the cropping system level.

The bulk of this work is based on data obtained at the "technical itinerary" level (i.e. the combination of techniques used on an agricultural plot to produce a product given specific constraints; a technical description of an individual distinctive cropping system) rather than at the farm level (i.e. an exploitation managed by the same producer and featuring one or plus technical itineraries), because more often than not Ivorian vegetable producers are actually producers of specific crops, under a monoculture logic (Dosso et al., 2023).

2. METHODS

The environmental analysis was based on LCA of individual technical itineraries, classified and grouped according with different criteria, namely: season of production (wet vs. dry season), city or origin, type of location (urban, rural, suburban), self-declared system type (conventional vs. transitioning to agroecology), specific crop, dominance of mineral vs. organic fertilisation, and intensity of use of synthetic phytosanitary products (four classes: 0, ≤1, ≤10, >10).

Hundreds of field surveys on operative, social and economic aspects were conducted by MARIGO in the period 2021-2023, representing in excess of 800 individual technical itineraries and >400 farms. The resulting datasets (Avadí et al., 2024; Avadí and Dosso, 2023), where data were normalised per hectare, were used to establish a typology of agricultural systems.

Comparisons of technical itineraries' impact scores, across different groupings and classifications of cropping systems, were tested for significance using basic statistical methods, such as ANOVA. Data on the adoption of different practices considered as agroecological, at the farm level, were combined into a "score of agroecological practices" and contrasted with impact scores at the same scale (computed as the mean of the different technical itineraries present per farm, because the original data collection was not exhaustive to all crops per farm), and the correlation between practices and impacts statistically tested for significance. Practices considered as agroecological were: associated animal husbandry, mixed farming, crop associations, crop rotations, concentrated vs. dispersed crop installation, service plants, insect nets or shelters, use of biopesticides, use of organic fertiliser, use of mulching, fallows; on a scale of 0 (no adoption) to 3 (strong adoption).

To complement the LCAs, an accounts-based economic analysis was based on statistical analysis with Spearman's correlation, to verify correlation among yield, gross margin and the phytosanitary use intensity gradient. Moreover, an econometric analysis used a multinomial logistic regression to estimate the effect of the different socio-economic factors on Ivorian market vegetable producers' adoption of agroecological practices (Bourbonnais, 2021; Greene et al., 2011).

3. RESULTS AND DISCUSSION

3.1 Environmental impacts

Crop systems, including their associated impact assessment results, were classified and summarised following various criteria and statistics (especially medians). The classification criteria were season of production, city or origin, type of location (urban, rural, suburban), self-declared system type (conventional vs. transitioning to agroecology), specific crop, dominance of mineral vs. organic fertilisation, and intensity of use of synthetic phytosanitary products (four classes: 0, ≤1, ≤10, >10).
There are apparent differences across individual crops and the above-described groupings of impact scores, including when impacts are disaggregated into individual impact categories.

These apparent differences in impacts across types, according to these classifications, were statistically tested to determine whether they were significant, by testing the correlations of various operational characteristics with impact scores to identify significant potential differences, leading to further investigation of these factors. Factors of interest were: season of production, city or origin, type of location, self-declared systems type, specific crop, dominance of mineral vs. organic fertilisation, and intensity of use of synthetic phytosanitary products. Only the city of origin and the phytosanitary use class were found to be associated with significantly different impact scores (one-way ANOVA, p-value <0.05). Nonetheless, if total phytosanitary inputs are contrasted with associated technical itinerary yield, there is no correlation, and furthermore the corresponding mean impacts per city do neither correlate with the phytosanitary/yield pair (Figure 1).

The self-declared systems type is not associated with significantly difference impact scores, which suggests that producers do not have a clear idea of what agroecology entails, of that efforts towards an agroecological transition are not systematic.

Impacts (single score, climate change, ecotoxicity) are the highest in Yamoussoukro, due to a higher rate of pesticides use combined with yields lower than those of Abidjan and Korhogo. In Bouaké, the pressure on eutrophication is the highest, probably due to the relation between nutrients inputs and yield, the latter being the lowest amongst cities.

The main contributors to impacts are, systematically, fertilisers provision and use, through direct field emissions. The contribution of pesticides (notably their provision) is proportional in order of magnitude to the phytosanitary use intensity.

Regarding the score of agroecological practices vs. impacts at the farm level (

Figure 2a), no correlation was found between the two indicators, and no regression model was able to link the two variables with an R^2>0.1. Moreover, no correlation was found between yield and environmental impact or score of agroecological practices (

Figure 2b). These results imply that the level of adoption of practices considered as agroecological is not a good predictor of yield nor of environmental impacts.

3.1 Environmental impacts vs. socio-economic indicators

The relationship between agroecological practices and environmental impact appears to be not significant for farmers. This calls for a better understanding of farmers' social representation of agroecology. The results of the correlation test indicate that the correlation among yield, gross margin and phytosanitary use intensity is very low. Phytosanitary management is not the mean key to explain the difference of gross margin between the different farms. The price of vegetables on the local market could influence the margin. There is a fluctuation in prices over the course of a year that the producer cannot influence (Kouame et al., 2017).

Positive correlations were found between the decision to adopt various numbers of agroecological practices and explanatory variables such as level of instruction, national origin and age. Negative correlations were found regarding gender. When the number of practices reaches 7, the different variables identified are not significant. It means that there are others factors that may explain farmers' decision to adopt more than 6 agroecological practices. These factors may include technical and financial support from external actors such as NGOs (e.g. IECD, 2020).

4. CONCLUSIONS

Environmental impacts of market vegetable crop production in Côte d'Ivoire seem to be largely determined by the intensity of phytosanitary inputs, with Yamoussoukro featuring the highest impacts by all metrics. Yamoussoukro features the highest rates of pesticide use amongst the four cities.

The (declared) level of adoption of practices considered as agroecological is not a good predictor of yield nor of environmental impacts. The benefits of adopting such practices, at least in this particular case, should be explored using different approaches. Complex socio-economic dynamics underscore adoption. The benefits of adopting such practices, at least in this particular case, should be explored using different approaches.

5. ACKNOWLEDGEMENTS

This work has been financed by the MARAÎCHAGE AGROÉCOLOGIQUE PÉRI-URBAIN – DeSIRA MARIGO project (https://www.projet-marigo.org/), 2021-2025, grant number FOOD/2020/419-988. The authors acknowledge the many Ivorian market vegetable producers who gave their time and data, as well as their MARIGO colleagues.

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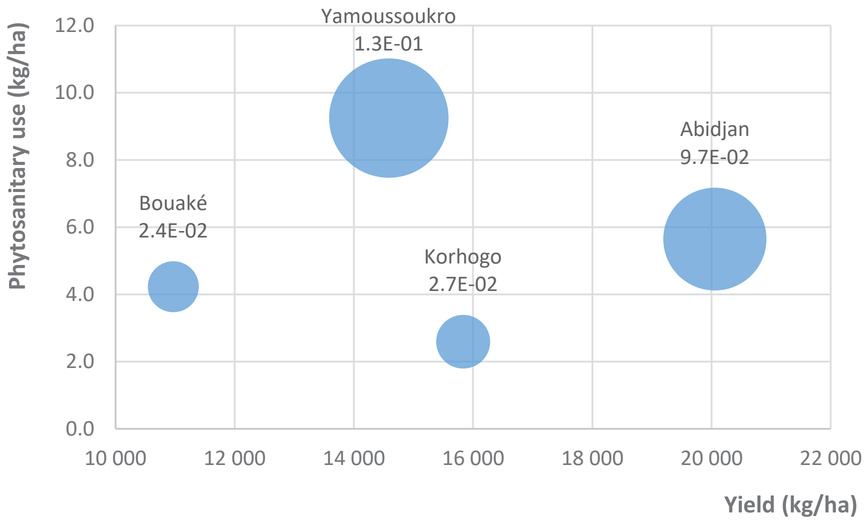

Figure 1. Relations at the technical itinerary level among mean phytosanitary use and yield, per city, with bubble sizes representing environmental impact score (EF 3.0, single score)

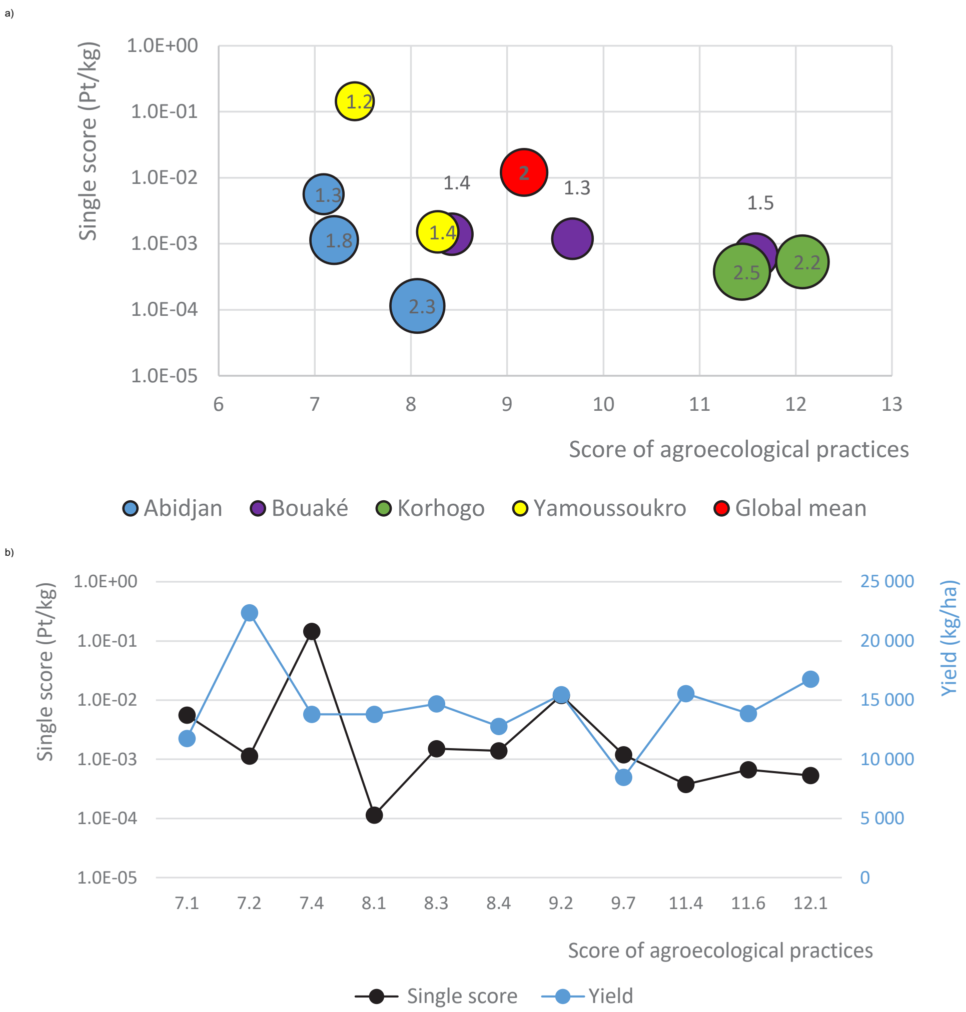

Figure 2. Relations at the farm level among mean [1] score of agroecological practices, [2] number of technical itineraries per farm, [3] environmental impacts per kg of product (EF 3.0, single score), and [4] yield, per city of origin and type of location (urban, suburban, rural), a) [1] vs. [3] with [2] as labelled bubble size; b) [1] vs. [3] vs. [4]

Life Cycle Assessment of major Myanmar crop products using HESTIA

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1. INTRODUCTION

Myanmar is a predominantly agricultural country. 64% of arable land is cultivated with rice[1], making Myanmar the eighth largest producer worldwide[1]. The rice sector is crucial to the country's food security, with more than 90% of rice consumed domestically[1]. Conversely, 75% of maize is exported[1]. Myanmar is also the second largest producer of urad beans and mung beans[2], the third largest producer of pigeon peas and sesame seeds, and the sixth largest producer of chickpeas[1]. Despite the large agricultural production volume, only one Life Cycle Assessment (LCA) on Myanmar agriculture has been published so far. Moreover, no LCAs have been published on urad beans (from any country) and only a few have been published on chickpeas, mung beans, pigeon peas, and sesame seeds, none of them focusing on South-East Asia. The aim of our paper is to fill these gaps.

2. METHODS

Inventory data were collected between 2016-2019 by surveying 1,708 households in the main producing regions of Myanmar, namely Southern Shan (for maize and pigeon peas), the delta zone (for rice, urad beans and mung beans), and the central dry zone (for rice, sesame seeds, and chickpeas). Data collection focused on use of seeds, fertilizers, pesticides, machinery, and draft animals, *inter alia*. Most farmers were practicing multicropping, intercropping, or both, and crop failures were also common. The collected data were reformatted and then uploaded to HESTIA, a platform that enables stakeholders to store data on the productivity and sustainability of agricultural products in a standardized way[3]. The original data were enhanced by means of HESTIA's gap-filling models, e.g., the amount of crop residue was estimated based on the IPCC 2019 model, and 20+ climate and soil measurements were added using satellite and other geospatial datasets. Foreground and background emissions and resource flows were automatically calculated by HESTIA as well as multiple characterized impact indicators. Results were compared with global averages from Poore and Nemecek (2018)[4] and drivers of impacts were analyzed to identify areas for improvements.

3. RESULTS AND DISCUSSION

The results discussed here will focus on maize (Fig. 1A). The average land use per kg of maize was 3.4 m^2a in the Shan region, more than double the global average of 1.6 m^2*a. This is almost entirely explained by the difference in maize yield, which is 3.2 t/ha in Myanmar and 5.3 t/ha globally. Greenhouse gas (GHG) emissions were four times higher than the global average (3.2 vs 0.8 CO2eq/kg). This difference is primarily due to GHG emissions from land use change, which were calculated using a statistical direct land use change model[5]. The high rates of deforestation are confirmed by the farmers' survey, as well as by satellite photos (Fig. 2).

4. CONCLUSIONS

Our study represents the first LCA on urad beans, mung beans, sesame seeds, pigeon peas, and chickpeas in Southeast Asia to our knowledge and fills a gap in the understanding of Myanmar's agricultural sustainability. For maize, low yields and deforestation were identified as the two main drivers of environment impacts. We proved the potential of HESTIA to automate calculations on large datasets and handle practices such multicropping and intercropping, although some questions (e.g., how to properly handle failed harvests in LCAs?) remain open for discussion.

5. ACKNOWLEDGEMENTS

Data was collected by the Food Security Policy Project, funded by USAID and the Livelihoods and Food Security Fund (LIFT). HESTIA is financed by the Login5 Foundation, WWF UK, Defra, the Ardevora Charitable Trust, and the Oxford Martin School.

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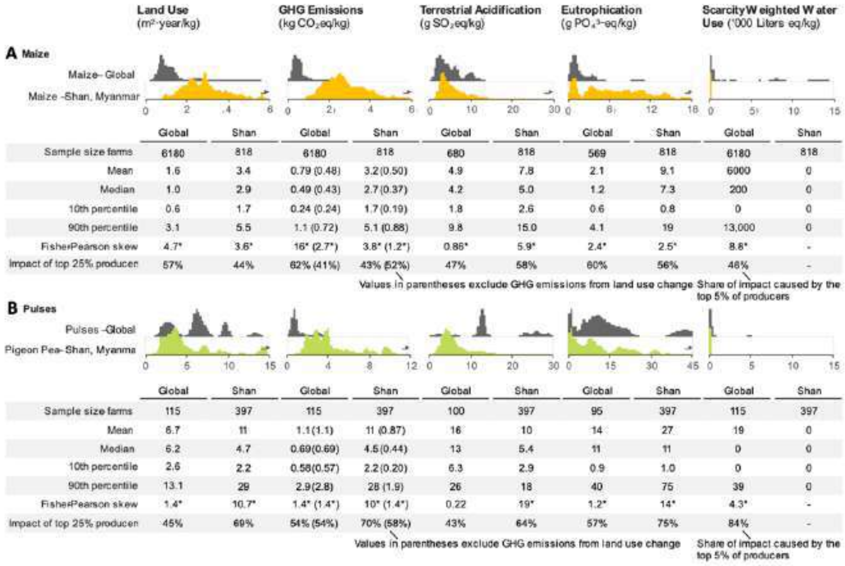

A Maize

	Land Use Global	Land Use Shan	GHG Emissions Global	GHG Emissions Shan	Terrestrial Acidification Global	Terrestrial Acidification Shan	Eutrophication Global	Eutrophication Shan	Scarcity Weighted Water Use Global	Scarcity Weighted Water Use Shan
Sample size farms	6180	818	6180	818	680	818	569	818	6180	818
Mean	1.6	3.4	0.79 (0.48)	3.2 (0.50)	4.9	7.8	2.1	9.1	6000	0
Median	1.0	2.9	0.49 (0.43)	2.7 (0.37)	4.2	5.0	1.2	7.3	200	0
10th percentile	0.6	1.7	0.24 (0.24)	1.7 (0.19)	1.8	2.6	0.6	0.8	0	0
90th percentile	3.1	5.5	1.1 (0.72)	5.1 (0.88)	9.8	15.0	4.1	19	13,000	0
FisherPearson skew	4.7*	3.6*	16* (2.7*)	3.8* (1.2*)	0.86*	5.9*	2.4*	2.5*	8.8*	-
Impact of top 25% producers	57%	44%	62% (41%)	43% (52%)	47%	58%	60%	56%	46%	-

B Pulses

	Land Use Global	Land Use Shan	GHG Emissions Global	GHG Emissions Shan	Terrestrial Acidification Global	Terrestrial Acidification Shan	Eutrophication Global	Eutrophication Shan	Scarcity Weighted Water Use Global	Scarcity Weighted Water Use Shan
Sample size farms	115	397	115	397	100	397	95	397	115	397
Mean	6.7	11	1.1(1.1)	11 (0.87)	16	10	14	27	19	0
Median	6.2	4.7	0.69(0.69)	4.5 (0.44)	13	5.4	11	11	0	0
10th percentile	2.6	2.2	0.58(0.57)	2.2 (0.20)	6.3	2.9	0.9	1.0	0	0
90th percentile	13.1	29	2.9(2.8)	28 (1.9)	26	18	40	75	39	0
FisherPearson skew	1.4*	10.7*	1.4* (1.4*)	10* (1.4*)	0.22	19*	1.2*	14*	4.3*	-
Impact of top 25% producers	45%	69%	54% (54%)	70% (58%)	43%	64%	57%	75%	84%	-

Figure 1. Variability in the productivity and environmental impacts of maize and pigeon pea producers in the Shan region of Myanmar compared to the global distribution of producers. (**A**) Maize producers. (**B**) Pigeon pea producers compared to all pulse producers. For Myanmar, data are weighted based on the area-based sample weights multiplied by crop yield to generate production weights, and for the global data, observations are weighted by the estimated share of global production represented by the observation and then resampled 10,000 times. Histograms represent the density of observations at different value intervals for each indicator. For GHG emissions, values in parentheses represent GHG emissions excluding emissions above and below ground carbon stock change related to deforestation and other land use change. All characterization models are the same as in Poore & Nemecek (2018).

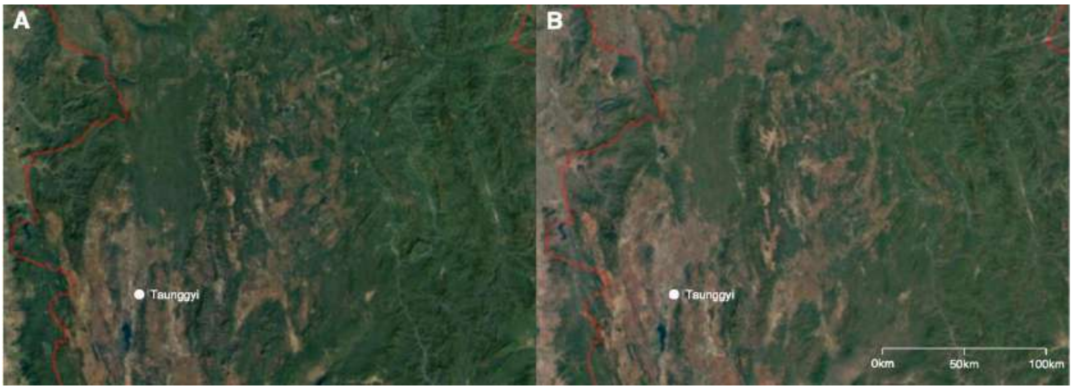

Figure 2. (**A**) December 1984. (**B**) December 2020. Images are natural color composites and green is forested area while brown is primarily cropland. Red lines are the boundary of the Southern Shan region and images are focused on the center of Southern Shan.

LCA of the Ivorian cashew value chain as a key component of a corporate sustainability framework

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1. INTRODUCTION

Cashew trees are grown in the north, north-west and northeast regions of Côte d'Ivoire, where they are now, along with cotton, the main cash crops. In Côte d'Ivoire, there is a major shortage of quality statistical data on agriculture. There are no reliable figures on land use, or on areas, production volumes, yields or the number of producers involved in the cashew nut value chain. On the basis of several sources, and taking 2021 as the reference year, the following figures represent the best estimations: Côte d'Ivoire is the first global exporter by volume (1.1 Mt), 2.4 Mha are devoted to cashew, the mean yield is 458 kg/ha (400 to 800, depending on the type of plantation), there are some 500 000 cashew farmers, and the rate of processing in the country does not exceed 12%. The Ivorian cashew value chain, including a typology of plantations, is depicted in **¡Error! No se encuentra el origen de la referencia.**.

A screening LCA was performed at the national level, in the context of a Value Chain Analysis for Development project (Fabre et al., 2021). Later, results are being used to inform a sustainability assessment framework aimed at Ivorian and West African cashew processors. The framework is intended for concerned operators as a sustainability management system, to assess improvements and perform benchmarking with alternative value chains, such as the dominant one where Africa-sourced RCN are processed in Asia. Such a dashboard of sustainability indicators, adapted to the West African cashew value chain and easy to update regularly, seems necessary so that Ivorian and West African stakeholders (processors and organised producers) can better manage and communicate on the sustainability of their activities and, ultimately, increase the generation of added value in the region. Background data on global cashew value chains, to be included in a tool based on the framework, would be useful for benchmarking.

2. METHODS

2.1 LCA

The scope of the study includes all the elements shown in **¡Error! No se encuentra el origen de la referencia.**. Two main functional units were selected for the agricultural phase: 1 t of raw cashew nut (RCN) and 1 ha of production. For kernels ("almonds"), 1 kg of kernels (all qualities combined) leaving the factory was used. The distribution (allocation) of impacts between processing co-products (kernels of different qualities) is based on the weight x market price of the different fractions (economic allocation). On the other hand, the allocation of transport is based on the weight of the different fractions (mass allocation). In plantations featuring associated crops, the data obtained did not allow other products to be taken into account. We have avoided substituting or modelling "avoided products" (for example, considering the quantity of fossil fuel or coal/wood that would be needed for the boiler if cashew shells were not used instead). This practice is considered to distort the biophysical nature of LCA (Avadí et al., 2021). Data was obtained from field surveys and literature. ReCiPe 2016 (Huijbregts et al., 2016) and EF 3.0 (Zampori and Pant, 2019) were retained as LCIA methods.

2.2 Sustainability assessment framework

The proposed framework addresses the sustainability concerns of cashew processors regarding: i) the environmental impacts of their supply and value chain (primarily in terms of carbon footprint, also enabling value chain actors to inform potential voluntary carbon market initiatives), ii) their real cost after taking into account environmental externalities, and iii) their socio-economic performance.

The environmental impacts will be computed using LCA and an adapted carbon balance framework (

), on the one hand, and the elements of the "Environment" dimension of FAO Tool for Agroecology Performance Evaluation (TAPE) (Mottet et al., 2020), on the other. The social and economic indicators are computed using a modified version of TAPE stage 2 and the additional Sustainable Development Goals (SDG) (FAO, 2023) indicators. Suitable Global Reporting Initiative (GRI) guidelines (GRI, 2023) and indicators are included as well, heavily focused on socio-economic aspects. Biodiversity indicators are based on a modified version of GLOBIO (Schipper et al., 2020). Environmental externalities are included via indicators from the Toolkit for Ecosystem Service Site-Based Assessment (TESSA) (Peh et al., 2022), and resilience indicators complementary to TAPE's are based on (Jacobi et al., 2018).

3. RESULTS AND DISCUSSION

This work presents only the LCA results, available in full detail in a project report (Lebailly et al., 2023). The full depiction of the average cashew processing company in Côte d'Ivoire, by means of the LCA-informed framework, will be the subject of upcoming publications. The carbon balance framework depicted in will be expanded and improved to encompass the whole value chain, also as the subject of upcoming publications.

Endpoint impacts on AoP Ecosystems dominate as negative impacts, but they are systematically outweighed by positive impacts on Human Health, dominated by Climate Change (mitigation, in this case through carbon sequestration in perennial biomass). In the case of cashew nut, C sequestration in perennial biomass is greater than end-of-life C losses.

Modern and rehabilitated plantations have slightly higher impacts than the other types, mainly because of the lower plant density, which, without degrading yield, contributes less to carbon sequestration (and therefore more to climate change, through land occupation and land-use change). The impacts of the country's 'average' RCN are determined by those of the most common, traditional plantations.

The impacts of <5 kt RCN/year plants are slightly lower than those of >5 kt RCN/year plants, basically due to relative efficiencies and energy use strategies. Of the marketable fractions, the majority of impacts are attributed to whole kernels, the most economically important fraction.

The impacts of transporting RCN and kernels are marginal. However, the relative impacts of the two sub-chains studied (RCN for export vs. kernels for export) are very different (1 order of magnitude). The main explanation for this is the processing efficiency, of around 21%, which implies that to produce 1 kg of kernels it is necessary to produce, transport and process 4.8 kg of RCN.

RCN production in traditional plantations (75% of all plantations) is the main contributor to the impacts of mean RCN and kernels transported to the port of Abidjan (77.3 and 83.5% of the respective impacts). Because of the relative abundance of each type of system in the country, RCN from the other types of plantation combined represents only 24.7 and 27.5% of the impacts, respectively.

The impacts of plantations are 89% due to land occupation and land-use change. The other processes contributing to the impacts all individually weigh in at <5%: use of glyphosate, fertilisers (in the nursery and during the first year), tools and tarpaulins, etc. The transport of RCN to the port contributes marginally to the total impact (<2%).

Compared with kernels from factories producing >5 kt RCN/year (>76% of the impacts of mean kernels), transport from the factory to the port contributes marginally to the total impacts (<1%), and processing itself contributes around 7% (basically the supply of electricity, as the consumption of hulls for the boilers does not contribute to the depletion of resources). The vast majority of the impacts of processing are in fact due to the agricultural phase. For kernels from plants of <5 kt RCN/year, on the other hand, steam production contributes ~8.5%, thanks to a lower technical efficiency, and to the assumption that fossil fuels are used for the boilers. Note the limited modelling of the plants, focusing on yields and energy consumption. Packaging materials contribute <2% to the total impacts of kernels.

Agricultural yields are higher in Côte d'Ivoire (458 kg RCN/ha.an) than in Mali (358 kg RCN/ha-an) or Sierra Leone (240 kg RCN/ha-an) (Michel et al., 2019b, 2019a), but lower than in Ghana (518) (Scholten, 2021). In Ghana, the use of pesticides (herbicides, insecticides) is widespread, and 3 times higher than in Côte d'Ivoire.

The average energy consumption of factories in Côte d'Ivoire appears to be slightly lower than that of Indian industries, and considerably lower than that of Ghanaian factories, but more data would be needed to control the uncertainty surrounding these data. Processing in some neighbouring countries (Mali, Sierra Leone, Burkina Faso) uses fuels with a higher environmental impact than in Côte d'Ivoire, namely wood and charcoal (A. Benoist, CIRAD, pers. comm.). RCN:kernel yields in Ghana are marginally lower than in Côte d'Ivoire (20% vs. 21%).

The substitution of Indo-Vietnamese processing by processing in Côte d'Ivoire represents a reduction in emissions contributing to climate change, this being mainly due to carbon sequestration in biomass coupled with a small contribution to deforestation in Côte d'Ivoire plantations (and due to the drastic reduction in transport). For effective benchmarking, carbon modelling across alternative supply chains would need to follow the same rules.

4. CONCLUSIONS

The Ivorian cashew value chain appears to be environmentally sustainable, especially in comparison with other chains in the region, but this qualification is qualified and conditioned by a number of factors. Cashew's contribution to deforestation (of forests, savannahs) should not increase beyond the current 4-7%. The use of chemical herbicides (especially glyphosate) should not increase, but the shortage of rural labour is becoming a challenge in this respect. The vast majority of the impacts of kernels are due to the agricultural phase, which implies that the focus of interventions should be on producers, especially the dominant type of system (traditional plantations). Energy consumption by processing plants is highly variable. Their efficiency is linked to economies of scale (plant size in terms of installed capacity). For example, GHG emissions associated with climate change for plants >5 kt RCN/year vary between 1640 and 1858 kg CO2-eq/t RCN processed.

5. ACKNOWLEDGEMENTS

The authors were founded by the VCA4D - Value Chain Analysis for Development 2016-2022 programme, through grant agreement 2016/375-804 and by the Agropolis Fondation through grant agreement ANR-10-LABX-0001-01 under the project call “Towards Sustainable, Desirable and Just Solutions – SDJs”.

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Table 1. Proposed carbon modelling framework for perennial crops LCA (biomass and LUC, excluding SOC turnover)

Inputs from nature		
Occupation, permanent crop, fruit	1	ha
Transformation, from permanent crop	1	ha
Transformation, from annual crop		ha
Transformation, from forest, natural		ha
Transformation, from grassland, natural (non-use)		ha
Transformation, to permanent crop	1	ha
Carbon dioxide, in air	$C_{biomass}$/age*44/12	t
Inputs from technosphere		
Installation of the plantation	1/age	p
Annual maintenance of the plantation	0	p
Biomass production (to substitute fuelwood)	($C_{biomass}$*x%)/age/50%	t
Emissions to air		
Carbon dioxide, biogenic	($C_{biomass}$*(1-x)%)/age*44/12	t

Notes: x represents the faction of total aboveground biomass that is used as fuelwood at the end of life of the plantation

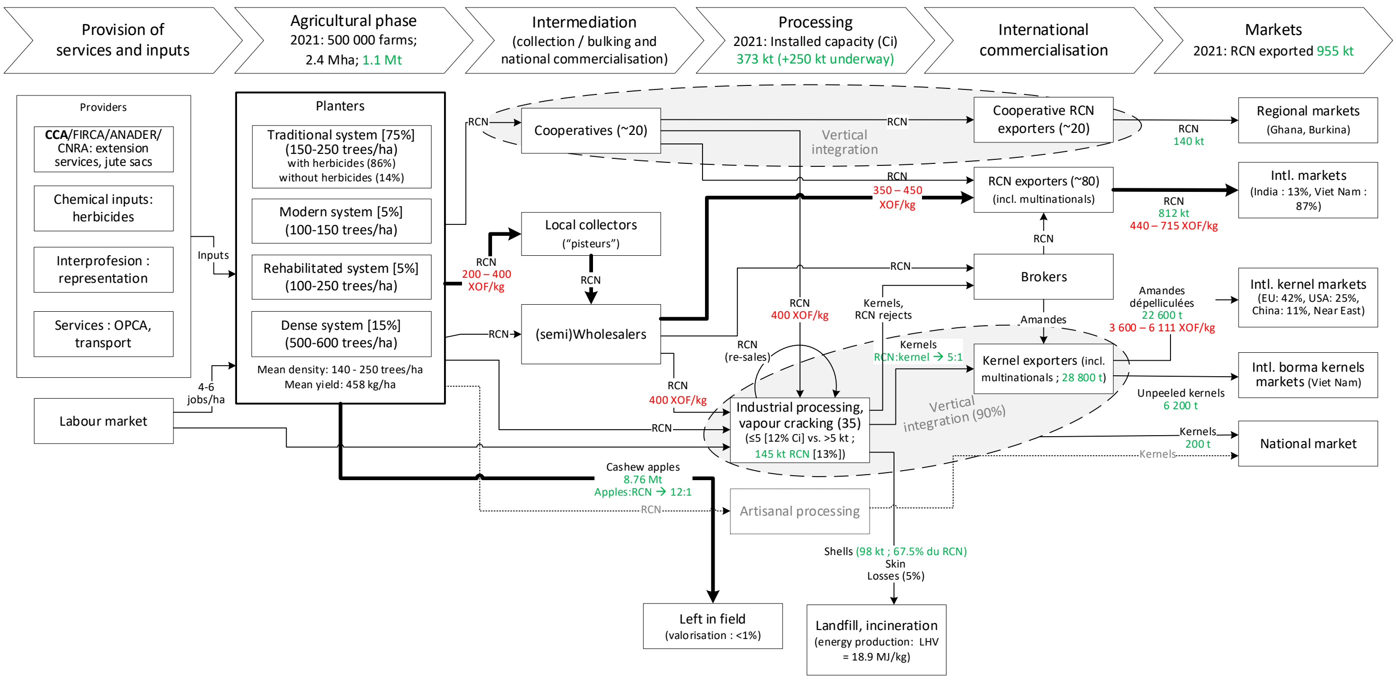

Figure 1. Material and economic flow diagram of the cashew nut value chain in Côte d'Ivoire (2021)

LCA of Robusta coffee production in Vietnam: How grafting and cycle lengths influence the impacts?

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1. INTRODUCTION

In their review, Chéron-Bessou et al. (2024) showed that inconsistent modelling and data quality levels across coffee LCA studies were hampering comparison across systems and origins. The overwhelming majority of published coffee LCA concerned Arabica coffee. However, Robusta coffee global share is getting close to half nowadays, *i.e.* 44% in 2023 (ICO, 2023) and more studies are needed to uncover the Robusta systems' diversity and performances. Vietnam is the main producer of Robusta coffee worldwide, relying on intensive practices to achieve high yields. Unveiling the diversity of farmer's practices, farm performances and their impacts is particularly critical now that most coffee farms in Vietnam are getting old and need to be rejuvenated. We compared the potential environmental impacts of various coffee systems in Vietnam Central Highlands (three provinces), by modelling the complete coffee perennial cycle and collecting precise data in the field to account for the diversity of systems.

2. METHODS

A cradle-to-farm gate LCA study was performed covering all activities from seedling production to dried green coffee (Figure 1). The whole perennial cropping cycle was modelled following Bessou et al. (2016). We defined a farm typology based on expert knowledge, fine-tuned and cross-validated with a first set of data collected through farm surveys in a reduced sample of farms (n=28) covering a range of locations and a variety of farmer profiles. Based on the typology and using a stratified sampling approach, we then collected data in farms across three main producing provinces (n=48). Inventory and field emissions were modelled using MEANS-InOut v4.3.2 (Auberger et al. 2018). Impact assessment was performed using several LCIA approaches to test result robustness and using regionalised LCIA methods when relevant.

3. RESULTS AND DISCUSSION

3.1 Farm typology

The pilot study confirmed that the coffee systems and farming practices were highly related with farmers' grafting trajectory, but also to farmers' possible partnership with coffee companies, ethnicity and location. Three main farm types were defined based on their grafting trajectories: the use of old varieties without any grafting (NG), the use of new varieties with grafted seedling from nurseries (G), and the use of old varieties followed by grafting of new scions onto old rootstocks to rejuvenate farms (GoR). For each farm type, we analysed variability across other typology criteria (partnership, ethnicity and location).

3.2 Preliminary results

The three trajectories were not equally spread across provinces. Overall, farmers using grafting (G and GoR) stood out both in terms of inputs and yields, with a higher reliance than NG on both synthetic and organic inputs (Table 1). On the contrary, irrigation water use was lower than for NG, who were found in the wetter province**.** As expected, fertilisation was a major contributor to climate change and eutrophication impacts, followed by composting. We are currently fine-tuning the characterisation of the emission profiles of composts and organic inputs. Regarding the grafting trajectories, G farmers had the highest impacts on climate change, ecotoxicity of freshwater, and resource use. Farmers tended to intensify more in the case of new varieties given the assumption that those grafted seedlings are promoted as "high-yielding". However, there is not enough hindsight yet to assess whether yields would be significantly higher for G than for NG and GoR and how sensitive to inputs new varieties would be.

4. CONCLUSIONS

Preliminary analysis shows that relying on old and non-grafted varieties or on newly selected and grafted seedlings may contribute to the environmental performance as much as other practices. Nevertheless, farmers with grafted seedlings are commonly associated with more intensive practices with high impacts (such as intensive use of fertilizer inputs).

5. ACKNOWLEDGEMENTS

The study was funded by the European Union (EU), Grand Agreement #101060693, Project BOLERO. Views and opinions expressed are those of the authors and do not reflect those of the EU.

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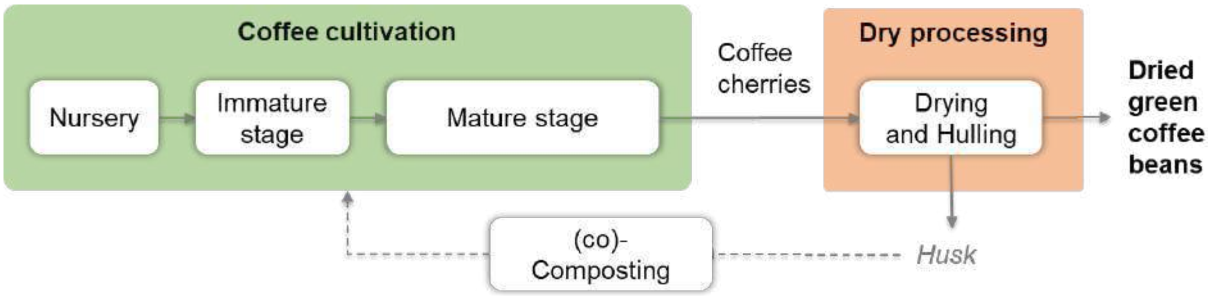

Figure 1. Main dried green coffee production stages modelled, including full perennial cycle.

Table 1. Farm description, main inputs and outputs per ha for the 3 main farm types (average values and standard deviation)

(StdDev) = standard deviation	**Non-grafted (NG) n=43**	**Grafted (G) n=23**	**Grafted onto old Rootstock (GoR) n=10**
Farm description			
Farm size (ha)	1,3 *(1,4)*	1,2 *(1,2)*	1,7 *(1,3)*
Coffee density (tree/ha)	1046 *(103)*	1158 *(240)*	1236 *(163)*
Inputs			
Irrigation water (mm/ha)	228 *(166)*	165 *(135)*	97 *(35)*
Organic inputs (kg/ha)	3253 *(5500)*	6763 *(5803)*	5061 *(3549)*
Total N in mineral fertilizers (kg N /ha)	362 *(136)*	378 *(146)*	479 *(142)*
Total P in mineral fertilizers (kg P2O5/ha)	191 *(120)*	275 *(146)*	302 *(122)*
Total K in mineral fertilizers (kg K2O /ha)	245 *(127)*	259 *(132)*	345 *(127)*
Outputs			
Yield/ha (tonne dried green beans)	3,1 *(1,4)*	4,0 *(1,2)*	5,8 *(1,4)*

LCA and carbon sequestration evaluation: cupuacu jam from agroforestry in the Amazon rainforest

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1. INTRODUCTION

In areas affected by deforestation, reforestation based on agroforestry is emerging as an effective solution to mitigate climate change and sustain farmers' livelihoods. Trees help remove carbon dioxide from the atmosphere while providing food and other ecosystem services (Martinelli et al., 2019). This study aims to assess the life-cycle environmental impacts of a cupuaçu jam from fruits grown via agroforestry in a previously deforested area in the Peruvian Amazon (Madre de Dios).

2. METHODS

The environmental impacts are evaluated via LCA (cradle-to-grave) using 1 kg of cupuaçu jam (including packaging) as functional unit. Figure 1 shows the main unit processes included in the analysis, including all the phases from cultivation stage to packaging disposal. The agroforestry area is cultivated with 12 tree species (640 trees/ha), and a cover crop. Cupuaçu has the highest density, with 210 trees/ha. This study considers a 20-year horizon for the cultivation stage, reflecting the estimated productive life of cupuaçu trees. Self-made fertilizer diluted in rainfall-water is manually applied, while neither irrigation nor pesticides are used. Field emissions from fertilizer and crop residues were estimated according to IPCC guidelines (IPCC, 2006) and SALCA-P model (Nemecek and Schnetzer, 2012). Inputs and outputs of the cultivation phase were partitioned among the co-products of the cupuaçu fruit (i.e., pulp for jam, pulp for juice and seeds) based on their economic value. Jam is made of cupuaçu pulp (57%) and cane sugar (43%). The jam is then transported from Peru to a retailer located in Italy. Primary data and Ecoinvent database were used for the inventory. The ReCiPe Midpoint 2016 V.1.0 method was used for the assessment. An estimation of the potential benefit due to carbon sequestration and storage in trees and soil was made: above-ground and below-ground biomass was estimated using morphometric equations (Baker et al., 2004, Aalde et al., 2006), and emissions from dead organic matter and soil were calculated following the IPCC guidelines for grassland converted to forest land.

3. RESULTS AND DISCUSSION

The environmental impacts of cupuaçu jam, excluding carbon stocks, and the relative contribution of each unit process are shown in Figure 2. The hotspot in Climate Change and other six impact categories is the transportation of the jam pots from Peru to the final retailer in Italy, mainly due to road transportation inside Peru from the production plant to the coastal harbor. Other hotspots are sugar cultivation and packaging production. Cupuaçu cultivation has a relative high impact on marine eutrophication, ozone depletion and freshwater eutrophication, while its contribution to the other impact categories is less than 1%. Approximately 0.9 kg of CO_2 eq are estimated to be stored per kg of jam produced (Table 1), mainly in the tree biomass.

4. CONCLUSIONS

The environmental impact of the cultivation phase of cupuaçu results to be low (0.03 kg CO_2 eq/kg fresh fruit) compared to the literature thanks to the low use of fertilizers and no use of machineries. Most of the life-cycle impacts of the jam arise from the inland transportation of the finished product from the cultivation area to the coast. Impacts could be reduced using more sustainable means of transportation. The sale of jam from agro-forestry areas can foster the removal of CO_2 from the atmosphere, but dynamic LCAs are needed to explore the climate implications of different end-of-life scenarios for the trees, when their productivity starts to decrease after the 20th year. Moreover, the effects of the agroforestry system on biodiversity and other ecosystem services should be explored.

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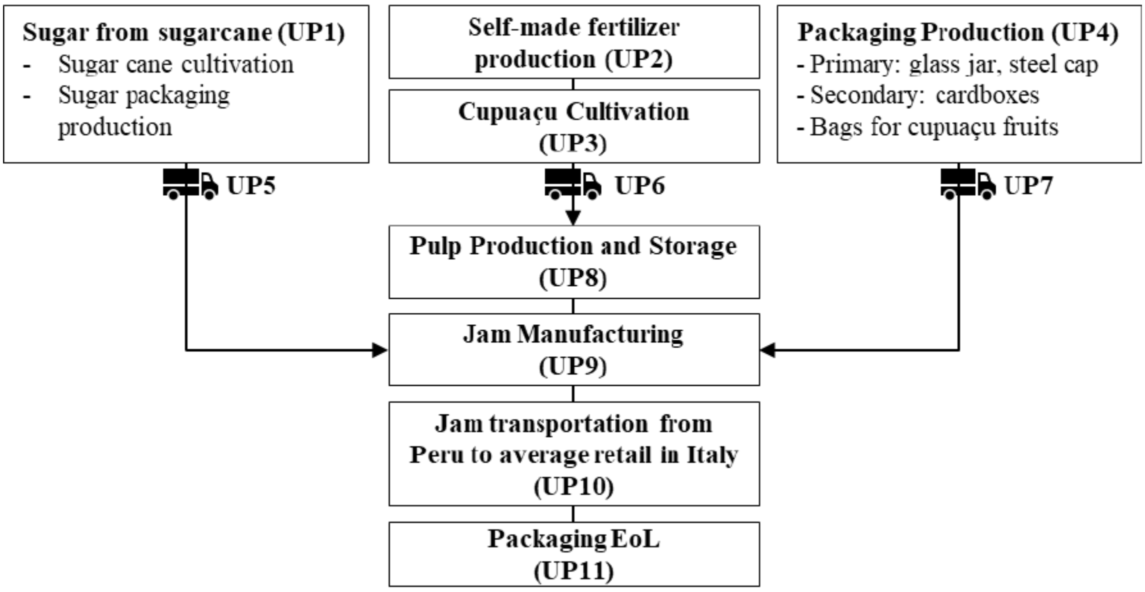

Figure 1. Product system

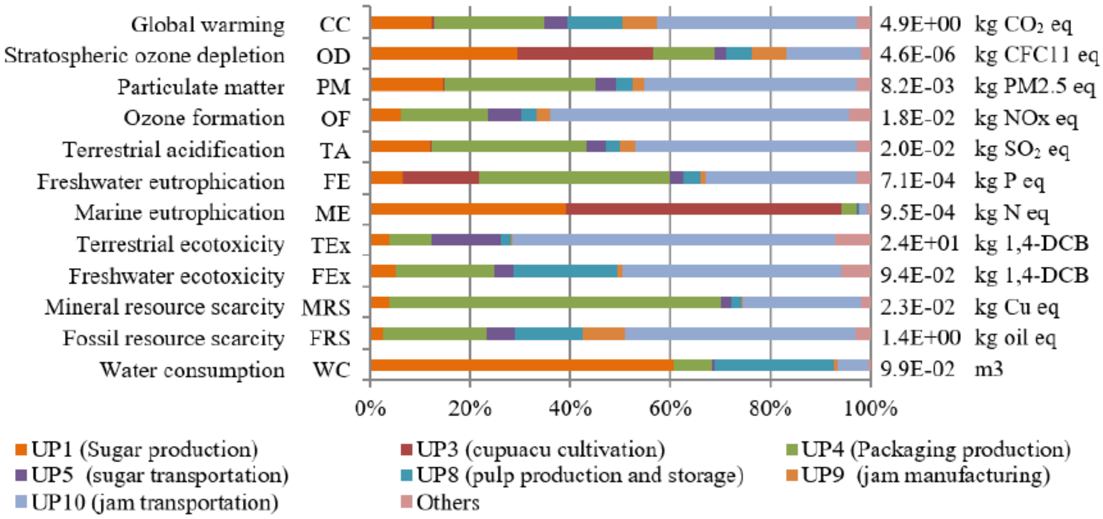

Figure 2. LCIA of 1 kg of cupuaçu jam and relative contribution of each unit process

AGB & BGB	Dead organic matter	Soil	Total
-0.79 kg CO_2 eq	-0.06 kg CO_2 eq	-0.05 kg CO_2 eq	-0.90 kg CO_2 eq

Table 1. Estimation of carbon sequestration and storage in above ground biomass (AGB) and below ground biomass (BGB) of cucpuaçu trees, dead organic matter, and soil, referred to 1 kg of cupuaçu jam

Social life cycle assessment of low-tech digesters in small-scale farms

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1. INTRODUCTION

Low-tech digesters have been successfully spreading in rural areas of low-income countries since the 1970s. They are simple technologies in which the reactor is made of masonry or plastic bags, without a mixing or heating system. Low-tech digesters are considered a clean and environmentally friendly technology which can help rural communities to meet their energy needs for lighting, cooking and electricity, thus leading to improved living conditions (Garfí et al., 2016). Apart from biogas, low-tech digesters also produce digestate that can be reused as biofertiliser, increasing crops productivity. Several studies have already proved its technical feasibility and environmental benefits (Garfí et al., 2016). However, to the best of the authors' knowledge, the social performance of low-tech digesters has not yet been studied. Therefore, the main objective of this study was to analyse the social impacts of two scenarios (**Figure 1**): i) organic waste piled up without any treatment (previous scenario); ii) implementation of low-tech digester to treat organic waste and produce biogas and a biofertiliser (digestate).

2. METHODS

A Social Life Cycle Assessment (SLCA) was carried out to assess the potential social impacts of the anaerobic co-digestion of cattle manure and cheese whey using a low-tech digester implemented in a small-scale farm in the Colombian Andes. The system boundaries considered for this study include the acquisition of materials, fuels and fertilisers, the construction and operation of the digester and the use on land of the digestate (food crop production). Data was acquired on-site by surveying stakeholders and experts. Stakeholders included the farmers/digester users, the local community, society, value chain actors, and consumers. Identified impact categories were human rights, labour conditions, cultural heritage, socio-economic repercussions, human health and education (UNEP, 2020). Moreover, subcategories and indicators were selected for each impact category.

3. RESULTS AND DISCUSSION

Results showed that the implementation of a low-tech digester had several social benefits. Particularly, farmers perceived improvements in working conditions, education, poverty reduction and enhancement of the economic status. On the other hand, the local community benefits from the digester in access to material resources, improvement of education and food security. In the case of consumers, their relationships with producers was perceived as improved.

4. CONCLUSIONS

The main results of this study show that the implementation of low-tech digester has a better social performance in comparison to piling up organic waste. As seen in **Figure 2**, the main social benefits include: i) poverty reduction, economic benefits and education improvement for farmers; ii) improvement of the access to material resources (technologies, fuels, fertiliser, food) and education for local community. The dissemination of this technology can enhance farmers standard of living and boost sustainability circular economy in small-scale farms.

5. ACKNOWLEDGEMENTS

The research was funded by the Centre for Development Cooperation (CCD) of the Technical University of Catalonia (UPC) (CCD2023-B001), and the Universidad Industrial de Santander, Colombia. Marianna Garfí is grateful to the Government of Catalonia (Consolidated Research Group 2017 SGR 1029). Kurt Ziegler-Rodriguez is grateful to the Universitat Politècnica de Catalunya and Banco Santander for the financial support of his predoctoral grant FPI-UPC (2022 FPI-UPC_21).

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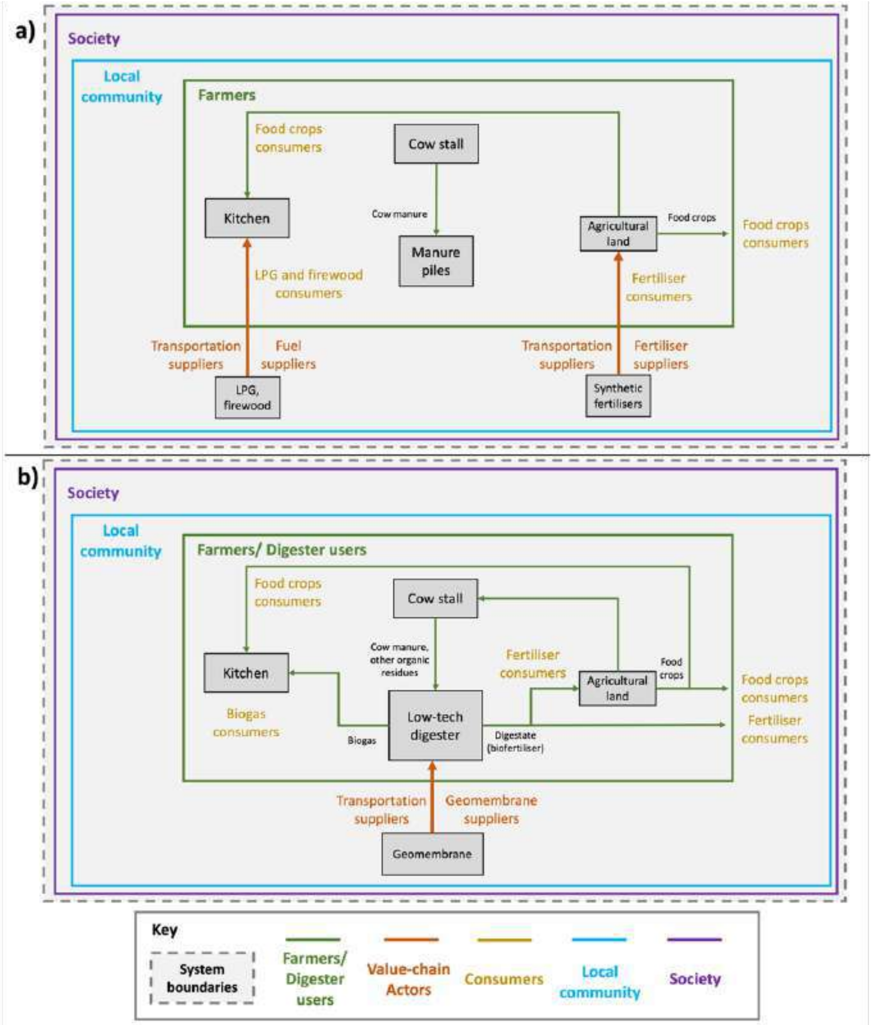

Figure 1. System boundaries of the studied systems: a) Scenario with no digester. b) Scenario with low-tech digester.

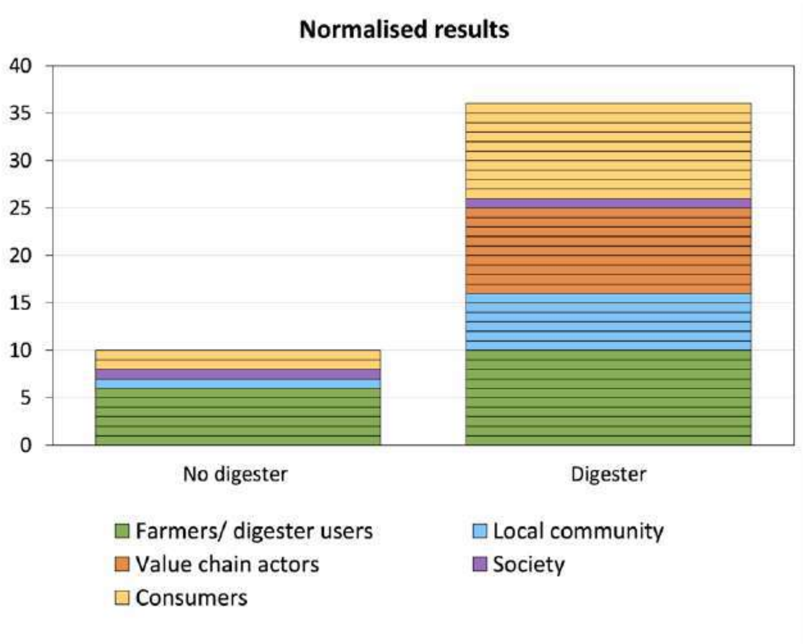

Figure 2. Normalised results grouped by scenario.

Life cycle impact assessment: new developments (I)

Development of a regionalized dynamic weighting method for the environmental impact of alternative protein sources

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1. INTRODUCTION

Our study proposes an eco-potential approach for global protein sources, highlighting the significant environmental impact for food production in developed countries (Nemecek et al., 2016). Key indicators (GHGEs, WU, ALU, and EU) directly relate to agri-food systems, with over a quarter (26%) of global GHGE originating from food and agriculture (Poore and Nemecek, 2018). Protein consumption, mainly from animal sources, cause substantial environmental impacts. Environmental and demographic factors (country arable land, population) serve as normalization factors. Our practical weighting system aids policymakers in interpreting LCA results on protein sources within a country´s environmental context, facilitating informed decision-making.

2. METHODS

The environmental impacts and eco-potentials of target products were calculated in four steps outlined in Figure 1. In step (I), country-level annual values for arable land use, greenhouse gas emissions, water use, and energy use were selected. Step (II) involved normalizing Regional (Country) Impact Weights (RIW) for the chosen impact categories, including ALU, GHGE, WU, and EU. Protein-related RIWpr 1-4 values were also determined. For protein related RIW calculation (step Ia), data on dietary protein supply (g/capita/day) per country and the environmental impacts (GWP, WU, EU, and ALU) of food protein sources were collected. Step (IIa) calculated values for RIWpr1-4 by normalizing protein-related impact indicators (ALUpr, GHGEpr, WUpr, and EUpr) by ALU and population. In step (III), eco-potential points (EPP1-4) for target food products in different countries were calculated by dividing the overall average environmental impacts by regional (country) total impact weights (RIW1-4), and similarly with protein-related regional (country) impact weights (RIWpr1-4) in step (IIIa). Finally, steps (IV and IVa) integrated product-specific eco-potential points (EPP1-4) by summing them for the final result.

3. RESULTS AND DISCUSSION

The results reveal a dynamic eco-potential, shaped by evolving per capita impacts at the country level. Higher country-weighted impact for a specific protein source suggests preferable production in a country with a lower relative impact weight. Although absolute impacts from protein production may be higher in a given country, its country-weighted impact could be lower. In Fig. 2, eco-potential points for A (Beef) and B Tenebrio molitor (mealworm) are shown.

4. CONCLUSIONS

Eco-potential signifies a regionally relevant impact value for a product, considering both its absolute environmental impacts and relative sustainability withing regional conditions. This dual perspective contributes to a more sustainable food system.

5. ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my supervisors for their unwavering support throughout this research work.

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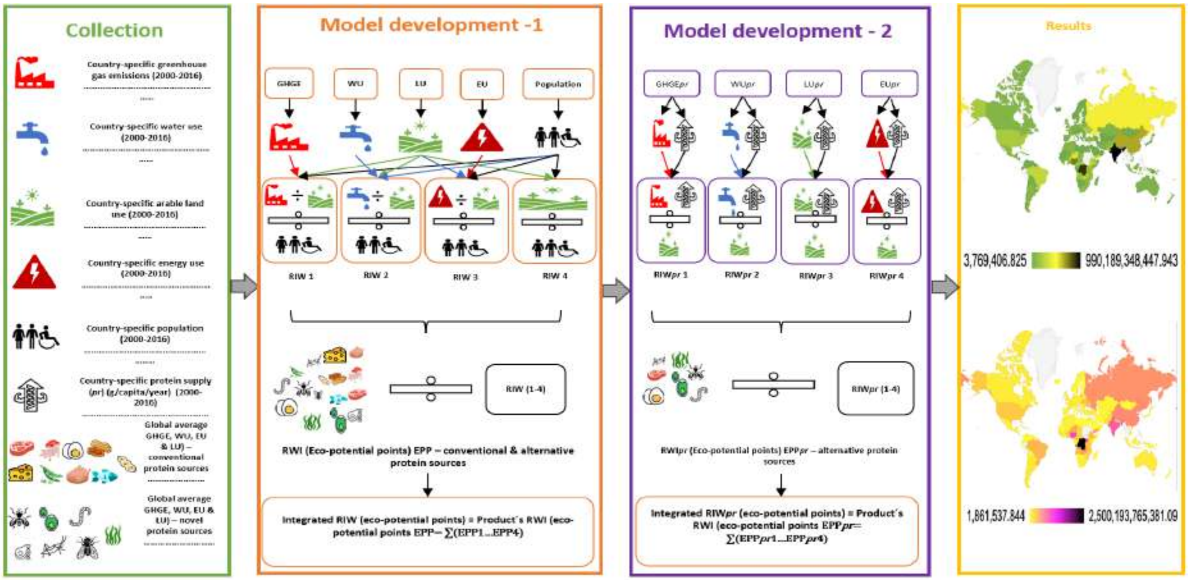
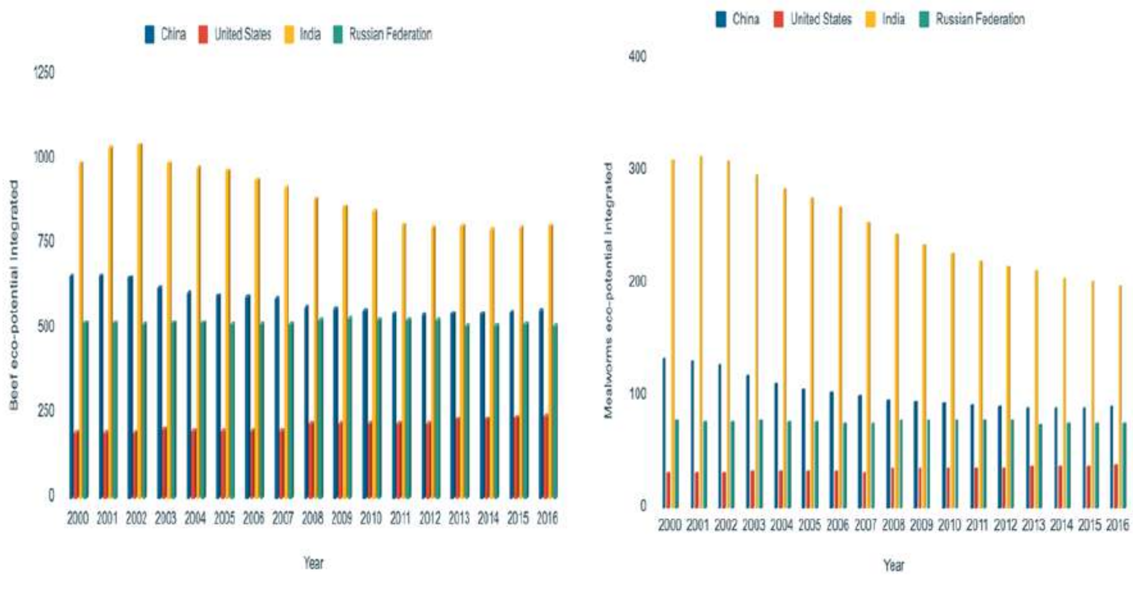


Fig. 1. Methodological framework for estimating the relative environmental impact and eco-potential of protein source production.

Note: *Pr* – protein; GHGE – greenhouse gas emissions; WU – water use; EU – energy use; LU – land use; RIW – relative impact weight; RWI – regional weighted impact; EPP – eco potential point; GHGE*pr* – greenhouse gas emissions per protein supply; WU*pr* – water use per protein supply; LU*pr* – land use per protein supply; EU*pr* – energy use per protein supply; RIW*pr* – regional weighted impacts per protein supply



A B

Fig. 2. Eco-potential of A (beef) and B Tenebrio molitor (mealworm) production, values expressed in eco-potential points

Ecotoxicity assessment of pesticide use based on Japanese PRTR data

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1. INTRODUCTION

Reports on pesticide emissions under Japan's PRTR (Pollutant Release and Transfer Register) system do not provide data on emissions by destination and assume that all emissions are released into the soil. LCA studies have been used mainly in Europe emission rate estimation models and ecotoxicity assessment factor models for pesticides. However, there are no models suitable for Japan. Therefore, we aimed to develop pesticide emission rate estimation and impact assessment models suitable for Japan and to assess the ecotoxicological impacts of pesticides used in Japan.

2. METHODS

2.1 Pesticide emission rate estimate model (LCI model)

In this study, a model was developed to estimate the rate of pesticide discharge, considering the differences between formulations and sprayers. We set boundaries (Table 1) and defined what went outside these boundaries as “emissions”. The liquid pesticides were quantified in air ($f_{airborne}$), off-field soil (f_{drift}), on-field soil($f_{agri.soil}$), and on crops (f_{crop}) (Eq.1). Atmospheric residue rates were estimated using $f_{airborne}$ considering differences between boomsprayer and aerial, and between insecticides/fungicides and herbicides, Drift curves were used to determine the emission rate from each application point (f_{drift}). Both granules and soil fumigants were applied to 100% of agricultural soil ($f_{agri.soil}$). The method described by Nemecek et al. (2022) was used to connect the emission rates and USEtox models (Eq.1a-1e). We divided f_{drift} into freshwater, natural and agricultural soils using the land use percentages described in the Land White Paper (Eq.1b-1d). These relationships are summarized in Table 1.

2.2 Characterization Factors (CF) for Ecotoxicity

We developed ecotoxicity CF (Characterization factors; PAF.m^3.d/kg$_{emitted}$) using the USEtox model (Fantke et al. 2017), however, the geo-climatic information used for the fate exposure factors was compiled only in Japan. We also created only Japan Physical property information for pesticides not provided in the USEtox database was obtained from EPI SuiteTM and toxicity data from ECOTOX. As a result, we created CFs for 143 of 168 active ingredients listed as Class I chemicals in Japanese PRTR data. This is the most recent dataset of pesticides discharged from Japanese cropland.

3. RESULTS AND DISCUSSION

We assessed the ecotoxicological impacts (PAF.m³.d/year) using the LCI and CF model in Japan. In the LCI model, comparing f_{drift} results with existing research models, boom sprayers were smaller in this model, while aerials and unmanned helicopters were more strongly affected by the drift curve, with emission rates ranging from 4% to 42%.

We also assessed the ecotoxicological impacts using PRTR data, which showed that insecticides and fungicides contributed about 60% and soil fumigants did for 34% of the total. Furthermore, we analyzed the top 10 substances with the highest ecotoxicological impacts and Figure 1 showed that chloropicrin (soil fumigant) had the highest emissions, tolfenpyrad (insecticide) was transferred the most from soil to freshwater, and oxine-copper (fungicide) had the highest emissions and toxicity.

4. CONCLUSIONS

We developed two models to assess the ecotoxicological impacts of pesticides in Japan. However, we could not assess metal-based pesticides and some pesticides because of a lack of data, which may have led to an underestimation.

5. ACKNOWLEDGEMENTS

We would like to thank Dr. Kobara for his advice regarding the experiments to determine the rate of air emissions and pesticides and also thank Editage (www.editage.jp) for English language editing.

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Table 1. Summary of Pesticide Emission Rate Estimate Model

Boundary	Ground surface to 100m above ground		
	Freshwater	Natural soil	Agricultural soil
Japanese land use rate (-)	0.036	0.848	0.116
Method	Emission compartments	Nemecek et al. (2022) method	Connected CF compartment
Liquid	Air ($f_{airborne}$) Off-field soil (f_{drift}) On-field soil ($f_{agri.soil}$)	$F_{air,C^*}= f_{airborne}$ (Eq.1a) $F_{fw,C^*}= f_{drift}\times 0.036$ (Eq.1b) $F_{nat.soil,C^*}= f_{drift}\times 0.848$ (Eq.1c) $F_{agri.soil,C^*}=f_{agri.soil}+ f_{drift}\times 0.116$ (Eq.1d)	F_{air,C^*} F_{fw,C^*} $F_{nat.soil,C^*}$ $F_{agri.soil,C^*}$
Granule Soil fumigant	100% On-field soil ($f_{agri.soil}$)	Nothing $F_{agri.soil,C^*}=f_{agri.soil}$ (Eq.1e)	$F_{agri.soil,C^*}$

*C means Continents

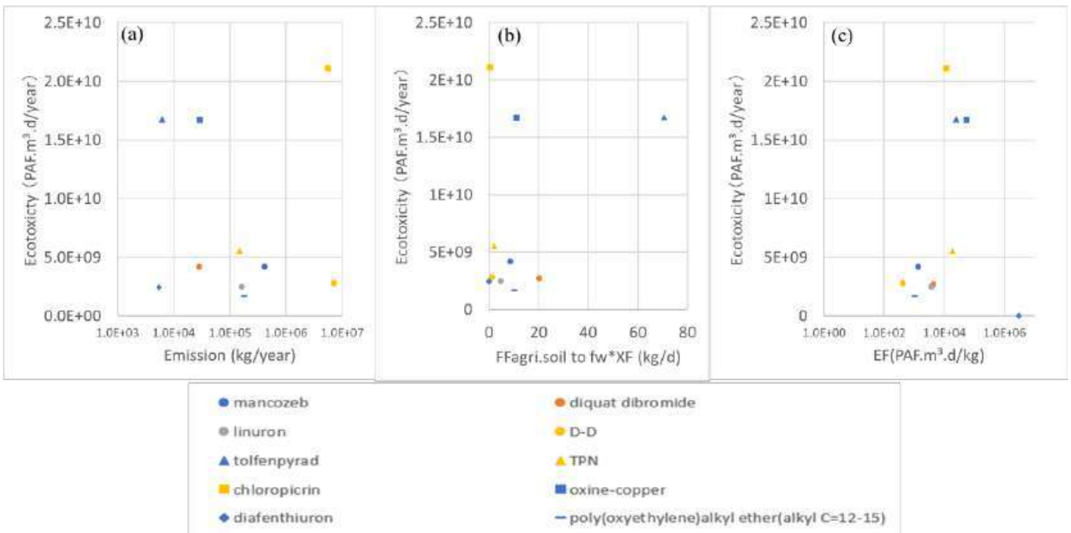

Fig.1 Relationship to ecotoxicological impact assessment

(a) Emissions (kg/year) (b) Amount transferred from agricultural soil to freshwater (kg/d)

(c) Intensity of toxicity (PAF.m^3.d/kg)

Framework for evaluating animal welfare in life cycle assessments of diets

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1. INTRODUCTION

While developments in society, science and philosophy point to an increasing relevance of animal welfare (AW) concerns (Meijboom et al., 2023), the impacts of diets on animals have so far largely remained unexamined. Modelling these impacts would represent an important improvement of existing sustainability assessments and could be utilized to investigate trade-offs and synergies with other impact categories (Bartlett et al., 2023). The approaches of the small number of life cycle assessments (LCAs) that have already conducted an AW assessment of diets are incongruent and leave room for methodological improvement (Turner et al., 2023). We address this by developing a conceptual framework that is applicable to LCA studies and systematizes key decision steps for AW assessment of human diets.

2. METHODS

To develop the conceptual framework, we conducted a critical review of existing AW assessments of diets. We investigated the core elements of the assessment approaches used in these studies, and derived a taxonomy with key decision steps for assessing AW impacts of diets. Based on this, we conducted a targeted literature search on the individual elements of the taxonomy in the fields of AW science and animal ethics. We used the AW science literature to work out quality criteria and technical challenges; and the animal ethics literature to discuss the normative requirements and implications of AW assessments of diets.

3. RESULTS AND DISCUSSION

We identified five main decision steps for AW assessments of diets (see Figure 1). The first refers to the assessment type: ethical, welfare and risk assessments can be distinguished here. The second step refers to the inclusion of domesticated as well as non-domesticated and un-intentionally affected animal species in the assessment. In the third step, the AW components are determined, including the AW concept employed and how the time dimension is considered. Based on this, in step four, proxy indicators that best represent the AW components are selected and graded. Finally, in step five, the indicators are aggregated by defining weightings at the level of animals of the same species, as well as by weighting impacts across species. Moreover, this step requires a decision on how to take into account the number of animals affected by a diet and how to classify the final assessment score. Each decision goes along with different technical and normative challenges. To address the normative challenges, ethical reflections are required to inform and examine unavoidable value considerations underlying the assessment (Coghlan, 2022). Addressing the technical challenges involves trade-offs between different quality criteria – e.g., the feasibility, accuracy and completeness of the assessment – that need to be resolved against the specific assessment aims. We discuss these challenges in connection with the individual decisions and provide recommendations for assessing AW at diet level and for future research in this area.

4. CONCLUSIONS

Assessing AW in diet modelling is an emerging and important research topic. We provide guidance for LCA researchers by highlighting the main decision steps and the challenges and normative assumptions involved in each step, as well as by discussing solutions considering the objectives and limitations of AW assessments of diets.

5. ACKNOWLEDGEMENTS

Funding was provided by the Swiss State Secretariat for Education, Research and Innovation, for the Horizon Europe Project FEAST (grant number 22.00156, 101060536).

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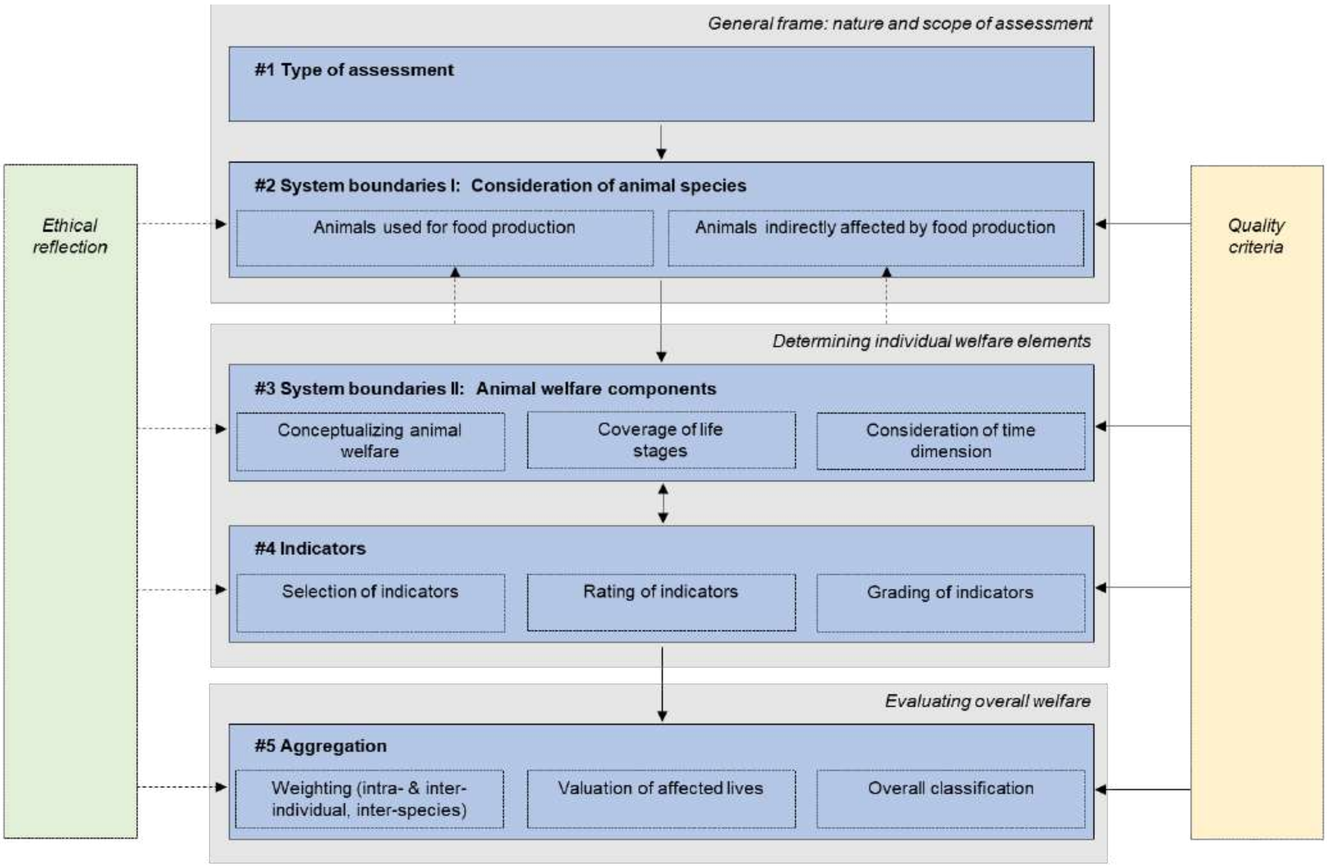

Figure 1. Key decision steps and considerations for evaluating animal welfare in life cycle assessments of diets (preliminary version)

Biodiversity impacts of major crops – Spatially explicit characterization factors for 152 major crops

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1. INTRODUCTION

The global food system and its associated agricultural expansion, and intensification are identified as the primary driver for ongoing biodiversity loss (Benton et al., 2021). Life cycle impact assessments has been used increasingly for assessing the sustainability of food production and processing systems (Crenna et al., 2019). However, the inclusion of biodiversity impacts in LCIA is rare due to lacking accepted methodological approaches, weaknesses considering the included drivers and the geographical coverage (Crenna et al., 2020). Although a range of academic case studies of current biodiversity impact assessment methods exist, a broad application among LCA-practitioners has not yet become established. Insufficient guidance, data gaps, limitations in geographical coverage, methodological complexity, low robustness, or reliability and other reasons which limit a widespread application were identified (Lindner et al., 2019). The presented paper provides an approach to solve some issues LCA-practitioners are facing when aiming to calculate biodiversity impacts in global food supply chains. Spatially explicit characterization factors for assessing the biodiversity impact of 152 major crops in 252 countries were calculated based on the method proposed by (Lindner et al., 2019), (Lindner et al., 2020).

2. METHODS

The biodiversity impact assessment method proposed by (Lindner et al., 2020) was adapted to calculate spatially explicit characterization factors. The provided parameter set was reduced to four parameters (pesticide input, nutrient input, tillage and field size) and adapted to match the data requirements. Pesticide inputs were available for 20 of the most used active ingredients for ten different crops (six specific and four aggregated crops). In total, the application rate of around 100 active ingredients was characterized using the LC-Impact characterization factors for terrestrial ecotoxicity in combination with the PestLCI consensus fate model to generate global ecotoxicity maps. The specific biodiversity contribution was calculated by adapting the biodiversity contribution function priorly used in Agribalyse (Lindner et al. 2022). A similar process was followed with tillage, field size and nutrient input parameters to generate biodiversity contribution maps and calculate the land use quality difference of 44 specific crops and aggregated crop groups. The aggregated crop groups were disaggregated by matching the crop groups with corresponding FAO crops and multiplying the quality difference with yield data from FAOSTAT. The biodiversity impacts of a total of 152 different crops from 252 countries have been assessed. All calculations were performed in R.

3. RESULTS AND DISCUSSION

The biodiversity impact value (BVI*m^2*a/kg crop) of 152 different major crops in 252 countries based on the adapted biodiversity impact assessment framework presented by (Lindner et al. 2019, 2020, 2022) was calculated. Global and spatially explicit characterization factors for 152 major crops were derived. Figure 1 presents an excerpt of the results aggregated on country level. Besides the main results several side-results could be generated. These include global terrestrial ecotoxicity maps of pesticide use for major crops and aggregated crop groups.

4. CONCLUSIONS

The aim of this study was to promote biodiversity impact assessment among LCA-practitioners by providing easily applicable spatially explicit global characterization factors for major crops. In doing so, the present work supports a wide application of biodiversity impact assessment in the global food-industry. Although these characterization factors are readily applicable, data gaps and uncertainties limit the accuracy of the results. Further research, more and higher precision of global GIS-Datasets can reduce uncertainties and enhance biodiversity impact assessment results.

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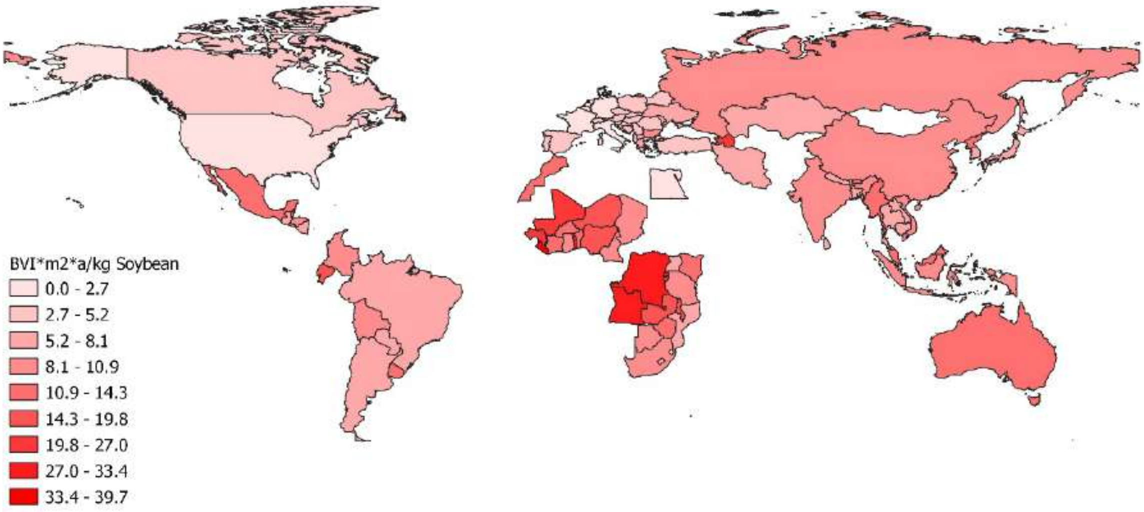

Figure 1: Country-aggregated biodiversity impact of one kg soybean

Parameter	Data basis	Reference year	Reference
Pesticide Use	Global maps of 20 of the most-used pesticide active ingredients for 6 dominant crops and 4 aggregated crop classes.	**2020**	**Maggi et al. 2020**
Tillage	Presents a global spatially explicit data set on the distribution of tillage practices for around the year 2005.	**2008**	**Porwollik et al. 2018**
Nutrient input specific	Provides spatially explicit N-application rates for 17 major crops including atmospheric deposition.	**2000**	**Mueller et al. 2012**
Nutrient input generic	Global nitrogen and phosphorus fertilizer application rates for agriculture production	**2013**	**Lu & Tian 2016**
Field Size	Estimations of the global distribution of field sizes	**2017**	**Lesiv et al. 2018**

Table 1: Parameters and global reference datasets used for biodversity impact assessment.

Assessing the impact of vegetables on biodiversity in life cycle assessment

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1. INTRODUCTION

Biodiversity loss in agricultural landscapes due to intensification of agriculture and degradation and loss of semi-natural habitats is a major issue that life cycle assessment (LCA) methods intend to address. No current LCA method is able to assess and compare impacts on biodiversity of vegetable production systems as a function of farming practices and the local context. The expert system SALCA-BD (Swiss Agricultural LCA—Biodiversity) (Jeanneret et al., 2014) integrates biodiversity into agricultural LCA as an independent impact category. Its detailed analysis allows for comparison of fields or farms by considering the practices applied to crops and semi-natural habitats (SNHs). It was initially developed for cropland, grassland, and SNHs and later adapted to orchards by van der Meer et al. (2017). The aim of this study was to adapt SALCA-BD to vegetable crops, which had not been included in cropland, by adding habitats and practices specific to vegetable production systems.

2. METHODS

SALCA-BD is based on an inventory of the habitats found on a farm, including crops and SNHs, and a list of practices that can be implemented in these habitats. The habitats and practices are associated with coefficients reflecting their influence on biodiversity. The coefficients, combined with the practices selected by the user, result in scores for 11 indicator species groups, which can be aggregated to a single final biodiversity score at field, rotation, and farm levels. Given the many types of vegetables, we used a clustering method to create a few categories that grouped vegetables that had similar potential to host biodiversity. Based on a literature review and consultation with experts, we attributed the coefficients to the habitats and the practices for vegetables. We tested the expert system at field and farm levels using scenarios and a farm case study. We quantified effects of changes to practice intensities at the field level on biodiversity using a field of white onion as an example. A farm in Brittany was used as a case study. It produced organic vegetables and rye on 21 ha of open fields in a four-year rotation, in addition it had 0.9 ha of extensive grassland, 2.6 ha of hedgerows around the fields, and 0.3 ha of ruderal area.

3. RESULTS AND DISCUSSION

White onion had lower biodiversity scores with high-intensity practices than with low-intensity practices, in both open field and greenhouse, for each of the indicator species group and for the aggregated biodiversity score (Table 1). The farm's score was 7.4 for its cultivated area and 14.6 when including its SNHs (Figure 1). At the field level, potato had the lowest score (5.3) and Jerusalem artichoke the highest (8.6). The SNHs had scores from 20.6 (grassland) to 22.7 (hedgerow).

The results highlighted the importance of SNHs for preserving biodiversity, in addition to low-intensity practices, which indicates that assessment at the farm level is more informative than that at the field level. Because it considers habitats and practices in detail, SALCA-BD is useful for assessing biodiversity at field and farm levels and for comparing farming systems with the similar land uses and management types (organic or conventional), which other LCA methods for assessing biodiversity cannot do. As SALCA-BD does not consider impacts of the background system, combining SALCA-BD with comprehensive methods for assessing impacts on biodiversity is a promising perspective for more complete assessment.

4. CONCLUSIONS

This study showed that SALCA-BD can model vegetable production systems when vegetables with similar characteristics are grouped into a single habitat. Few studies in the literature have investigated impacts of vegetable production systems and their associated practices on biodiversity. The farm case study highlighted the importance of SNHs and low-intensity practices for enhancing biodiversity. SALCA-BD considers field size indirectly when assessing an entire farm, including its SNHs. Consideration of spatial issues and soil biodiversity would increase the value of SALCA-BD. Due to its detailed consideration of habitats and practices, SALCA-BD is useful for assessing biodiversity at field and farm levels and for ecodesign. Impacts of the background system could be considered by combining SALCA-BD with comprehensive methods for assessing biodiversity.

5. ACKNOWLEDGEMENTS

The authors thank the experts who contributed to this version of SALCA-BD.

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Table 1. **Biodiversity scores for white onion grown using low-intensity (Low) or high-intensity (High) practices in an open field or greenhouse for the 11 indicator species groups.** Differences represent the percentage change in High’s score compared to Low’s score.

	Open field			Greenhouse		
Indicator species group	Low	High	**Difference**	Low	High	**Difference**
Field level	7.47	4.71	-37%	5.24	3.30	-37%
Crop flora	24.13	16.41	-32%	16.08	10.61	-34%
Grassland flora	0.00	0.00	-	0.00	0.00	-
Birds	9.06	4.13	-54%	3.75	1.75	-53%
Mammals	4.29	4.03	-6%	2.92	2.75	-6%
Amphibians	2.56	1.55	-40%	0.00	0.00	-
Snails	2.92	2.17	-26%	2.92	2.17	-26%
Spiders	9.85	4.92	-50%	8.10	4.03	-50%
Carabid beetles	7.95	4.66	-41%	7.25	4.39	-39%
Butterflies	5.44	3.12	-43%	3.44	2.00	-42%
Wild bees	3.00	2.21	-26%	3.00	2.21	-26%
Grasshoppers	0.00	0.00	-	0.00	0.00	-

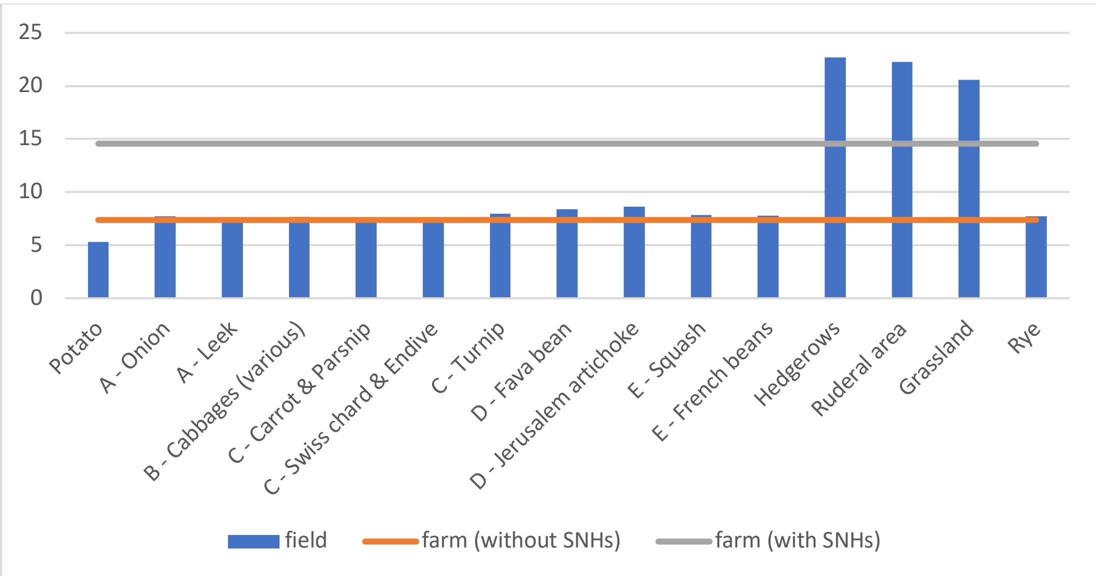

Figure 1. **Biodiversity scores for individual crops and semi natural habitats (SNHs) of an organic vegetable farm, and whole-farm results with and without the inclusion of SNHs.** The capital letter before the name of each vegetable refers to its category.

Characterization factors for land use impacts on terrestrial ecosystem quality considering intensities and fragmentation

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1. INTRODUCTION

Land use is a highly relevant impact category for food systems. As a major threat to terrestrial biodiversity, land use has been included in biodiversity impact assessment for a few decades. However, the complexity of modelling impacts up to an endpoint like ecosystem quality and the need for harmonization across different impact categories imply that impact assessment models are still undergoing further development. Within the Global Guidance for Life Cycle Impact Assessment (GLAM) project in phase 3, the Life Cycle Initiative hosted by UN Environment aims to create a life cycle impact assessment method across multiple impact categories, including land use impacts on ecosystem quality represented by regional and global species richness. A working group of the GLAM3 project focused on such land use impacts and developed characterization factors (CFs) that consider, for the first time, both land use intensities and habitat fragmentation (Scherer et al. 2023a). This conference contribution presents these new CFs.

2. METHODS

The CFs for land occupation and transformation cover five species groups (plants, amphibians, birds, mammals, and reptiles) and five broad land use types (cropland, pasture, plantations, managed forests, and urban land) at three intensity levels (minimal, light, and intense) across 825 terrestrial ecoregions, following two approaches (marginal and average). The CFs build on the species−habitat relationship introduced by Kuipers et al. (2021). This relationship resembles a species−area relationship, but instead of the actual land use area, it uses the equivalent connected area to consider habitat fragmentation. Land use intensities were incorporated by adjusting the habitat affinities for broad land use types at the level of ecoregions using global scaling factors mostly derived from the PREDICTS database. To translate regional to global species loss, we used global extinction probabilities that were also recently updated and extended within the GLAM3 project (Verones et al. 2022).

3. RESULTS AND DISCUSSION

There are noticeable differences among different sets of CFs (Figure 1). CFs using a marginal approach are higher than CFs using an average approach. More intense land use leads to higher potential species losses than less intense use. Amphibians have, on average, the highest CFs, and plants the lowest. The ecoregion-level CFs also exhibit great spatial variation, with values ranging over several orders of magnitude. A contribution-to-variance analysis showed that the CFs for global species loss are most sensitive to global extinction probabilities and habitat affinities.

4. CONCLUSIONS

Among the various sets of CFs provided, the user can choose a set aligned with the study's goal and scope. The CFs are compatible with other CFs developed within the ecosystem quality task force of GLAM3. The CFs are publicly available on Zenodo (Scherer et al. 2023b).

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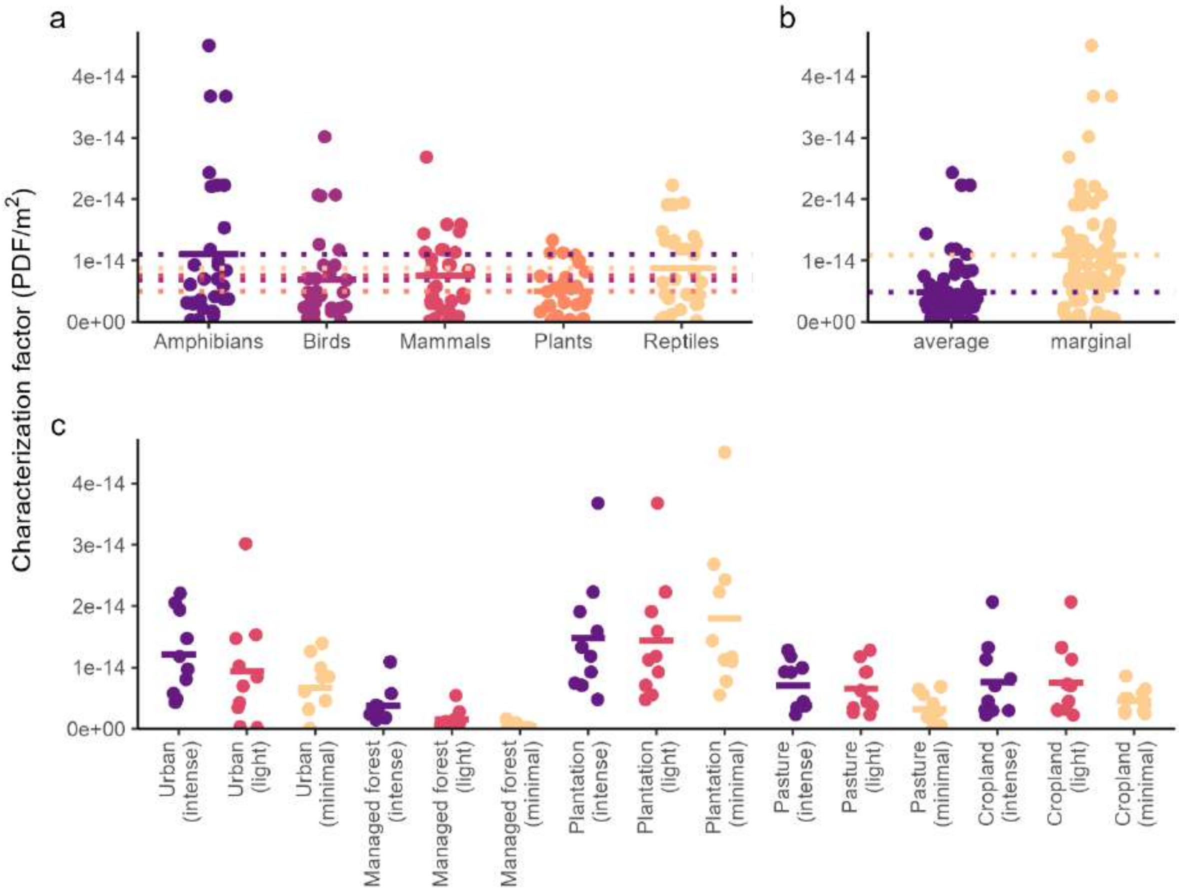

Figure 1. Globally aggregated land occupation characterization factors (represented by the points) for global species loss for different (a) species groups, (b) approaches, and (c) land use classes. The horizontal bars indicate averages of the characterization factors. For the global aggregation in this figure, the ecoregion-level CFs were weighted by land use area. Source: Scherer et al. (2023a)

Life cycle impact assessment: new developments (II)

The effect of El Niño events and climate change in the water scarcity characterization factors based on AWARE

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1. INTRODUCTION

Peru is a country with heterogeneous water use distribution, and agricultural activities concentrated in the basins with the lowest water availability (i.e., those along the Pacific coast). In this region, the effects of quasi-cyclical El Niño events generate increased run-off along the Northern Pacific coast, as well as detrimental impacts in urban and productive sectors. In addition, projections highlight high susceptibility to the effects of climate change. In this sense, the present study aims to evaluate the effect of El Niño events on water scarcity characterization factors (CFs) based on the AWARE model (Boulay et al., 2018) and calculate the future CFs from a climate change perspective.

2. METHODS

The calculation of CFs in El Niño events, on the one hand, was carried out using a retrospective approach; hence, water availability was gathered from historical data from gauging stations. Human water demand was estimated based on the assumption that water use is directly proportional to the Gross Domestic Product (GDP) of the manufacturing sector (industrial water demand), and harvesting surface (agricultural and livestock water demand). Domestic water demand were calculated based on the population in each watershed. On the other hand, the CFs in the climate change context were estimated based on a prospective approach. Therefore, future water availability data for the period 2035-2065 in the RCP8.5 scenario were obtained from Lavado-Casimiro et al. (2021). Future human water demands were calculated based on the study by Sanchez-Matos et al. (2023). The ecosystem demand was calculated based on the approach by Andrade et al., (2020).

3. RESULTS AND DISCUSSION

El Niño events can significantly influence water scarcity CFs, especially along the northern Peruvian coast, since increased precipitation leads to increased runoff. However, this variation can cause more damage than actual water gains, due to the water deprivation generated by the interruption of water collection, storage, and distribution systems for agricultural and domestic uses. Interestingly, this scenario is not well captured in the original CFs (Tables 1 and 2), which may be underestimating the actual level of water scarcity.

Future water scarcity CFs revealed that in the South Pacific coast watersheds, levels of water scarcity are expected to increase, while in most of the Amazon watersheds, low levels of water scarcity would be maintained.

4. CONCLUSIONS

Water scarcity CFs are affected by El Niño events, which may underestimate the impacts of water scarcity of agricultural products along the North Pacific coast. Furthermore, since water scarcity is a site-specific environmental impact, it can vary due to the effects of climate change, suggesting that the AWARE method should be updated periodically to better represent the temporal variation of this impact category.

5. ACKNOWLEDGEMENTS

We would like to thank the *European Research Executive Agency* for funding the BAMBOO Project (101059379). Dr. Joan Sanchez-Matos wishes to thank the *Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica* (CONCYTEC) from the Peruvian government for funding his postdoctoral contract PE501080172-2022-PROCIENCIA.

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Table 1. Comparison of original annual water scarcity characterization factors (CFs), with CFs in El Niño events, an updated CFs (2020) of northern Peruvian coast watersheds. Results reported in m^3eq/m^3.

Watershed	Original	Future[1] (ACCESS)	Future[2] (MPI)	Future[3] (HadGEM2)	Updated (2020)	2015*	1997-1998*	1987*	1983-1984*
Tumbes	28.3	0.4	0.5	0.4	0.4	0.7	0.4	0.3	0.2
Piura	4.9	59.9	64.8	50.2	59.7	82.3	40.3	-	-
Chira	4.9	1.1	2.6	2.3	1.5	34.6	10.8	5.8	1.1
Chancay-Lambayeque	58.1	1.4	2.1	1.4	2	21.5	19.8	3.2	2.8
Santa	4.7	39.6	32.8		25.2	2.4	1.7	1.8	1.3
Chicama	25.4	7.4	14.8	5.1	7.8	31.4	13.4	44.5	4.3

*years registered as El Niño event at least during 12 months, [1] FC calculated with ACCESS1-0 model, [2] FC calculated with MPI-ESM-LR model, [3] FC calculated with HadGEM2-ES model

Table 2. Comparison of original monthly water scarcity characterization factors (CF^s), with CFs in Coastal El Niño event (2016-2017), an updated CFs (2020) of northern Peruvian coast watersheds. Results reported in m^3eq/m^3.

Watershed	DEC	JAN	FEB	MAR	APR	MAY
CFs in El Niño event (2016-2017)						
Tumbes	0.8	0.2	0.1	0.1	0.1	0.1
Piura	100.0	100.0	0.2	0.1	0.2	0.7
Chira	100.0	100.0	1.6	0.3	0.6	1.6
Chancay-Lambayeque	10.9	1.0	0.6	0.2	0.3	0.5
Santa	1.3	0.5	0.4	0.2	0.3	0.7
Chicama	100.0	2.1	0.5	0.1	0.2	0.6
Original CFs						
Tumbes	3.7	1.1	0.5	0.3	0.4	0.9
Piura	28	5.6	2.3	1.6	1.4	2.2
Chira	28	5.6	2.3	1.6	1.4	2.2
Chancay-Lambayeque	2.2	6.1	4.6	2.4	100	100
Santa	0.9	0.7	0.5	0.3	0.6	4.4
Chicama	7.5	8.7	3.1	1.5	5.9	100
Updated CFs (2020)						
Tumbes	0.7	0.2	0.1	0.1	0.1	0.1
Piura	100.0	100.0	1.1	0.5	0.6	1.4
Chira	2.1	0.7	0.3	0.2	0.2	0.3
Chancay-Lambayeque	2.5	1.6	0.7	0.4	0.4	0.6
Santa	2.0	1.2	0.7	0.5	0.8	2.3
Chicama	5.1	1.7	0.7	0.4	0.6	1.6

Drivers of trends and uncertainty in prospective water scarcity impact assessment with AWARE2.0

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1. INTRODUCTION

More than 75% of global water consumption result from irrigated agriculture [1]. Therefore, robust water scarcity impact assessment methods are indispensable for food sector LCAs. The AWARE (Available Water Remaining) method, a consensus-based midpoint approach for water consumption impact assessment, has recently been updated and refined [2], [3]. Since work in prospective LCA suggests that AWARE characterization factors (CFs) are sensitive to climate change and increasing human water consumption [4], prospective studies seem to require future projected AWARE CFs. However, AWARE is subject to uncertainty, especially due to its hydro-logical input data [5]. Simulating climate data (e.g., precipitation) for hydrological future projections increases uncertainty. This work for the first time employs an ensemble approach to increase the robustness of future projected AWARE2.0 CFs, assessing model uncertainty and differentiating influences of climate change and water consumption.

2. METHODS

CFs are calculated for three future scenarios using future projected water availability and consumption data. 15 combinations of climate simulations with hydrological models, keeping irrigated areas and non-irrigation water demand constant, provide input data for each scenario (Figure 1). A second dataset is created by adjusting the 45 realizations with projected water demand. For each realization, AWARE2.0 CFs are derived in 5-year time steps until 2100. Statistical analysis focuses on the following questions: How do the different future scenarios affect trends in the CFs? How do climate change and human water consumption contribute to the CF change? Is the choice between different future scenarios relevant for LCA results? Finally, future projected CFs for use in prospective LCA will be provided, along with comprehensive uncertainty information.

3. RESULTS AND DISCUSSION

On global average, the climate simulations might agree on trends in CFs, but the uncertainty of the climate data appears to remain relevant to AWARE2.0. While in some parts of the globe the climate simulations seem to agree on the signs of long-term CF trends, there seems to be a significant portion of watersheds where simulations disagree (Figure 2). Given this uncertainty, we will determine whether and where the choice of the “right” future scenario might be irrelevant to LCA. [6] suggest that in some regions increasing human water consumption might influence water scarcity stronger than climate change alone. Comparing realizations with and without dynamic water consumption, we will assess whether this also applies to AWARE2.0.

4. CONCLUSIONS

Existing projections of AWARE do not adequately illustrate the underlying uncertainty. This work for the first time improves the robustness of future projected AWARE2.0 CFs in an ensemble approach. The results increase the interpretability of both retrospective and prospective LCA by evaluating possible future trajectories of the CFs, revealing model uncertainties, and differentiating the influence of climate change and human water consumption.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the work of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) and specifically thank Hannes Müller Schmied, Naota Hanasaki, and Peter Burek for providing data and support.

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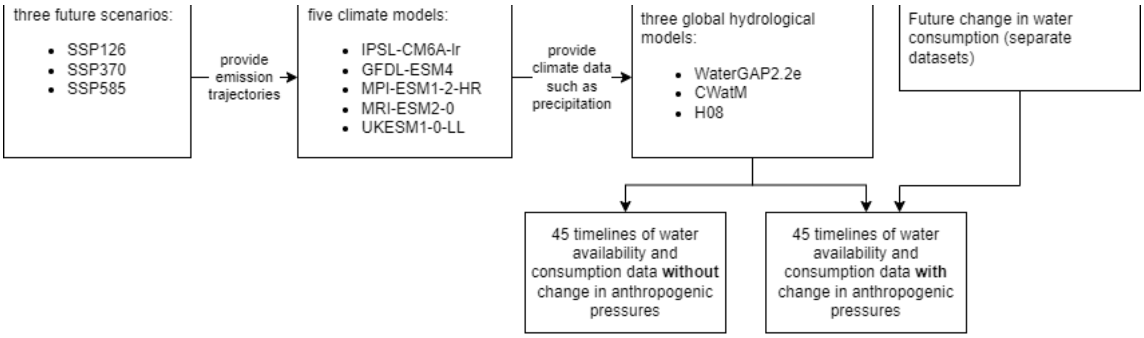

Figure 1. 45 timelines each of future projected water availability and consumption data with and without change in anthropogenic pressures are used to future-project AWARE CFs, evaluate their trends and assess their uncertainty.

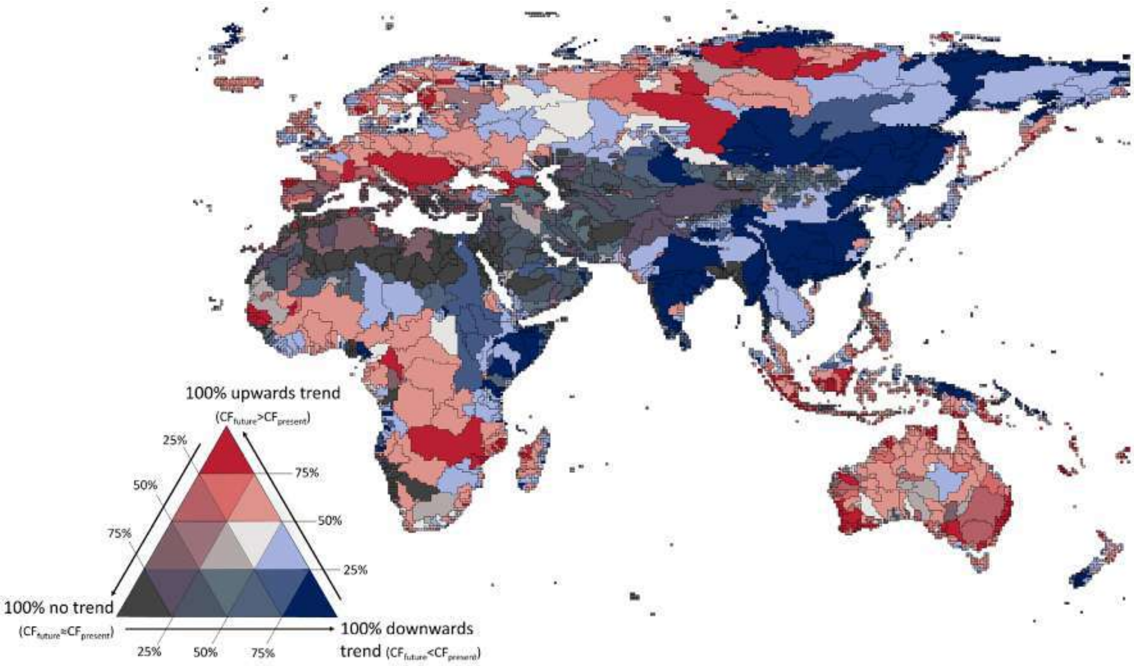

Figure 2. Eastern Hemisphere: Agreement of models on long-term (present until the end of the 21st century) trends in AWARE2.0 CFs for August in SSP126. This figure uses five climate models providing input to three hydrological models, resulting in 15 different realizations of the same future scenario. "100% no trend" therefore indicates where all 15 realizations show no trend in CF, e.g. because the CFs already exceed the cut-off at 100 m^3 world-eq./m^3. The light colours in the "no trend" bin of 0% – 25% indicate high disagreement between realizations.

Resource criticality in LCIA: regionalised characterisation factors for water and land

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1. INTRODUCTION

Food systems rely heavily on land and water resources, which are under growing pressure. Resource criticality assessment methods investigate the extent to which a resource may become a limiting factor for a product, a sector or a country according to various dimensions, including geological, economic and geopolitical. These methods have been successfully applied to LCAs of high-tech products to characterize mineral resource supply risk. Applying these methods to food systems requires considering additional resources, including water and land. This work extends current supply risk framework providing new characterisation factors for these two key resources, considering spatial variability. The approach quantifies the accessibility of water and land, and is therefore complementary to the land and water use indicators already available in LCA. In addition, it allows all resources (mineral, land and water) to be considered within the same metric. The applicability and interest is discussed by means of LCA food product case studies.

2. METHODS

Supply Risk (SR) characterisation factors are derived from the resource criticality method of the Joint Research Centre (Blengini *et al.*, 2017). This method has been originally developed for mineral resource and is recommended for use in LCA due to its scientific robustness, transparency, applicability and high level of acceptance (Hackenhaar *et al.*, 2022). The SR framework is implemented in land and water resources with a mapping of SR components of the original context adapted to the new resources, where appropriate (see Table 1). Land and water being local resources, their accessibility is strongly influenced by local drivers. The developed SR are hence regionalized at the country level with a global coverage. Furthermore, as land and water supply shortages can occur due to limited physical quantities, resource scarcity indexes are included into the SR. The AWARE index (Boulay *et al.*, 2018) is used for water, and a land stress index based on the same methodology is proposed. The LCIA resource supply risk characterisation model is then developed according to the approach proposed by Santillán-Saldivar *et al.*, (2022). The importance of resource use is quantified by the physical amount of resource recorded in Life Cycle Inventories of products or services, i.e. land occupied for land SR and water withdrawn for water SR. The SR are then applied to LCAs of food products in order to evaluate the implementation of the approach.

3. RESULTS AND DISCUSSION

Figure 1 shows the SR map for land and Figure 2 shows the SR map for water. The results make it possible to compare the accessibility of land and water between countries on the basis of physical, economic and geopolitical parameters. SR indexes are hence different from resource scarcity indexes. Countries with high resource scarcity indexes (e.g. Australia for water or India for land) may have low SRs, as the resource accessibility can be improved through for instance resource management (land administration, water management) or decreased resource concentration. The LCA case studies show the interest and feasibility of applying SR methods to food products. Indeed, it allows to determine the main critical resources over the products life cycles and to identify products least vulnerable to critical resources.

4. CONCLUSION

The developed land and water SR characterisation factors allow to assess resource accessibility along the life cycle of food products. Further development could focus on finer spatial resolution of the indexes, or integrating resources quality parameters (e.g. soil for land).

5. ACKNOWLEDGMENT

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Table 1 : Adaptation of the Supply Risk indexes for mineral resources to land and water for the Joint Research Centre criticality method.

Resource Supply risk		
Original parameter for mineral resources	**Adaptation to land**	**Adaptation to water**
Global import concentration	*Not applicable*	*Not applicable*
Import Reliance	-	Import Reliance
Not included	Land stress	Water stress
EU import concentration	Internal Land concentration	Country import concentration
World Governance Indicator	Land Administration Quality	Integrated Water Resource Management
Trade Restriction	Land transaction restriction	Transboundary Basin Cooperation
End of Life Recycling Rate	Land Recycling	Non-conventional water resource rate
Substitution Index	Human Development Index	Human Development Index

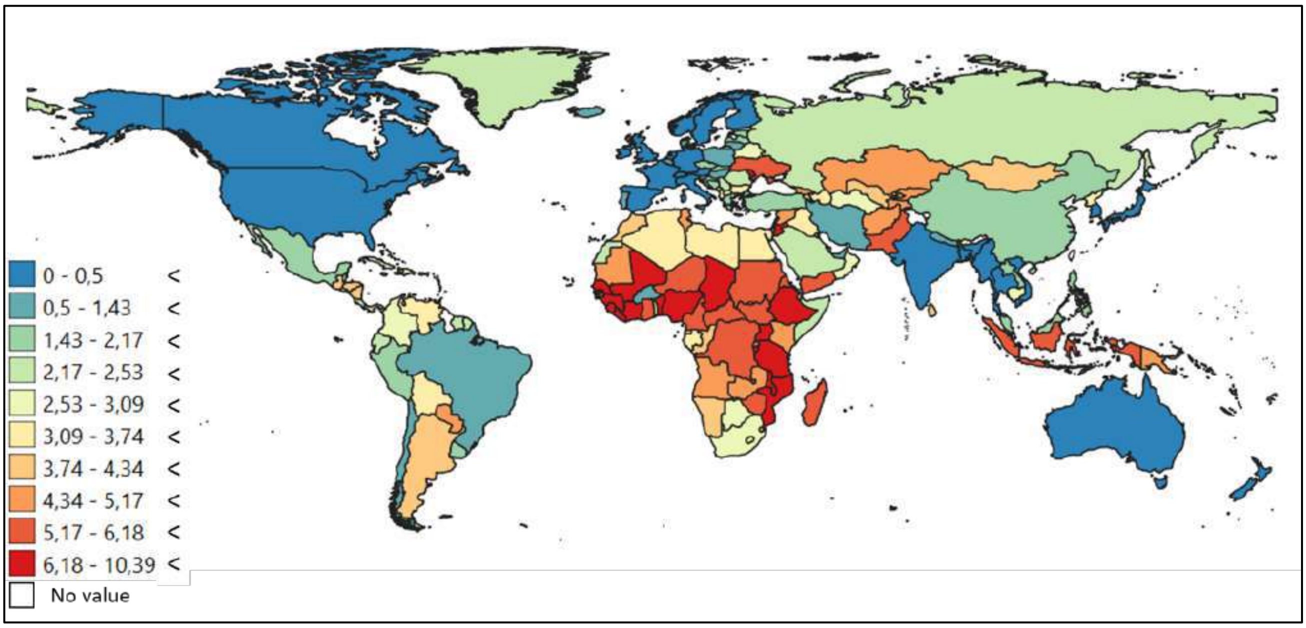

Figure 1 : Land Supply Risk per country (quantile interval clustering). The higher the land Supply Risk, the higher the risk of land not being accessible in a country.

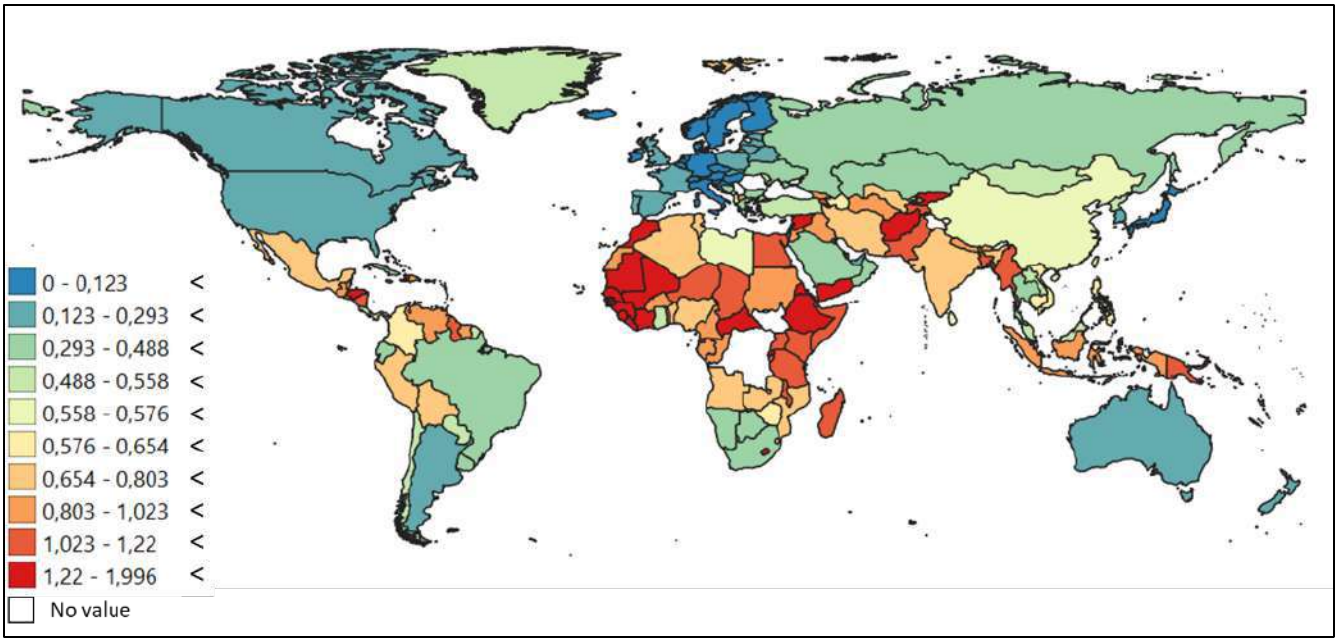

Figure 2 : Water Supply Risk per country (quantile interval clustering). The higher the water Supply Risk, the higher the risk of water not being accessible in a country.

Regional characterization of the albedo impacts of global agricultural land use at the global scale

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1. INTRODUCTION

Agricultural expansion is one of the leading drivers of land cover changes, causing substantial climate impacts [1]. While the impacts of greenhouse gas emissions (GHG) caused by agricultural land use have been well characterized, there are other ways land use impacts the climate—namely through changes to surface albedo [2]. Albedo represents the fraction of the incoming solar energy that is reflected by the earth's surface. A change in the surface albedo disrupts the top-of-atmosphere energy balance, causing a radiative forcing. This leads to climate changes which can be as big or even greater than those associated with the GHG emissions of land use [2]. As such, it is important that this be integrated into the life cycle assessment (LCA) of agricultural products. However, existing methods are mainly limited to site-specific case studies (e.g., [3]) with limited ability for these results to be applied to other contexts. To that end, here we develop a spatially differentiated characterization model of the albedo impacts of land use and compute localized characterization factors that can be widely applied in LCA.

2. METHODS

The characterization model is based on a change in the surface albedo between an occupied land state and a reference state. Here we have taken the reference state as the Potential Natural Vegetation (PNV) and have focused the land occupation on agricultural land uses, namely pasture lands, croplands, and agroforestry. We used satellite data of land cover types [4] and surface albedo values [5] and developed a data sampling algorithm that allowed us to predict the albedo of multiple land cover types at a given location. As such, these methods can be applied to a wide range of land covers. The albedo values were then combined with radiative kernels which express the radiative forcing from a unit change in albedo [6]. Finally, we used IPCC factors [7] to convert the radiative forcings into GHG emission equivalents (kg CO_2e).

3. RESULTS AND DISCUSSION

The resulting characterization factors (**¡Error! No se encuentra el origen de la referencia.**) show that the albedo-induced climate impacts of agricultural land occupation (per unit area and per year of land occupation) are largely negative–i.e., associated with global cooling with respect to the PNV. However, there are locations where these impacts will contribute further to global warming (**¡Error! No se encuentra el origen de la referencia.**), highlighting the importance of spatial differentiation in the characterization of these impacts. The impacts are highly correlated to the type of PNV. In general, where the PNV is forest or savanna, the characterization factors are largely negative, while the bulk of the positive impacts (i.e., those associated with warming) commonly occur where the PNV is desert or grassland (**¡Error! No se encuentra el origen de la referencia.**).

4. CONCLUSIONS AND OUTLOOK

The presented methodology successfully characterizes the albedo-induced climate impacts of agricultural land use with near-global coverage. The resulting characterization factors reveal that agricultural land occupation largely has a cooling effect with PNV taken as the reference state. The spatial variability in the results emphasizes the importance of methods that allow for spatial differentiation of impacts. Additionally, this method is not restricted to the use of PNV as a reference state and could be easily applied in a consequential context.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge the financial support of the industrial partners of the Consortium on Life Cycle Assessment and Sustainable Transition (a research unit of the CIRAIG). The authors remain solely responsible for the content of this study.

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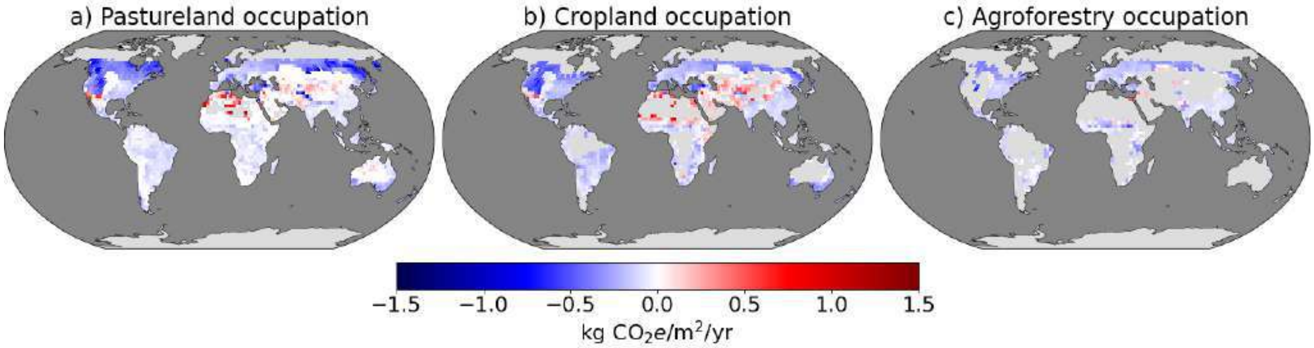

Figure 1. Characterization factors for a) Pastureland occupation, b) Cropland occupation, and c) Agroforestry occupation with respect to the reference state (PNV). Negative values represent cooling whereas positive values represent warming. Grey indicates no data values.

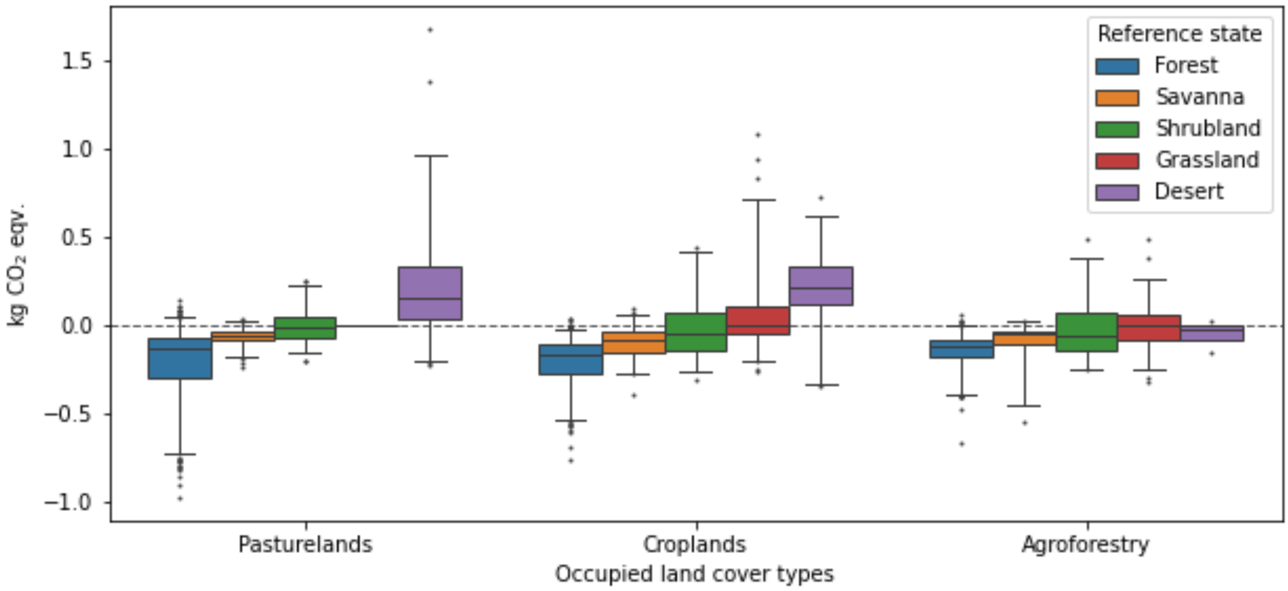

Figure 2. Characterization factors separated by PNV type. Negative values represent cooling whereas positive values represent warming with respect to the reference state, i.e., the PNV represents the zero line.

Assessment of Agricultural Microplastic Emissions Impacts via Novel Comprehensive Multimedia Characterization Factors

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1. INTRODUCTION

Use of plastic in agriculture, through practices like mulching, fertilizer and seed coatings, or netting, can lead to environmental leakage, posing potentially significant threats to ecosystems, human health, and socio-economic assets. However, current Life Cycle Assessment (LCA) does not properly consider these impacts. The international research group MarILCA has proposed a framework to include plastic litter impacts in LCA, highlighting the interdependence of environmental compartments and emphasizing the importance of studying microplastic (MP) transfers between them [1]. While MarILCA has presently focused on marine impacts, this project aims to investigate the impacts of MP emissions in other compartments, especially agricultural soil, by establishing multimedia characterization factors for a new impact category, physical effects on biota, using effect factors for aquatic, terrestrial and sedimentary ecosystems.

2. METHODS

A level III multimedia model (Figure 1) is developed by building upon the SimpleBox4Plastics model [2] but simplifying it to meet the needs of LCA models and ensure compatibility with the USEtox methodology following the approach implemented by [3]. The model calculates rates for transport mechanisms between compartments (deposition, runoff, erosion, sedimentation, resuspension, advection), agglomerating and attaching processes, as well as loss mechanisms (deep burial, leaching, escape to stratosphere, degradation). These rates are organized into a rate matrix $\bar{k}$ that is inverted and set to negative to obtain the Fate Factor (FF) matrix. The combined Effect and Exposure Factor (EEF) matrix is composed of aquatic, sedimentary and terrestrial effect factors. The Characterization Factor (CF) matrix is calculated using equation (1). CFs for sedimentary and aquatic species are combined into single factors representing each marine or freshwater ecosystems [4]. CFs are expressed in [PAF·m^3·yr/kg] at midpoint level and in [PDF·m^2·yr/kg] at endpoint level. This methodology is then tested using the case study carried out by [5], which compares the impacts of producing 1 ha of lettuce in Norway using biodegradable (PBAT/starch) and non-biodegradable (LDPE) mulch films.

$$\overline{CF} = \overline{EEF} \times \overline{FF}$$

3. RESULTS AND DISCUSSION

CFs are calculated for each type of polymer for a size of 100 µm and for 3 ecosystems: marine, aquatic and terrestrial (Figure 2). For low-density MPs, the highest endpoint CFs are those for aquatic ecosystems with emissions into lake (4.93-12.57 PDF·m^2·yr/kg), followed by those for marine ecosystems with emissions into ocean (2.34-4.58 PDF·m^2·yr/kg). The high-density MPs' CFs are lower (0-1.60 PDF·m2·yr/kg) and more heterogeneous across emission compartments. Depending on the polymer, the highest values are either for aquatic ecosystems with emissions into lake or freshwater or for terrestrial ecosystems with emissions to natural soil. Figure 3 shows the contribution of physical effects on biota to the total impact on Ecosystem Quality of the different mulch films studied. Physical effects on biota are higher for the non-biodegradable film, 20.54 PDF·m^2·yr (3.15% of the overall impact), compared to the biodegradable one, 2.27 PDF·m^2·yr, (0.27-0.34% of the impact). For the non-biodegradable film, the contribution of physical effects on biota is similar in magnitude to terrestrial acidification, land transformation biodiversity, and freshwater ecotoxicity, short term. Although adding the impacts of MPs does not change the study's conclusions here, it could potentially be the case in other studies.

4. CONCLUSIONS

This study enables, for the first time, the integration of potential ecosystem impacts of MPs emitted by agricultural activities into LCA. This is achieved through novel endpoint CFs for emissions in all compartments, based on fate factors and effect factors for aquatic, sedimentary, and terrestrial ecosystems. As demonstrated in the case study, it makes more informed decisions on plastic use possible in agriculture and other sectors to minimize ecosystem impacts.

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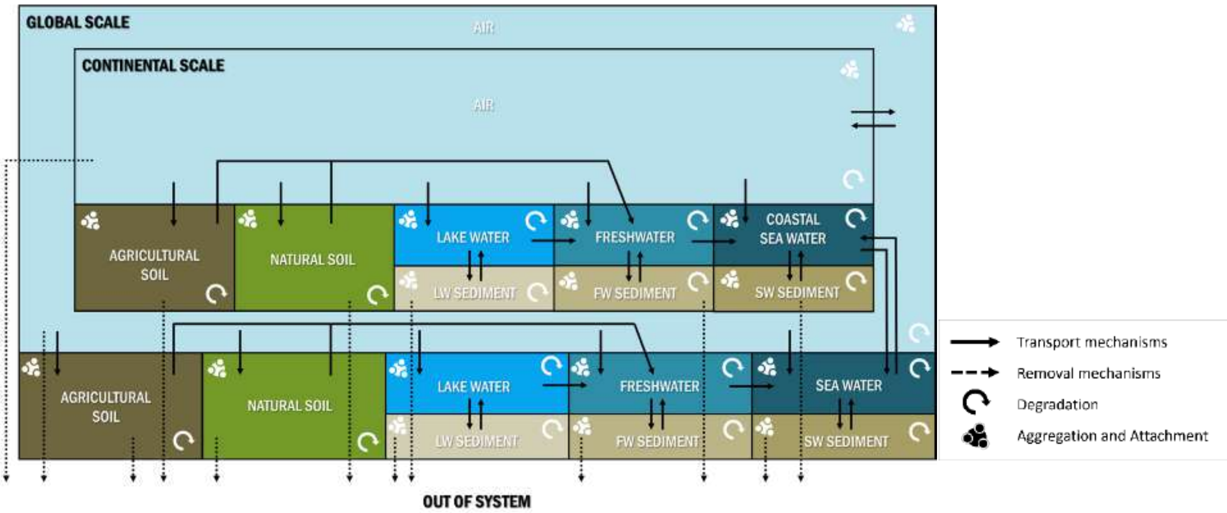

Figure 1. Diagram of the level III multimedia model.

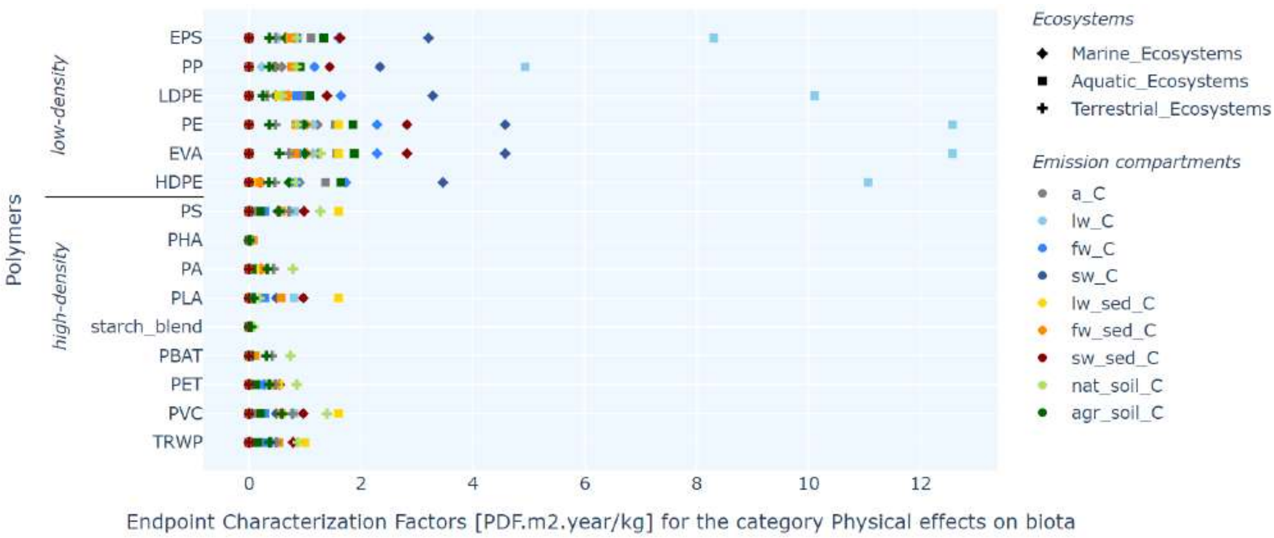

Figure 2. Endpoint characterization factors for the category Physical effects on biota for different polymers at 100 µm.

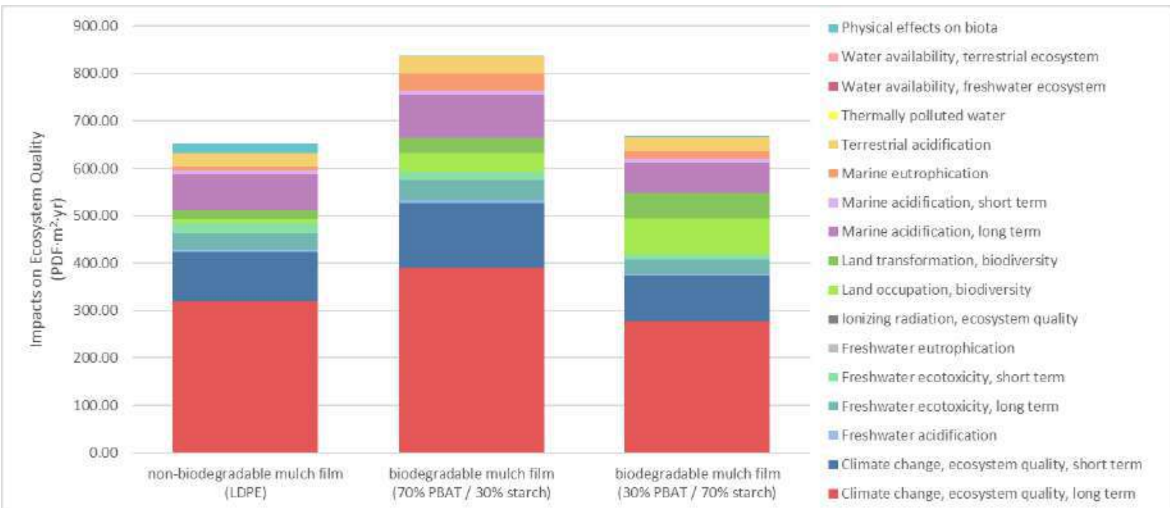

Figure 3. Contributions of the different impact categories to Ecosystem Quality for the different mulch film scenarios to produce 1 ha of lettuce.

Topical Discussions

Topical Discussions

9 Sep

Lecture room Aula Capella

14.30- 16:00 | Topical discussion session 1

Carolina Carrillo Diaz. *Mérieux NutriSciences | Blonk*

Bridging the Environmental Footprint Data Gap: Enhancing Collaboration between Users and Creators of Background Databases.

16:30-18:00 | Topical discussion session 2

Jürgen Reinhard and Lisanne de Weert. *AdAstra Sustainability*

Renan Novaes. *Embrapa*

Iana Salim. *Mérieux NutriSciences | Blonk*

Opportunities from land use change assessments frameworks to unlock supply chain interventions.

10 Sep

Lecture room Aula Capella

14:30-16:00 | Topical discussion session 3

Delanie Kellon. *Global Feed LCA Institute (GFLI).*

Achieving alignment and transparency within the feed and food supply chain: embracing the complexity of new developments in impact assessment and modelling.

11 Sep

Lecture room Aula Capella

08:30-10:00 | Topical discussion session 4

Niels Jungbluth. *ESU-services Ltd.*

Ujué Fresán. *ISGlobal*

Recommendations for sustainable nutrition in the political debate.

11:30-13:00 | Topical discussion session 5

Roline Broekema. *Wageningen University and Research.*

Ecolabeling of food products is happening the devil is in the details.

Topical discussion session 1

Bridging the Environmental Footprint Data Gap: Enhancing Collaboration between Users and Creators of Background Databases

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1. BACKGROUND AND MOTIVATION

The growing pressure on the environment due to food production drives the demand for environmental footprint data of both feed and food. Due to the scarcity of primary data, background databases are often used in LCAs and in the increasingly relevant field of corporate climate action.

Users of life cycle inventory (LCI) datasets seek for high data coverage, that's ideally the most representative, up to date, high-quality data available for feed and food products produced through specific management practices and technologies, and even by specific suppliers. Because of their connections to the producing industry and knowledge of the market, these users are often in a strong position to access, estimate, review and even generate critical activity datapoints as opposed to database creators; meanwhile, the latter hold crucial knowledge and tools for the consistent creation of databases useful for the industry and the academy that comply with (international) standards. All these inputs are key for the creation of meaningful background databases upon which to make decisions to lower the industry's impact over the environment. Therefore, stimulating knowledge exchange between database users (industry and academy) and database creators is potentially beneficial for the whole LCA community.

2. FORMAT OF THE SESSION AND SCHEDULE

First, the discussion sessions will be opened, the topic introduced, and past experiences exchanged and discussed among the authors, who are also the chairs. Examples include setting up platforms for environmental foot printing of animal production and publishing sector data in LCI databases.

Afterwards, the audience will split into break-out sessions in the room where the session started.

To facilitate an in-depth structured discussion for all participants and to ensure a meaningful discussion, diverse groups will be composed, with people from various backgrounds and types of organizations. The chairs of the session go around the groups to facilitate the discussion. After each discussion point, the chair of the discussion will ask each group for their main takeaways, after which the next discussion point will be introduced that the breakout-groups will discuss. This will be repeated for all main discussion points. To close the discussion session, the chair will give a summary of the entire session.

A digital platform will be used to communicate the discussion points and allow attendants to add their ideas. Input during the group discussions is documented by the attendants, main takeaways are documented in the same digital platform by the chairs. This will be synthesized into a list of practical solutions during a concluding plenary discussion by the chairs of the session. The audience is 'called to action' by asking for volunteers to start a pilot group to continue this work. The outcome can be shared with the participants after the session.

3. MAIN DISCUSSION POINTS

- What are the most relevant characteristics of environmental impact datasets (including LCI datasets) for users? (e.g. availability, representativeness, update frequency, etc.)
  Who holds relevant information to build LCI datasets/to improve the existing ones in agreement with the characteristics discussed in the previous question?
- How can you collaborate in co-creating those datasets or improving the existing ones? What are the benefits and practical challenges? How can those challenges (e.g. confidentiality, funding, no continuous commitment) be overcome?
- How to stimulate knowledge exchange between LCI data users and creators?

4. DETAILED RUN OF SHOW INCLUDING TIMETABLE AND INVITED PANELLISTS CONFIRMED

1. Audience welcome & introduction of the topic: context by first chair and experiences by cochairs: 10 - 15 minutes.
2. Organizing breakout groups: 3 minutes
3. First discussion point on section 3: 15 mins
   a. Introduction to topic: 1 minute
   b. Breakout-group discussion of topic: 10 mins
   c. Plenary Summary of discussion topic: 5 mins
4. Second discussion point on section 3: 15 mins
   a. Introduction to topic: 1 minute
   b. Breakout-group discussion of topic: 10 mins
   c. Plenary Summary of discussion topic: 5 mins
5. Third discussion point on section 3: 15 mins
   a. Introduction to topic: 1 minute
   b. Breakout-group discussion of topic: 10 mins
   c. Plenary Summary of discussion topic: 5 mins
6. Summary of discussion & call to action: Forming pilot group to continue this work: 10-15 mins.

5. EXPECTED OUTCOMES/TAKE HOME MESSAGES

A list of solutions to stimulate cooperation between data users, data owners and database creators and increase and sustain the availability and quality of available LCI data. Pilot group of collaborators to test these potential solutions, sharing concerns, ideas and solutions between LCA practitioners during the session. On the long term, sparking inspiration for long-term collaboration between companies.

6. MODERATOR(S)

For step 1, 2 and 6 of the detailed run of show, Carolina Carrillo Diaz will moderate.

For the remaining steps, all chairs will moderate the smaller break-out group discussion.

Opportunities from land use change assessments frameworks to unlock supply chain interventions

Jürgen Reinhard[1], Lisanne De Weert[1], Renan Milagres Novaes[2], Iana Câmara Salim[3]

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1. BACKGROUND AND MOTIVATION

Land use change (LUC), or land conversion, is responsible for 10% of global greenhouse gas (GHG) emissions, and 80% of biodiversity loss. The vast majority of land conversion worldwide is driven by agricultural expansion over natural ecosystems: forests, savannas, prairies and wetlands. Despite being a central contributor to the corporate carbon footprint of most food companies, LUC is likely the most poorly quantified life cycle stage in the LCA of agricultural and food products.

Statistical LUC (sLUC) approaches derived from country-level statistics can be assessed using tools like the LUC Impact tool by Blonk Sustainability, which relies on FAOSTAT data. The strength of sLUC based on country-level data is its global scalability across commodities, but it faces certain challenges in terms of precision, which hinders actionable insights to address land conversion in food supply chains.

Recently, novel LUC assessment approaches based on high-resolution geospatial data have emerged, shedding light on the spatial and temporal variability of LUC events and related impacts. Orbae (orbae.eco) by AdAstra Sustainability and BRLUC (brluc.cnpma.embrapa.br) by Embrapa are the most prominent examples of such approaches, revealing direct LUC (dLUC) in any farm, sourcing region or jurisdiction (jdLUC) in their purview. Built out of publicly available, peer-reviewed information, they unlock new opportunities to intervene in the most complex and opaque food supply chains.

As with any innovation, these novel approaches reveal new frontiers that require collective efforts from the scientific community to reach the best accuracy and reliability, while allowing for scalability and accessibility.

2. FORMAT OF THE SESSION AND SCHEDULE

The session is organised as follows:

- Presentation of recent updates in GHG protocol LUC accounting requirements, sLUC approaches based on FAOSTAT (LUC Impact) and geospatial dLUC (Orbae and BRLUC) (45 min)
- Panel discussion (45 min)

3. MAIN DISCUSSION POINTS

The session will be the opportunity for participants to learn and address the following discussion points:

- dLUC, jdLUC, sLUC: what do they mean in the context of the GHG Protocol and SBTi FLAG guidances? Which should LCA practitioners use and when?
- LUC beyond deforestation: challenges and research opportunities.
- iLUC: where does indirect LUC help decision-making?
- Unlocking supply chain interventions in the absence of full traceability: supply shed and landscape approaches.

4. DETAILED RUN OF SHOW INCLUDING TIMETABLE AND INVITED PANELLISTS CONFIRMED

5. TIMETABLE

Time (min)	Topic	Description	Speaker*
5	Introduction	Welcome, agenda and introduction of speakers	LdW/JR
5	Standards	Recent updates in GHG protocol LUC accounting requirements	LdW
10	sLUC	LUC calculation based on national-level statistics (FAOSTAT), as implemented in *LUC Impact.*	IS
10	dLUC	Direct LUC approach based on geospatial data for Brazil, as implemented in *BRLUC*.	RM
10	dLUC	Global approach for direct LUC, using geospatial data, as implemented in *Orbae*.	JR
5	Transition	Transition to panel discussion: inviting all panelists to the front.	LdW
20	Expert panel	Panelists will be asked questions which are prepared by the moderator to deepen understanding of the LUC approaches, and how they complement each other. The audience will be able to ask questions.	JR, RM, IS, LdW
20	Audience pan el	The moderator will ask the audience several “show of hands” questions on which, and how, they use LUC approaches in their work. Based on responses, some attendees (especially those representing industry) will be asked more detailed questions.	LdW, A
5	Closure	Wrapping-up the session with key take-aways.	LdW, JR

*LdW = Lisanne de Weert, JR = Jürgen Reinhard, RM = Renan Milagres Novaes, IS = Iana Salim, A = audience.

PANELLISTS CONFIRMED

- Jürgen Reinhard, co-founder of AdAstra Sustainability and LCA practitioner at the forefront of LUC modelling, has confirmed his commitment to chair the session. He will also be part of the panel.
- Renan Milagres Novaes (Embrapa) is confirmed as co-chair and panelist.
- Iana Salim (Mérieux NutriSciences | Blonk) is a confirmed co-chair and panelist.

6. EXPECTED OUTCOMES/TAKE HOME MESSAGES

Participants will discover the potential of sLUC and geospatial dLUC approaches for use in LCA, in corporate accounting and impact monitoring towards achieving science-based targets. They will familiarise themselves with key concepts and methods and contribute to identifying scientific and technological questions worth further research. They will discover how LUC assessment approaches can be combined to unlock supply chain interventions aiming to stop land conversion and foster the restoration of natural ecosystems.

7. MODERATOR(S)

Lisanne de Weert (AdAstra) will be moderating the session.

8. ACKNOWLEDGEMENTS

Orbae by AdAstra is a start-up innovation project supported by Innosuisse, the Swiss Innovation Agency.

Achieving alignment and transparency within the feed and food supply chain: embracing the complexity of new developments in impact assessment and modelling

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1. BACKGROUND AND MOTIVATION

The Global Feed LCA Institute (GFLI) is an independent, non-profit created by the feed sector to develop an Animal Nutrition Life Cycle Analysis database to make it possible for the feed and livestock sectors to calculate the environmental footprint of products in a transparent and trustworthy manner.

To this end the feed sector developed the GFLI database to be made up of feed specific datasets calculated using a harmonized methodology based on the Food and Agriculture Organization of the United Nations (FAO) Livestock Environmental Assessment and Performance (LEAP) partnership guidelines (on Animal Feed Supply Chains and later, on Feed Additives), and also aligned with the European Union's (EU) Product Environmental Footprint category rules (PEFCR Feed for Food Producing Animals). This alignment with the FAO-LEAP and EU-PEF guidelines for feed ensures the integrity and quality of GFLI's feed datasets. In this way, the GFLI database makes it possible for the feed, livestock and aquaculture sectors to access robust, harmonized and transparently calculated feed LCA data.

GFLI was created based on a commitment to collaboration with diverse value chain partners from across the feed and livestock sectors, as well as with FAO, government agencies, NGOs, universities, and research institutes. Given the growing number of new and evolving methodologies and LCA guidance relevant to the feed and food sectors, in addition to the diversity of developments in sustainability reporting requirements, GFLI is working to extend its strategic partnerships to also achieve meaningful engagement with the food and retail sectors to improve methodological harmonization and limit fragmentation across the full value chain. One key area of discussion and collaboration with chain partners is how to tackle inconsistencies in impact assessment methodologies and emission modelling.

2. FORMAT OF THE SESSION AND SCHEDULE

The moderator will briefly introduce the purpose of the session and then open the discussion by posing questions to specific chairs. All chairs will be encouraged to build on the initial intervention in addition to responding to input from the audience. The chairs will have coordinated in advance regarding the discussion topics and the expected outcomes to ensure that their interventions are relevant, but the session will not be scripted and will seek the emergence of new ideas and exchange of views driven by comments from the audience. The moderator will be responsible for ensuring that the discussion stays on track, and that all chairs have the opportunity to raise key points necessary to ensure a productive exchange and the delivery of expected outcomes.

3. EXPECTED OUTCOMES/TAKE HOME MESSAGES

The chairs and audience will discuss strategies for limiting methodological fragmentation across the feed and food supply chain regarding:

1. The expansion/adaptation of the GFLI database to address new reporting requirements that introduce new or updated methodological developments (e.g. SBTi-FLAG), and how to handling inconsistent or incomplete impact assessment methods.
2. Modelling challenges related to the integration of higher-tier (more precise, granular) modelling into the baseline database, and how to handle the need for increased precision with the goal of dataset comparability.
3. The development and implementation of the GFLI Branded Data Methodology and its role in incentivising the improvement of supply chain transparency.

The overarching take home message will be that improving methodological and data quality transparency is critical to the global feed and food supply chain, and that greater collaboration with actors across the full value chain is imperative to developing effective pathways forward.

4. CHAIR'S COMMITMENT

Delanie Kellon (GFLI Secretariat) has accepted the invitation.

Laura Nobel (GFLI Secretariat) has accepted the invitation.

Lode Verbruggen (Kemin / GFLI TMC) has committed to respond by 26 April, 2024.

Pedro Cordero (Nutreco / FEFAC President) has committed to respond by 26 April, 2024.

Peter-Jan Roose (Brightwolves) has accepted the invitation.

Recommendations for sustainable dietary patterns in the political debate

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Keywords: dietary recommendations, health, environment, lobbying, stakeholders

1. BACKGROUND AND MOTIVATION

Nutrition has an impact on human health and the natural environment. In the past dietary recommendations often have been developed by people with a health background. The share of food products for the total environmental impact e.g. of Swiss final consumption is about 20-25%, depending on the assessment method (Jungbluth et al. 2022). This environmental damage in turn also affects human health. For example, periods of heat in summer lead to deaths due to the climate crisis. If dietary recommendations are only focusing on one of the two aspects, both, human health and the environment suffer. In recent years dietary recommendations are becoming the subject of political debate and visible influence of stakeholder interests. In Switzerland e.g. the partly public founded organisations for promoting milk (Swissmilk) and meat (Proviande) consumption are trying to influence the debate[1] and promote more or at least the same amount of animal products to be considered in dietary recommendations. In Mediterranean countries there are e.g. conflicts between traditional food like fish and the clear conflicts with sustainability goals. Such developments might lead to sub-optimal recommendations from an overall health perspective. A report on sustainable nutrition prepared by ESU-services' tries to merge both aspects of diets, to ensure sustainability in a healthy and environmentally friendly way (Jungbluth et al. 2022).

2. FORMAT OF THE SESSION AND SCHEDULE

It is planned to provide short presentations by the panellists about the different stakeholders influencing the political debate on dietary recommendations in different countries as a start in the workshop. This will be interrupted by voting from the audience on different questions. Then we speak about the discussion points mentioned below. At the end main findings are summarised in a brief note.

1 https://www.linkedin.com/pulse/esu-services-distanziert-sich-vom-greenwashing-den-publireportagen-/

3. MAIN DISCUSSION POINTS

Input of panellists The following key questions are addressed. The panellists are asked to report shortly about their national (or stakeholder experiences).

- What are the most relevant conflicting issues between health and environmental sustainability in terms of diets?
- Which stakeholders are participating in the debate on dietary recommendations and what is their motivation for the promotion of specific food items?
- Is there a scientific basis for weighting direct health, economic and environmental aspects?
- How can the conflicting goals between promoting scientifically based sustainable diets and stakeholders' interests be solved?
- How can we close the gap between scientific results and political outcomes of discussions?
- How can we better bridge the gap between long-term know ToDos and the actual developments regarding diets
- Which country specific differences are visible due to promoting food items with strong domestic interest groups and economic interests?
- Do you see measurable changes in average consumption patterns in the last 10 years to more sustainable diets?

Electronic voting of the audience To make sure that the audience intervenes actively we will ask attendees for their opinion on the questions debated by the panellists via online voting systems Mentimeter.

- What are the main conflicts for dietary recommendations if combining direct human health and indirect health and environmental effects? Amount of: Fats; Vegetables and fruits; Meat; Eggs; Milk and dairy products; Fish; Processed foods; Imported foods
- What are the main pressure groups promoting certain product groups against scientific evidence on their healthiness or environmental sustainability? Farmer and farmer organisations; Product associations (e.g. industries processing milk, meat, fish, novel food products, ….); Politicians (promotion of regional/national foods); Retailers; Pure scientists considering only one field; Others.
- What relevance should be given to each of the following sustainability dimensions when establishing dietary guidelines? Distribute 100 points. Direct health effects; Environmental impact including indirect health effects; Other Socio-economic aspects.
- How should dietary recommendation be set? Exclusively based on scientific evidence; Allowing different stakeholders with potential conflict of interest take part as well.
- Which country do you consider as a reference to follow in the unbiased promotion of sustainable diets in their dietary guidelines? Open answer.
- Do you consider promoting healthy plant-based meat and drinks in the dietary guidelines would help in the transition toward healthy diets with low environmental impact? Yes; Yes, but only if having the same price that animal-based ones; No.

4. DETAILED RUN OF SHOW INCLUDING TIMETABLE AND INVITED PANELLISTS CONFIRMED

General input by Niels Jungbluth and problem setting: 10 minutes and recommendations of LANCET as a bottom line, Ujué Fresán: 10 minutes

Oral input to key questions from a national/stakeholder perspective: 5 / panellist

Electronic voting on questions in previous chapter: Partly alternating with answers of the panellists

Additional experiences reported from the audience: 5*3 (one from each continent) and oral statements by stakeholder groups: 5 each. Input from missing stakeholders: Industry, Government, Authorities, Nutritional societies/research

Discussion of organisers, audience, and panellists:

5. EXPECTED OUTCOMES/TAKE HOME MESSAGES

Questions: What are the main controversies regarding putting recommendations for sustainable diets? Is there scientific basis for balancing direct and indirect health effects? Should stakeholder interest be considered in dietary guidelines? The session should bring attention to the political debate on dietary recommendations and the underlying factors which make it difficult to implement changes which are necessary from an overall health perspective including issues caused by environmental impacts.

6. MODERATOR(S)

Niels Jungbluth and Ujué Fresán will lead the discussion. Participants are invited to provide their experiences and participate in the discussion.

7. REFERENCES

Jungbluth N., Ulrich M., Muir K., Meili C., Bussa M. and Solin S. (2022) Analysis of food and environmental impacts as a scientific basis for Swiss dietary recommendations. ESU-services GmbH, Schaffhausen, Switzerland, retrieved from: http://esu-services.ch/publications/foodcase/.

Topical discussion session 5

Ecolabeling of food products is happening – the devil is in the details

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1. BACKGROUND AND MOTIVATION

In recent years, several initiatives have started using an LCA-based ecolabel to gain insight into the environmental impact of all food products. They help companies set and achieve reduction targets and communicate the results transparently to businesses and consumers. Both in France and the Netherlands the government supports such an initiative and many national governments in Europe are exploring the development of similar programs (UK, Denmark). Private ecolabeling initiatives, like Ecoscore, Foundation Earth, Inoqo, Sustained and How Good support retailers in their communication and tend to call on scientific committees and task forces. Many retailers and food service companies have implemented ecolabeling initiatives (Colruyt, Migros, Coop Switzerland, Coop Sweden, Oda) and others did pilots (Carrefour, Lidl). We have identified approximately 15 ecolabeling initiatives and have analysed many of them, identifying key differences and elements of seemingly successful initiatives.

The European Commission has been attempting to address issues like unfair product comparisons, unverifiable labels and false green claims, with the development of the Product Environmental Footprint and several policy proposals (e.g. Green Claims initiative and Food Labelling Framework). This means that the successful ecolabeling initiatives of the future will likely need to consider PEF and other related policies.

This discussion session will initially bring you up to speed with the latest developments in ecolabeling. Several stakeholders like national government representatives, owners of private ecolabeling schemes and business representatives will share insights into their involvement in ecolabeling. Additionally, we will discuss the role of Life Cycle Assessment in ecolabeling and focus on key details, crucial for identifying the differences between and within food product categories.

2. FORMAT OF THE SESSION AND SCHEDULE

The session will start with two introductory presentations. The first presentation (WUR, 15 minutes) will explain the need for ecolabeling, what ecolabeling is, how it connects to European policy development and provide a deep dive into a large number of ecolabeling initiatives. The second presentation (ADEME, 10 minutes) will highlight the developments in frontrunning country France and the advancement towards European harmonisation of ecolabeling through the Eco Food Choice project.

After the introductory presentations, the discussion panel will be introduced. Four panel members from governments, private ecolabeling initiatives, retail and policy institutions will be invited to introduce themselves, their work on ecolabeling and the main dilemmas that they face in this context. (5 minutes each).

The moderator will guide the discussion with panel members and the audience (30 minutes) following the dilemmas faced by the panel members and key discussion points which we have previously identified (see chapter 3). Throughout the whole discussion session the audience will be engaged through several polls on the topics we are discussing.

3. MAIN DISCUSSION POINTS

Discussion points will partly come from the panel members. However, there are several key discussion points which have already been identified: 1) The added value of LCA (and PEF(CRs)) in ecolabeling, 2) The right balance between primary and secondary data, 3) The level of aggregation of results (still under debate by EC), 4) What format of communication is most effective, 5) How to account for nutrition, 6) How to account for ecosystem services and biodiversity, and 7) How to quickly scale up LCA for ecolabeling.

4. DETAILED RUN OF SHOW INCLUDING TIMETABLE AND INVITED PANELISTS CONFIRMED

00 – 15 minutes: Introduction into ecolabeling by WUR (Roline Broekema)

15 – 25 minutes: Introduction on French ecolabeling and ECO FOOD CHOICE project by ADEME (Vincent Colomb)

25 – 30 minutes: Work on ecolabeling and the main dilemmas by JRC (Laura Garcia Herrero)

30 – 35 minutes: Work on ecolabeling and the main dilemmas by Foundation Earth (Nicola Organ)

35 – 40 minutes: Work on ecolabeling and the main dilemmas by Colruyt (Ingrid Boom)

40 – 45 minutes: Work on ecolabeling and the main dilemmas by ADEME (Vincent Colomb)

45 – 80 minutes: Panel discussion guided by the dilemmas of panellists

80 – 90 minutes: Questions of the audience and wrap up

5. EXPECTED OUTCOMES/TAKE HOME MESSAGES

Ecolabeling is happening. Life Cycle Assessment is a necessary base for robust ecolabels which support consumers in making informed decisions in purchases they make and provide businesses incentives to mitigate their environmental impact. The key to future successful ecolabeling is in finding the right balance between scalability and specificity.

6. MODERATOR(S)

The moderator for the discussion session is Koen Boone, supported by Roline Broekema, both from WUR.

7. ACKNOWLEDGEMENTS

The Dutch Ministry of Agriculture, Nature and Food Quality.
The LIFE Programme - the EU's funding instrument for the environment and climate action.

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Sustainable livestock systems

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

01

Reduction of greenhouse gas emissions from pig and poultry production in Japan by climate change mitigation measures

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1. INTRODUCTION

The reduction of greenhouse gases (GHG) is an important issue for society in relation to the SDGs, for example, the reduction targets in Japan are 46% reduction by 2030 and carbon neutral (net zero) by 2050. Climate change mitigation measures are being developed for the livestock sector to achieve the targets, and it is necessary to introduce a combination of various technologies to maximize GHG reduction. However, it has not yet been clear how much GHG reduction is possible through such a combination, although it is important information. Furthermore, while the national reduction targets focus on the emissions from domestic sources, reductions should be achieved without increasing emissions throughout the product supply chains including overseas emissions. The objective of this study is to evaluate GHG reductions by introducing climate change mitigation technologies in pig and poultry production systems in Japan at the farm level based on the LCA concept.

2. METHODS

The GHG emissions from pig, broiler, and layer farming systems with and without mitigation technologies were investigated. The functional units were defined as 1 kg-liveweight for pig, 1kg-liveweight for broiler, and 1kg of egg for layer. The mitigation technologies taken into account were as follows: low-protein diets[1)], wastewater treatment with carbon fiber reactor[2)], and nitratation promotion in composting for pigs[3)]; low-protein diets and litter incineration for broiler[4)]; and low-protein diets for layer. For each livestock species, farming systems with and without mitigation technologies were defined as mitigation systems and conventional systems, respectively. Since availability of some mitigation technologies depends on manure management methods (composting, slurry storage, wastewater treatment, etc), the GHG emissions from the mitigation and conventional systems were evaluated for each of manure management method in Japan, and weighted averages were calculated according to the percentages of each manure management method for each livestock species. Since almost all feeds are imported for pig and poultry production in Japan, the processes of animal housing and manure management were included in the system boundaries to evaluate domestic GHG reductions, whereas the system boundary of the mitigation system also included the changes in the GHG emissions from feed production and transport from the conventional systems to ensure GHG reduction throughout the product supply chains. An example of the pig systems is shown in Fig. 1.

The GHG emissions were calculated by modifying the LCA models the authors had developed previously, while a LCA model was developed for layer using the same inventory data and emission factors. The GHG reduction rate for the mitigation technologies were based on the reports[1-4].

3. RESULTS AND DISCUSSION

The mitigation system that introduced low-protein diet, carbon fiber reactor for wastewater treatment, and nitratation promotion for composting, reduced the GHG emissions from pig production by 38% for the major manure management method in Japan that treats feces by composting and urine by wastewater treatment (Fig 2). The mitigation system that introduced low-protein diet and litter incineration reduced the GHG emissions from broiler production by 42% for the major manure management method that treats broiler litter by composting. The weighted averages of GHG reduction by mitigation technologies according to the percentage of each manure management method were 27%, 36%, and 10% for pig, broiler, and egg production, respectively (Table 1).

4. CONCLUSIONS

The mitigation technologies examined in this study were found to reduce the GHG emissions from pig and poultry production in Japan by 26% as a whole.

5. ACKNOWLEDGEMENTS

This study was supported by the research project "Development of Technologies to Reduce Greenhouse Gas Emissions in the Livestock Sector" (Grant JPJ011299) funded by MAFF, Japan.

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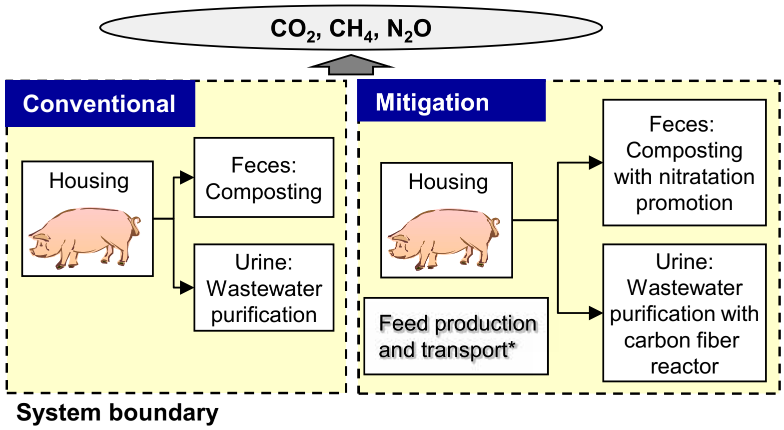

Figure 1. An example of conventional and mitigation systems for pig production.

*Only changes from the conventional system were taken into account.

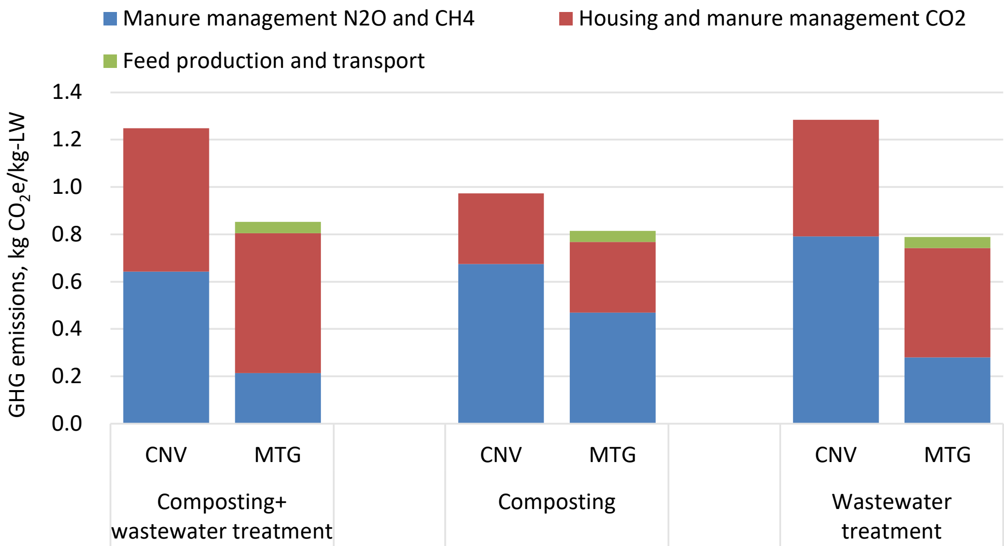

Figure 2. GHG emissions from conventional (CNV) and mitigation (MTG) systems for pig production with different manure management methods.

Composting+wastewater treatment, feces and urine are treated by composting and wastewater treatment, respectively; Composting only, a mixture of feces, urine, and bulking agent is treated by composting; Wastewater treatment, a mixture of feces and urine is treated by wastewater treatment. LW, liveweight.

Table 1. GHG reductions in pig and poultry produciton in Japan.

1000 t-CO_2e/year	Conventional	Mitigation	Reduction rate
Pig	2170	1589	27%
Broiler	1372	884	36%
Layer	806	729	10%
Total	4348	3202	26%

Evaluation of Eco-efficiency in a Swine Production System in Post-weaning Phase: A Sustainability Approach

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1. INTRODUCTION

In recent decades, global concerns about environmental sustainability, resource scarcity, and climate change have heightened the need for a comprehensive understanding of the environmental impacts of various segments of agribusiness, including swine farming. However, inventories of emissions specific to the Brazilian swine industry are still scarce, especially regarding the detailed phases of production, making it indispensable to quantify and analyze the impacts caused by the emission of gases in swine production, particularly GHG (carbon dioxide, methane, and nitrous oxide). This study sought to estimate and evaluate the global warming potential of the post-weaning piglet production process on a farm integrated into the swine industry chain in the Midwest region of Brazil, considering feed processing, animal rearing, and waste treatment system.

2. METHODS

The integration of the mathematical models used in this study, included in the Life Cycle Assessment tool, enabled a comprehensive evaluation of environmental and production aspects.

3. RESULTS AND DISCUSSION

The adaptation period, referring to the first week (Feed 1), had the greatest impact on emissions and the low performance of the piglets in this stage; considering the necessity of piglet gut maturation, the diet in the first week post-weaning is high in protein components, however, digestibility is low (Pluske et al. 2019; Valentim et al, 2021). As the animal's age and time in the nursery phase increased, it was concluded that Feed 3 was the most efficient in weight gain and low resource use, consequently leading to lower GHG emissions. The raw waste that remains in the facilities for a certain period, considering it as the largest emission source of the evaluated system. Results like these (Table 1) support the claims of authors such as Garcia-Launay et al. (2018), Wilfart et al. (2016) and Sonesson et al. (2015), and Ali et al. (2017), that concluded, for the most part, that animal performance, feed consumption, and the ingredients therein directly influence the greenhouse gas emissions of manure in different treatment systems.

4. CONCLUSIONS

From the results of this study, it was evident that the adaptation period, corresponding to the first week (R1), had the greatest impact on greenhouse gas emissions (GHG), due to the low performance of the piglets at this stage. As the age of the animal and the time spent in the nursery phase increased, it was concluded that R3 was the most efficient in terms of weight gain (WG) and low resource utilization, consequently leading to lower GHG emissions. Although R3 is more efficient in terms of GHG emissions, feeds R1, R2, and R4 have a higher potential for biogas production. Therefore, it was found that directing the biogas generated by the biodigester for energy production makes the high biogas potential favorable from an environmental perspective.

5. ACKNOWLEDGEMENTS

We thank CAPES and CNPq for the financial support.

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GHG Type	Average	DestPad	Variance	CoefVar	Minimal	Maximum
Enteric CH4	0.00116	0.00012	0.0000	11.03	0.0010	0.0014
Total CH4 emission	0.26969	0.0675	0.0045	25.04	0.2015	0.3610
Total N2O Emission	0.00633	0.0037	0.0000	58.80	0.0024	0.0123
CO2 manure emission/kg WG	0.29869	0.0616	0.0037	20.62	0.2391	0.3924
Biogas potential (m3)/kg WG pre-treatment	0.25640	0.0528	0.0027	20.60	0.2053	0.3366
Biogas potential (m3)/kg WG post-biodigester	0.06027	0.0161	0.0002	26.83	0.0427	0.0810

Table 1 – GHG emissions by type of piglet production after weaning.

Mitigation actions to reduce the carbon footprint of dairy sheep farming systems. Net benefits assessment from an Italian case study

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1. INTRODUCTION

Sardinian (Italy) sheep sector is a compelling case study to analyze the interplay between the semi-extensive livestock systems and climate change mitigation policies (Atzori et al., 2022). Mitigation strategies must be selected and proposed on the basis of both environmental utility and economic sustainability criteria (Jones et al., 2014). SheepToShip LIFE project was implemented with the aim of reducing by 20% in 10 years the greenhouse gases (GHGs) emissions from Sardinian dairy sheep chain. To achieve this goal, different mitigation actions (MA) tailored for the main Sardinian sheep milk production systems were identified and tested. In this work, the trade-off between MA and net environmental benefits are analyzed using a Life Cycle Assessment (LCA) approach.

2. METHODS

In order to identify the MA to be proposed within an Environmental Action Plan for the dairy sheep farms in Sardinia, 20 demonstrative farms have been selected through a process of characterization of production systems and their distribution in Sardinia (Atzori et al., 2022). Considering that the MA aimed to reduce the GHGs emitted during the entire production process of the farm, the LCA (conducted in accordance with the ISO 14040-44 standard) (ISO, 2021) was performed before and after the implementation of each MA. The eco-innovative techniques identified in SheepToShip LIFE were tested in 10 out of the 20 farms with the aim of demonstrating effective ways to reduce the sheep farm's CF. They can be attributed to four areas of intervention: a. Herd management aimed at increasing animal productivity; b. Livestock feed production (management of the fodder chain); c. Cultivation techniques (land use); d. Energy consumption and choice of technologies.

3. RESULTS AND DISCUSSION

The MA implemented on herd management were developed to improve fertility and increase milk and meat production ensuring lambing occurs in the optimal period, in order to solve the problems of low fertility of ewe lambs and low milk yield that greatly affect the farm's environmental performance. Herd management was also improved with a solution aimed at increasing diet digestibility to enhance feed efficiency. MA on livestock feed production concerned i) feed self-sufficiency, ii) reduction of the economic and organizational burdens of intensive soil use, and iii) reduction of work and organization cost deriving from frequent soil tillage for forage production. MA for soil management included i) the reduction of soil tillage intensity, ii) the decrease of the loss of soil organic matter, and iii) the improvement of conserved forage digestibility. The ultimate goal of these techniques was to lower fuel consumption and address the issue of the on-farm low quality forages. The MA developed to reduce energy consumption were undertaken to enhance the sustainability of electric power use.

4. CONCLUSIONS

Herd management MA showed the highest values for the reduction of GHG emissions and gross margin increase (Table 1). This is likely due to the fact that these solutions directly targeted the productivity of animals, which is the major driver of emission intensity at farm level.

5. ACKNOWLEDGEMENTS

This study was supported by the LIFE financial instrument of the European Union (project SheepToShip LIFE - Looking for an eco-sustainable sheep supply chain: environmental benefits and implications, LIFE15 CCM/IT/000123).

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Table 1. Observed range of percentage variation of Carbon Footprint (CF, kg CO_2eq/kg of Fat and Protein Corrected Milk [FPCM]) and gross margin (€), after the implementation of mitigation techniques (aggregated in four areas of intervention).

AREA OF INTERVENTION	CF KG CO_2EQ/KG FPCM		GROSS MARGIN €	
	min	max	min	max
HERD MANAGEMENT	- 3	- 27	+ 1	+ 120
LIVESTOCK FEED PRODUCTION	- 3	- 9	+ 1	+ 28
CULTIVATION TECHNIQUES	- 3	- 7	+ 1	+ 8
ENERGY CONSUMPTION	- 0.5	- 5	+ 1	+ 2

Environmental Sustainability Evaluation of PIC Genetics vs. Industry Average North America

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1. INTRODUCTION

Swine production has long been guided by efforts to increase productivity, decrease production costs, and minimize environmental impacts. Consumers and businesses are increasingly aware of sustainability issues in our food systems, which have increased pressure for organizations to become more efficient and strategic about resource allocation and investment.

Environmental impacts from swine production are influenced by myriad factors, but ultimately dominated by feed production and manure management. The Pig Improvement Company (PIC) specializes in swine genetics and has sustainability targets in their breeding program. In this assessment, we compared PIC genetic lines against industry-average genetics. This analysis supports benchmarking the sustainability benefits of genetics research and development in the swine sector. This work also aims to characterize potential benefits associated with adopting PIC genetics to continually reduce energy use and GHG emissions. As genetic improvements evolve, an established benchmark provides a point of comparison for how innovations affect environmental performance. The main objective is to present the environmental benefits and costs of PIC genetic lines against industry average genetics in North American swine production.

2. METHODS

This LCA is a cradle-to-farm gate assessment based on a functional unit of 1000 kg of live weight as a product of the full system including 3 generations of breeding providing weaned piglets to commercial wean-to-finish barns. Because the basic question is regarding the differences between genetic lines, the upstream system boundary includes the entire breeding herd back to the great grandparent level as well as the production of terminal sires that provide semen for artificial insemination. PIC routinely collects data from their customers including key performance indicators of commercial sows and wean-to-finish barns. In addition, data from a third-party data aggregator that collects industry wide performance was used to represent the industry average. The study was reviewed for conformance with ISO standards. Foreground allocation was avoided using an internal substitution approach for culled sows and excess piglets. ReCiPe 2016, EF 3.1 and the most recent IPCC characterization results are reported. Monte Carlo simulations were performed to quantify the effects of input uncertainty on the study conclusions.

Genetic projections to the year 2030 were also calculated to provide an estimate of the expected benefit to the year over year genetic improvement targeted by the breeding program.

3. RESULTS AND DISCUSSION

The PIC genetic line has significantly lower ($P<0.05$) Environmental impact in 13 of the 18 categories for ReCiPe 2016 (H) (Figure 2), 19 of the 25 categories for EF v3.1 and all the climate change categories in the IPCC 2001 framework (not shown).

Figure 1 presents the projected differences by the year 2030 based on the PIC breeding program where there is an expected improvement of approximately 6% across all the impact categories in ReCiPe 2016. There are some statistically non-significant categories in this projection due to the increased uncertainty applied through the pedigree matrix. The eco-toxicity categories show directional improvement but cannot be considered significant. This conclusion is in line with broad recommendations that toxicity differences should be much larger before significance can be confidently reported because of the very large range of characterization factors.

4. CONCLUSIONS

The performance of PIC genetic lines compared to the North American industry average presented in this work clearly show the benefits of a breeding program targeting sustainability metrics. This conclusion is strengthened by the observation that the industry average performance includes reports from enterprises using PIC genetics, thus the conclusions are conservative. In general, the PIC genetics are approximately 9 % better in their environmental performance across the suite of impact assessment categories in both the ReCiPe 2016 and Environmental Footprint impact assessment frameworks. In terms of climate change impacts based on the IPCC AR 6 framework the PIC genetic lines are approximately 10% better performing across all the reported climate metrics.

5. ACKNOWLEDGEMENTS

Banks Baker, Dan Hamilton, and Craig Lewis from PIC contributed data and discussion guiding the study. The Context Network provided logistical support.

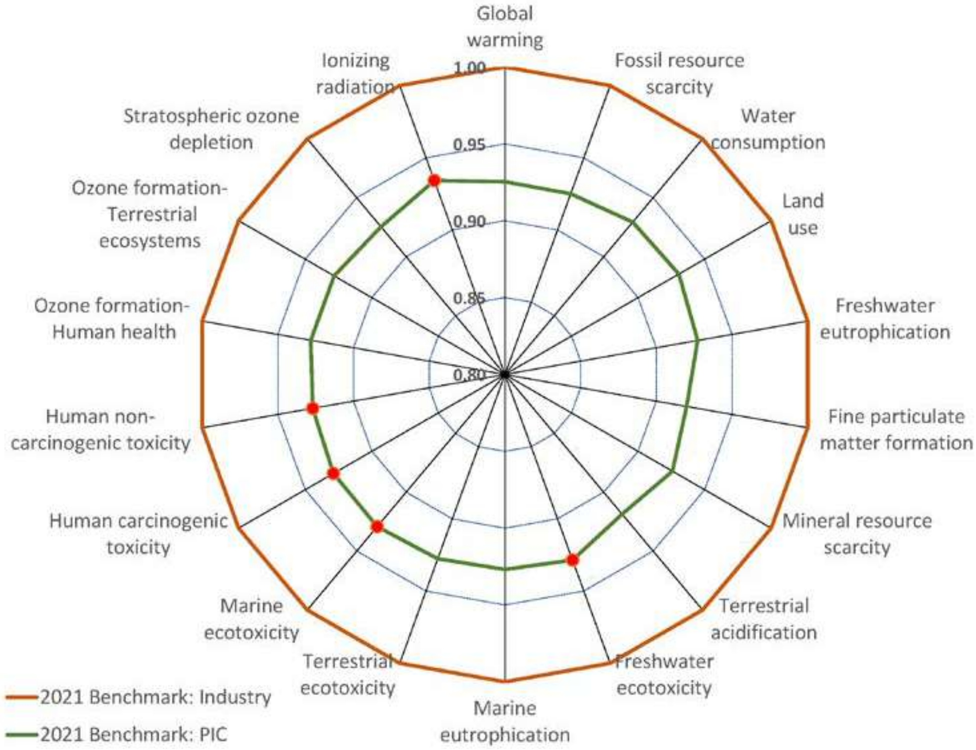

*Figure 2. Radar plot showing the relative improvements across the impact categories for the ReCiPe 2016 framework. Categories with the red markers are **not** statistically different.*

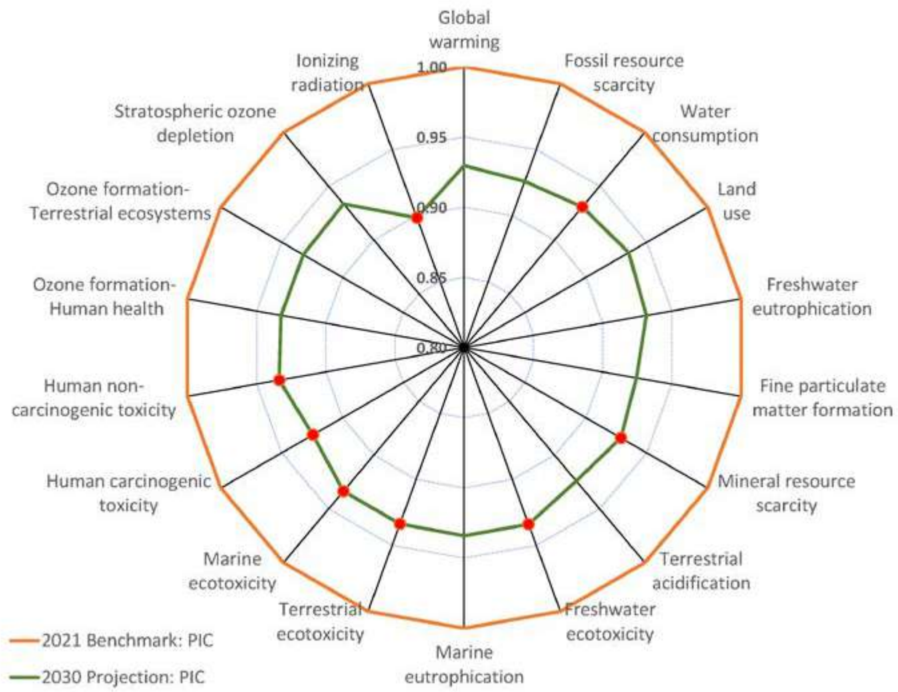

*Figure 1. 2021 benchmark versus 2030 projections for PIC genetics using the ReCiPe 2016 LCIA framework. Categories with red dots are **not** statistically different based on ANOVA.*

Life cycle assessment of alternative heating ventilation and air conditioning (HVAC) systems for poultry housing in Canada

Leandra Vanbaelinghem, Vivek Arulnathan, Nathan Pelletier

1. INTRODUCTION

Most non-renewable energy use in poultry house operations is attributable to heating, ventilation, and air conditioning (HVAC) systems (Costantino et al. 2016). Alternative HVAC systems, such as ground source heat pumps (GSHP) and earth-air heat exchangers (EAHE), have been well studied for commercial and residential applications, but understanding of their feasibility and mitigation potential in the livestock sector remains limited. This study quantifies the potential for GSHPs and EAHEs to improve sustainability outcomes in layer hen poultry houses.

2. METHODS

An ISO 14044-compliant life cycle assessment of a case study free-run poultry house using a GSHP to heat the layer barns and cool the egg cooler room in Quebec, Canada, is compared to a theoretical conventional system (natural gas boiler and absorption chiller) and an EAHE with a conventional system as a backup. These HVAC scenarios were incorporated within the Canadian egg supply chain life cycle model from Turner et al. (2022). The three HVACs' electricity grid mix inputs and heating demands were modified to investigate the systems' application in various Canadian provinces where egg production is prominent. Provincial scenarios included Quebec, British Columbia, Alberta, Nova Scotia, and Ontario.

3. RESULTS

GSHPs reduce HVAC-specific impacts of conventional HVAC systems between 2.4%-95.1% for Quebec and 1.5%-63.6% for British Columbia across the same ten impact categories. However, an impact increase between 4.8%-20.9% for Quebec and 0.5-10.6% for British Columbia is found across the same six impact categories remaining. Nine impact categories show GSHPs reduce conventional HVAC burdens by 7.3%-74.5% in Ontario, but an increase in impact (0.9%-36%) is seen for the remaining five impact categories. In Alberta and Nova Scotia, an increase in impact between 2.7%-49.1% and 0.2%-30.2% compared to conventional systems across 10 and 11 of the 14 impact categories is seen, respectively. Unlike GSHPs, EAHEs always reduce HVAC-specific burdens across all impact categories, except for terrestrial ecotoxicity in British Columbia (0.3% increase in HVAC impact). The greatest environmental burden reduction from EAHEs is found in Quebec (21.8%-52.2%), followed by British Columbia (7.7%-40.3%), Ontario (0.8%-44%), Alberta (1.8%-73.3%) and Nova Scotia (2.6%-36%).

4. DISCUSSION

Consistent with other alternative HVAC LCA studies, the environmental benefits of electricity-driven technologies, such as GSHPs and the ventilation system of the HVACs, were found to vary based on the proportion of renewable or non-renewable energy sources in the electricity grid mixes (Kljajić et al. 2020; Violante et al. 2022). EAHEs offered environmental benefits across all provinces' electricity grid mixes compared to conventional HVAC systems, especially in greener energy grids. This is explained by the heating component constituting a greater share of the HVAC burdens in greener energy grids when compared to non-renewable driven electricity grid mixes where ventilation contributes a much larger share of HVAC impacts. GSHPs provided environmental benefits in greener electricity grids (Quebec and British Columbia) and no environmental benefits (Alberta and Nova Scotia) or fewer environmental benefits (Ontario) in non-renewable energy-driven electricity grid mixes compared to conventional HVACs.

5. CONCLUSIONS

For Quebec, GSHPs provided the greatest average impact contribution reduction to the total life cycle impact of egg production but generated environmental trade-offs. For all other provinces, EAHEs were found to be environmentally preferable over GSHPs in reducing average conventional HVAC impact contribution without environmental trade-offs.

6. ACKNOWLEDGEMENTS

This research was supported with funding from the Egg Farmers of Canada Research Chair in Sustainability.

Keywords: Egg production; earth-air heat exchanger; heat pumps; poultry houses; climate control

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Data that supports the findings of the abstract:

Table 1. The average HVAC contribution to the total average life cycle impact of egg production across provinces. NGB represents the stand-alone conventional HVAC systems, GSHP represent the ground-source heat pump system and EAHE represents the earth-air heat exchanger with the conventional system as back-up. Red percentages show the highest average contribution for a province, yellow percentages show the second highest, and green percentages show the lowest average contribution.

Provinces	NGB	GSHP	EAHE
Quebec	2.7%	1.2%	1.6%
British Columbia	2.9%	2.4%	2.7%
Alberta	12.3%	14%	11.3%
Nova Scotia	9%	9.9%	8.1%
Ontario	6.8%	6.3%	5.7%

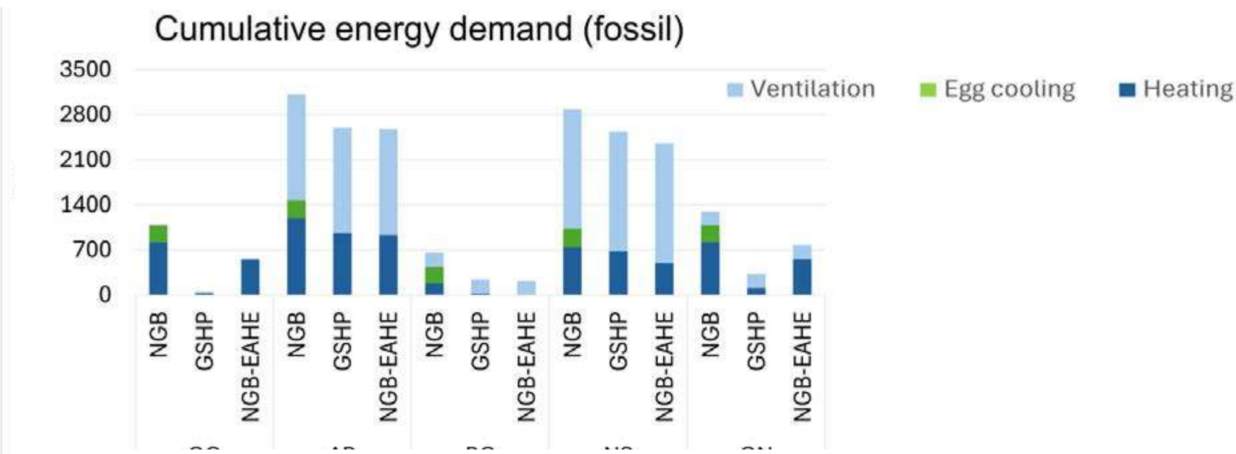

Figure 1. Comparative LCIA results of HVAC scenarios' components for cumulative energy demand (fossil) in MJ per tonne of eggs produced across Canadian provinces. "NGB" represents the stand-alone conventional HVAC systems.

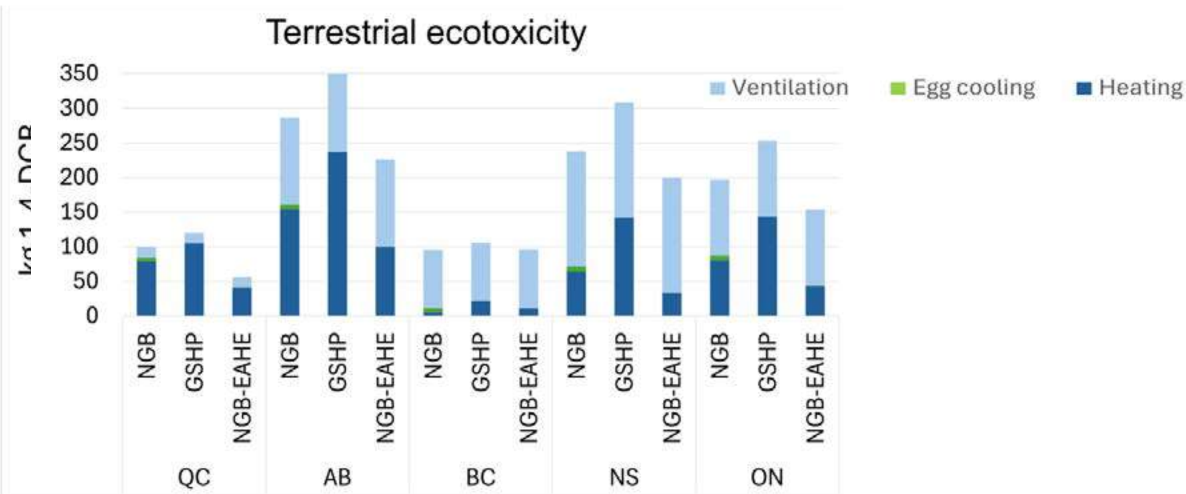

Figure 2. Comparative LCIA results of HVAC scenarios' components for terrestrial ecotoxicity in kg 1,4-DCB per tonne of eggs produced across Canadian provinces. "NGB" represents the stand-alone conventional HVAC systems.

Life cycle environmental sustainability assessment of feed supplementation strategies to reduce enteric methane emissions in dairy cattle production

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1. INTRODUCTION

Enteric methane emissions from cattle are important contributors to the total global greenhouse gas (GHG) emissions of livestock production systems (Gerber et al., 2013; Steinfeld et al., 2006). Thus, reducing their level represents a priority at the global level (European Commission, 2021). While feed supplementation represents an option to reduce GHG emissions in dairy mixed systems in OECD countries (Gerber et al., 2013), the environmental consequences related to the implementation of these types of strategies are not documented comprehensively (e.g., at the system level, where positive effects and side effects are included). In this context, the present study aimed to analyze the environmental sustainability of feed supplementation strategies ready for implementation in high-yielding commercial dairy herds by following a life cycle assessment (LCA) approach. These strategies included supplementation of feed rations of dairy cows with fat as with cracked rapeseed (S_1), nitrate (S_2), and 3-nitrooxypropanol (3-NOP) (S_3).

2. METHODS

First, the effects of the three selected feed supplementation strategies reported in scientific publications were identified. Secondly, a cradle-to-farm gate LCA analysis was conducted, where the identified effects were considered for the three scenarios compared to a reference scenario (typical dairy production in Denmark – S_0). Supplementation of feed rations in the three scenarios was based on recommended doses (20 g extra fatty acids per kg dry matter (DM) in S_1, 10 g nitrate per kg DM in S_2, and 60 mg 3-NOP per kg DM in S_3). Fifteen environmental impacts were estimated to capture the potential effects. The results were presented per kg energy-corrected milk (ECM).

3. RESULTS AND DISCUSSION

For each of the considered strategies, the effect on enteric methane was quantified (-8% for S_1, -10% for S_2, and -30% for S_3). Furthermore, several other effects were identified, which included the effects on feed intake; nutrient and other compounds excretion; associated emissions (CH_4, H_2, enteric N_2O, NH_3); milk yield and composition. The effects on animal welfare could not be assessed because of data and methodological limitations.

The climate change impact was reduced by 7%, 7%, and 13% per kg ECM milk in S_1, S_2, and S_3, respectively, compared to S_0 as a result of lower biogenic emissions (enteric CH_4) and increased fossil fuel emissions (caused by the production of supplements). The reduction of enteric CH_4 also caused decreases in photochemical ozone formation and toxicity-related impacts of organic substances. Furthermore, in S_1 and S_2, soybean meal was partially substituted with cracked rapeseed and nitrate respectively, and thus, small reductions in land use and land use change impacts were determined. Manufacturing of nitrate and 3-NOP caused small increases in several impacts (e.g., eutrophication, acidification, resource use, and ozone depletion). Compared to S_0, S_2 had 32% higher eutrophication and acidification impacts because of higher N excretion.

4. CONCLUSIONS

The net reduction in GHG emissions per kg ECM relative to the reduction in methane varied across scenarios. Small increases in other environmental impacts were determined because of the manufacturing of nitrate and 3-NOP, while more considerable increases were found in S_2 because of higher N excretion and emission.

5. ACKNOWLEDGEMENTS

The present study was conducted in the project ‘Fodring og Fænotype af den klimaeffektive mælkeko’ funded by the Ministry of Environment and Food.

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07

Life Cycle Assessment (LCA) of intensive sheep milk production system

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1. INTRODUCTION

The coverage of nutritional needs of the ever-growing population must be consistent with the simultaneous preservation of the environment and available resources. Since sheep milk production is associated with implications such as increased greenhouse gas emissions [1], the LCA method can be used to quantify the effects of the production process on targeted environmental indicators and to identify hotspots that must be eliminated [2]. In the present study, LCA was applied to intensive sheep farming systems for milk production in Greece, the hotspots were identified and an alternative scenario was examined in order to reduce the environmental impact of production process. The results will be used to develop an electronic platform for environmental and economic impact assessment in agri-chain.

2. METHODS

For the scope of the study, three representative intensive farming systems in Greece were selected. Data were collected on the farm characteristics, the inputs used and the outputs for one-year period, while the average of the inventory data was used for the calculations. Then, based on the results of the initial analysis, an alternative scenario was considered to re-evaluate the effects of the system. The functional unit chosen was 1 L of Fat and Protein Corrected Milk (FPCM) and the system boundaries were defined as cradle-to-farm gate, while mass allocation method was applied between milk (83%), wool (5%) and meat (12%). Data processing and analysis were performed using SimaPro v.9.4.0.2 software and the assessment of effects on the indicators shown in Table 1, was done with CML-IA baseline v.3.07/EU25 method.

3. RESULTS AND DISCUSSION

From the analysis carried out for the initial case, it emerged that different inputs had a significant impact on different environmental indicators. Specifically, enteric fermentation, maize grain, soybean and energy consumption had significant effects on carbon footprint at rates of 23.1, 9.7, 16.0 and 5.2% respectively, which is often observed in similar farming systems [3]. Hay consumption had a significant impact on multiple indicators, reaching almost 63% on AD, due to the high consumption of resources during its cultivation. Also, the consumption of barley straw significantly affected TE and FAE (59 and 56.1% respectively).

In the alternative scenario, the replacement of soybean and maize with broad beans and barley straw respectively and grid energy with solar energy was considered, and the effect of the system on carbon footprint, was calculated. All other parameters were assumed to remain unchanged and the new value was found to be 2.68 averse to the original value of 3.53 kg CO_2eq/L of FPCM, with enteric fermentation being the main hotspot with 30.0% contribution. The reduction of carbon footprint value achieved was 24.1%, which is an important step towards the adoption of alternative farming methods to reduce environmental impacts.

4. CONCLUSIONS

In the present paper the effects of sheep milk production on environmental indicators were presented. Soybean, maize and enteric fermentation were identified as hotspots. An alternative production scenario was presented, where hotspots were mitigated and the carbon footprint was reduced by 24.1%. Considering the alternative practices from an economic point of view as well, will also minimize financial loss to the producers.

5. ACKNOWLEDGEMENTS

This research was carried out as part of the project «Development of an electronic platform for environmental and economic impact assessment of bio-energy production systems in C. Macedonia for sustainable and competitive management by companies in agri-chain» (Project code: KMP6-0067147) under the framework of the Action «Investment Plans of Innovation» of the Operational Program «Central Macedonia 2014-2020» that is co-funded by the European Regional Development Fund and Greece".

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Table 1. Environmental impact assessment for base case study and alternative scenario

IMPACT CATEGORY	UNIT	BASE CASE STUDY	ALTERNATIVE SCENARIO
Abiotic Depletion (AD)	kg Sb-eq	5.47E-06	5.82E-06
Abiotic Depletion-fossil fuels (ADf,)	MJ	9.46E+00	8.00E+00
Global Warming (GWP100)	kg CO2-eq	3.53E+00	2.68E+00
Ozone Layer Depletion (ODP)	kg CFC-11-eq	7.37E-08	4.70E-08
Human Toxicity (HT)	kg 1,4-DB-eq	3.45E-01	2.77E-01
Freshwater Aquatic Ecotoxicity (FAE)	kg 1,4-DB-eq	1.73E+00	3.10E+00
Marine Aquatic Ecotoxicity (MAE)	kg 1,4-DB-eq	4.50E+02	3.74E+02
Terrestrial Ecotoxicity (TE)	kg 1,4-DB-eq	1.26E-01	2.23E-01
Photochemical Oxidation (PO)	kg C2H4-eq	8.29E-04	4.39E-04
Acidification (AF)	kg SO2-eq	8.63E-03	7.67E-03
Eutrophication (ET)	kg PO4-eq	1.15E-02	1.20E-02

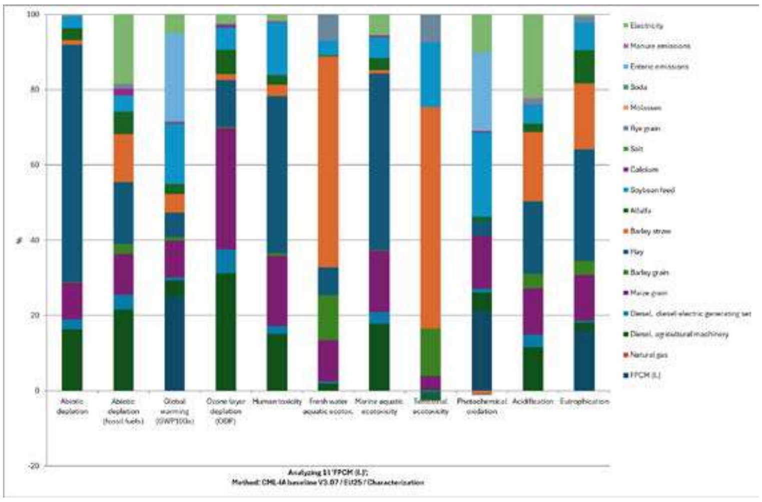

Figure 1. LCIA results for intensive sheep milk production

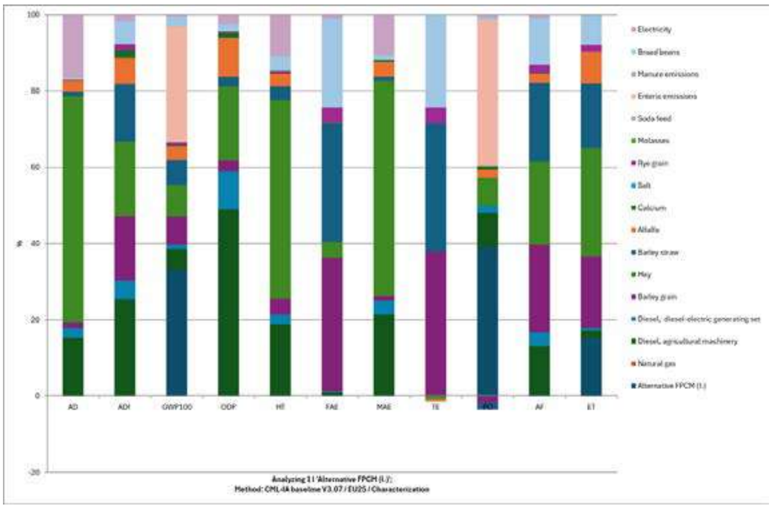

Figure 2. LCIA results for alternative production scenario

Insect meal from rice by-product as low-impact feed in aquaculture: life cycle assessment of different insect diets

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1. INTRODUCTION

As the production and use of feed is recognised as a major environmental impact factor in aquaculture, research is increasingly focused on the discovery of new, more sustainable formulations and feeds. Insect bioconversion can allow the re-utilization and valorization of these by-products to produce alternative protein sources for fish farming, thus reducing the environmental impact (Siddiqui et al., 2022). Within this scenario, the newRIFF project aims to explore the possibility of replacing traditional protein sources in Rainbow trout feeds with protein meal from two insect species (*Hermetia illucens* and *Tenebrio molitor*) bred on locally available waste matrices, including by-products of rice processing. Therefore, the aim of this study is to evaluate the environmental performance of different isoproteic insect substrates. Once the two best substrates in term of insect growth performance have been defined, those will be used for massive insect rearing to produce insect larvae meal. The latter will then be incorporated into the formulation of aquafeed for trout farming and the Life Cycle Assessment (LCA) of the entire supply chain, from food waste to the produced fish, will be carried out.

2. METHODS

The Life Cycle Assessment (LCA) approach was applied to analyse the environmental impact of formulated isoproteic diets (Table 1). The functional unit chosen was 1 kg of diet and the "from cradle to farm gate" perspective was applied to define the system boundaries. Both primary data and secondary data were used for the analysis. In particular, primary data were used for the analysis of the impact of the rice by-products. Then, an economic allocation was performed between rice and rice by-products. Secondary data were used to model the impact of the other wastes included in the analysis, their processing (e.g., drying and grinding if necessary) and the transport for their supply (set at 30 km).

3. RESULTS AND DISCUSSION

CONTROL SUBSTRATE showed better environmental results than the other ones in all impact categories except for Ozone depletion, Land use and Resource use, fossil (Table 2). Climate change of the tested diets ranged from 0.1 (CONTROL DIET) to 0.4 kg CO_2 eq/kg diet (DIET 4). However, if the avoided impact for the avoided processing of reused wastes was added to the analysis, the climate change impact decreased from 6% for DIET 4 to 43% for DIET 1. However, when compared to other diets in the literature, these substrates had a lower impact: Thevenot et al. (2018), reported an impact of 1.14 kg CO_2 eq/kg of diet, while Oonincx et al. (2012) reported an impact of 0.68 kg CO_2 eq/kg of diet. However, it is important to note that the composition of the cited substrates was composed of ingredient primary and the authors also considered the impacts of their production in the analysis and that it was not possible to compare nutritional aspects due to lack of data.

4. CONCLUSIONS

In this study, the environmental impacts of the analysed diets increase as the inclusion of rice by-products increases. It is important to note that insect breeding substrates can influence the growth performance and nutritional composition of insect meal, therefore it will be necessary to assess the environmental performance of the entire supply chain, including the production of insect meal and trout farming for a definitive and clear overview of this new proposal

5. ACKNOWLEDGEMENTS

The present study was supported by newRIFF project (new life for Rice by-products and agricultural wastes: Insects bioconversion for Fish Feed production).

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Table 1: Percentages (%) of inclusion of different ingredients and wastes in different formulated diets.

INGREDIENTS	CONTROL DIET	DIET 1	DIET 2	DIET 3	DIET 4
Breading waste	46.9	9.3		1.9	
Feed waste	39.6	75.2	64	78.6	43.5
Dry distillery stillage	5.4	2.5	9.5	2.5	12.2
Coffee silver film	6.6	1.9			2.1
Hazelnut film	1.5	0.6			
Broken rice		1.5	3.5		
Broken parboiled rice				3.5	8
Green grain			3		2
Rice husk		2.5	2		
Parboiled rice husk				2	
Rice bran		5	15.5		
Parboiled rice bran				9	5
Other rice by-products		1.5	2.5		
Other parboiled rice by-products				2.5	27.2

Table 2. Environmental impact of the different formulated diets. Impact values were calculated using the Environmental Footprint (EF3.0) V1.03

IMPACT CATEGORY	Unit	CONTROL DIET	DIET 1	DIET 2	DIET 3	DIET 4
Climate change	kg CO_2 eq	0.098	0.108	0.232	0.122	0.408
Ozone depletion	mg CFC11 eq	0.014	0.011	0.025	0.013	0.040
Photochemical ozone formation	g NMVOC eq	0.169	0.207	0.390	0.258	0.802
Particulate matter	disease inc./1M	0.003	0.006	0.011	0.008	0.027
Human toxicity, non-cancer	CTUh/10M	0.002	0.005	0.006	0.005	0.012
Human toxicity, cancer	CTUh/10M	0.0002	0.0002	0.0004	0.0003	0.0010
Acidification	mol H+ eq/100	0.049	0.097	0.168	0.128	0.412
Eutrophication, freshwater	g P eq	0.016	0.017	0.029	0.019	0.046
Eutrophication, marine	g N eq	0.07	0.33	0.67	0.51	2.02
Eutrophication, terrestrial	mol N eq/100	0.14	0.36	0.63	0.49	1.67
Ecotoxicity, freshwater	CTUe	0.85	1.77	3.58	1.49	5.08
Land use	Pt	3.97	3.87	10.98	2.78	12.59
Water use	m3 depriv.	0.70	1.01	2.53	2.70	11.26
Resource use, fossils	MJ	1.49	1.18	2.56	1.36	4.14
Resource use, minerals and metals	mg Sb eq	0.09	0.18	0.40	0.18	0.68

Best practices on scientific computing applied to dairy LCA models

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1. INTRODUCTION

Large dairy cooperatives can have farmers in several countries, with a diverse typology of dairy farms. In order to give comprehensive, and tailored advice to farmers on how to reduce their greenhouse gas emission intensities, specific LCA tools are often needed (Arla Foods, 2024). Here we present the software solution behind the Climate Check Tool used by Arla in their climate change mitigation strategy (Arla Foods, 2022).

Here we present the LCA model that is behind the Climate Check tool as well as implementation details. We argue that implementation details matter because they are essential to improve the reliability and usefulness of LCA models.

2. METHODS

Underpinning the Climate Check Tool there is a LCA model that given a farm survey and literature data returns a series of key performance indicators such as contributions to their climate footprint. It has several configuration options, including either following attributional or consequential models, land use change models etc. The data sources and general methodology has been documented in several reports including Schmidt and Dalgaard (2012, 2021). Here we explain the python implementation of the LCA model that is currently being used.

3. RESULTS AND DISCUSSION

The model uses as data inputs a survey filled by farmers annually. The model is composed of several modules representing different activities at the farm such as growing livestock and crops. The equations that underly the farm inventories are assembled as directed acyclic graph (Figure 1), which allows to automatically update in which order the calculation should be done as we update the model. The model has nearly 7000 internal parameters, represented as nodes in the graph. The edges illustrate interdependence between parameters. Specific test modules validate intermediate parameters of the model to allow an early validation of the survey. Unit tests are used to verify components of the model are working as expected. An online repository stores the different versions of the model using version control. This allows to easily redo calculations with older versions of the model for verification. The python model can be used through an *application programming interface* (API) deployed by the client. This gives full control of the data to the client as well as the power to easily scale the calculation, calculating KPIs for thousands of records in a short amount of time. Overall, we attempt to follow best practices in scientific computing as described in Wilson et al. (2014)

4. CONCLUSIONS

Following best practices in scientific computing in LCA models have several advantages: it facilitates a fine control of the versions of the model, ability to scale the calculations, provides full control to the client of their data, and facilitate a thorough validation of new records. Moreover, it eases debugging and the expansion of the model to the needs of the client. We recommend following best practices, to increase the impact of LCA models in industry.

5. ACKNOWLEDGEMENTS

We thank Maike Brask and Karen Helle Sloth from Arla Foods for their advice.

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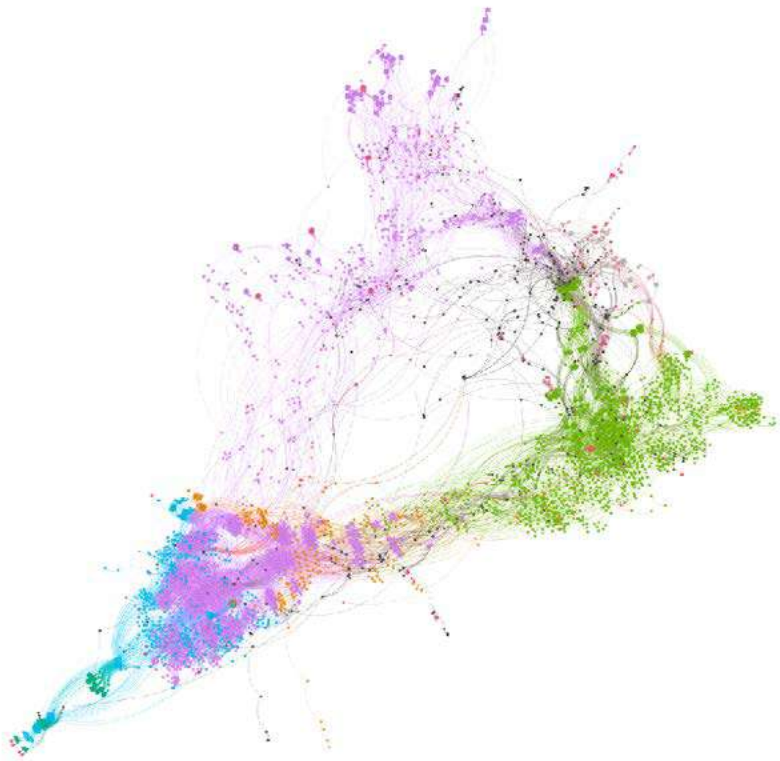

Figure 1. Network representation of the internal parameters of the model and how they are connected. Different colours represent different modules (e.g. pink: livestock and green homegrown crops)

Optimization of resource use and reduction of environmental impact in different pig genetics

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1. INTRODUCTION

In a scenario of climate change, limited availability of resources, and the need to supply protein to a growing world population, the sustainability of pork production requires a more efficient use of resources and a reduction of its environmental impact, while also improving productive performance and resilience of pig populations. The feed conversion efficiency (FCE) is a key driver of environmental and cost impact. The aim of this study is comparing different crossings derived (thus, with different FCE) from their purebred lines to find improved environmental and economic pig production systems, considering different parameters (such as growth rate, feed consumption and digestibility, etc.). In response to these challenges, the OPTIPORC project arises from the common interest of five pig breeding companies comprising the Catalan Association of Select Swine Breeders (Associació Catalana de Criadors de Bestiar Porcí Selecte, ACCBPS).

2. METHODS

The quantification of the environmental impact for different genetics groups was performed using Life Cycle Assessment methodology. Primary data were collected from 2022 to 2024 through interviews, measures, and samples. The fattening production system was inventoried. In some cases, primary data were not available and secondary data had to be used. When possible, this secondary data were retrieved from Catalan databases, providing an average for the territory. Otherwise, secondary data were retrieved from Ecoinvent 3.8 (Wernet et al., 2016) and Agribalyse 3.1 (Asselin-Balençon et al., 2020). The scope of the study was from cradle to farm gate. Finally, environmental Footprint method, in its version 3.0 (European Commission, 2013) was used to assess the environmental impact. Five different scenarios were differentiated, with a total of 8 genetics archetypes with different origins, to represent the variability efficiency. A total of 18 different feeds and 800 fattening pigs have been inventoried.

3. RESULTS AND DISCUSSION

Impact results are shown for different genetics groups of 20 to 30 animals, separated males and females, in kg of live weight (table 1). All the male cases present lower carbon and water footprint in comparison with the females. This was expected because male have better feed conversion ratio leading to a more efficient use of resources. The origin 2 presents a lower environmental impact tan the origin 1, regardless of being Duroc or Pietrain purebred lines. The results present differences in the environmental impact between the crossbreds. For example, the carbon footprint of 1 kg live weight (LW) of pig produced was 3.8 to 4.8 kg of CO_2 eq. and the water footprint was of 7.3 to 9.3 m^3 eq (table 1).

4. CONCLUSIONS

This study provides an example of LCA used as a decision support tool for companies, in this case to help pig producers to identify best (environmental) cross of genetics and feed strategy. This study has allowed to verify the importance of the genetic selection in the environmental impact. There are a lot of factors and parameters that can modify the results, for example feed and water consumption, or the nitrogenous and phosphorus digestibility.

5. ACKNOWLEDGEMENTS

Authors thank specially the EIP-Agri initiative (EU) and the Department of Climate Action, Food and Rural Agenda (Generalitat de Catalunya), as well as to the pig breeding companies Selección Batallé S.A., UPB Genetic World S.L., Grup Gepork S.A., Baró Germans S.A., and Pinsos Sant Antoni S.A., for supporting the development of OPTIPORC project (Grup Operatiu 107 2021 2A).

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Table 1. Impacts per kg of live weight (LW) of the different case of studies at farm gate.

	Lot	Origin 1								Origin 2			
	Crossbred*	Du1 x (Ld-Lw)		Du2 x (Ld-Lw)		Pi x (Ld-Lw)		Pi x (Ld-Lw)		Du x (Ld-Lw)		Pi x (Ld-Lw)	
	Male (M) or female (F)	M	F	M	F	M	F	M	F	M	F	M	F
Climate change	kg CO2 eq	4,6E+00	4,8E+00	4,6E+00	4,7E+00	4,2E+00	4,1E+00	4,0E+00	4,2E+00	3,8E+00	4,1E+00	4,0E+00	4,1E+00
Ozone depletion	kg CFC11 eq	1,3E-07	1,3E-07	1,3E-07	1,3E-07	1,2E-07	1,5E-07	1,6E-07	1,6E-07	1,5E-07	1,6E-07	1,5E-07	1,6E-07
Ionising radiation	kBq U-235 eq	1,7E-01	1,8E-01	2,3E-01	1,9E-01	1,7E-01	2,7E-01	2,9E-01	3,0E-01	5,2E-01	5,7E-01	5,3E-01	5,5E-01
Photochemical ozone formation	kg NMVOC eq	7,2E-03	7,6E-03	7,2E-03	7,6E-03	6,6E-03	8,9E-03	9,0E-03	9,4E-03	8,3E-03	9,0E-03	8,7E-03	8,9E-03
Particulate matter	disease inc.	3,6E-07	4,0E-07	3,4E-07	3,8E-07	3,2E-07	3,6E-07	3,5E-07	3,9E-07	3,1E-07	3,5E-07	3,4E-07	3,6E-07
Human toxicity, non-cancer	CTUh	7,0E-08	7,4E-08	7,0E-08	7,4E-08	6,5E-08	8,5E-08	8,3E-08	8,8E-08	8,0E-08	8,7E-08	8,5E-08	8,7E-08
Human toxicity, cancer	CTUh	2,0E-09	2,1E-09	2,0E-09	2,1E-09	1,8E-09	2,5E-09	2,6E-09	2,7E-09	2,4E-09	2,6E-09	2,5E-09	2,6E-09
Acidification	mol H+ eq	1,2E-02	1,3E-02	1,2E-02	1,3E-02	1,1E-02	2,0E-02	2,0E-02	2,1E-02	1,9E-02	2,0E-02	2,0E-02	2,1E-02
Eutrophication, freshwater	kg P eq	4,2E-04	4,5E-04	4,3E-04	4,5E-04	3,9E-04	5,2E-04	5,1E-04	5,4E-04	4,9E-04	5,3E-04	5,1E-04	5,3E-04
Eutrophication, marine	kg N eq	1,6E-02	1,7E-02	1,6E-02	1,7E-02	1,5E-02	1,8E-02	1,8E-02	1,9E-02	1,7E-02	1,8E-02	1,8E-02	1,8E-02
Eutrophication, terrestrial	mol N eq	6,8E-02	7,5E-02	6,5E-02	7,3E-02	6,1E-02	9,5E-02	9,3E-02	1,0E-01	8,5E-02	9,4E-02	9,1E-02	9,5E-02
Ecotoxicity, freshwater	CTUe	1,2E+02	1,3E+02	1,3E+02	1,3E+02	1,2E+02	1,4E+02	1,3E+02	1,4E+02	1,3E+02	1,4E+02	1,4E+02	1,4E+02
Land use	Pt	1,9E+02	2,0E+02	1,9E+02	2,0E+02	1,7E+02	2,1E+02	2,1E+02	2,2E+02	2,0E+02	2,1E+02	2,1E+02	2,1E+02
Water use	m3 depriv.	8,1E+00	8,6E+00	7,9E+00	8,5E+00	7,3E+00	8,0E+00	7,7E+00	8,2E+00	8,4E+00	9,3E+00	8,5E+00	8,7E+00
Resource use, fossils	MJ	1,4E+01	1,5E+01	1,5E+01	1,5E+01	1,3E+01	1,8E+01	1,9E+01	2,0E+01	2,2E+01	2,4E+01	2,3E+01	2,4E+01
Resource use, minerals and metals	kg Sb eq	1,3E-05	1,4E-05	1,3E-05	1,4E-05	1,2E-05	1,5E-05	1,5E-05	1,6E-05	1,6E-05	1,7E-05	1,7E-05	1,7E-05

* Du: Duroc; Pi: Pietrain; Ld: Landrace; Lw: Large White. These purebred lines differed between origins (Scenarios).

Assessing the environmental impacts of beef production chains integrating grazing and landless systems

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1. INTRODUCTION

Livestock production has significant global environmental impacts, with meat consumption projected to rise alongside population growth. Mixed beef production systems offer a promising alternative, generally resulting in lower environmental impacts per kilogram of carcass compared to conventional methods. Mixed systems typically involve adult cattle grazing alongside calves' fattening within landless systems. While landless systems have lower climate change impacts, grazing systems benefit biodiversity and carbon sequestration. Mixed systems aim to achieve higher productivity with reduced environmental impacts (FAO, 2017).

2. METHODS

Four mixed beef systems based on the origin of the calves were assessed using LCA. The systems included suckler cow farms fattening their offspring (BSF: Beef Single Farm), farms where calves are raised elsewhere (BAF: Beef Abroad Farm), and systems where dairy calves from Spain (DN: Dairy National) or abroad (DA: Dairy Abroad) are fattened. The system boundaries were set at the slaughterhouse gate, and the functional unit was 1 kg of carcass weight. Primary data from farmers' and slaughterhouses' surveys were used, and allocation between coproducts followed updated environmental guidelines (EPD, 2022). Seven impact categories were evaluated using ReCiPe 2016 v10 method. An uncertainty analysis using Monte Carlo simulation was carried out, considering the variability in survey data and the uncertainty of the fermentation and manure management emission factors.

3. RESULTS AND DISCUSSION

DN and DA systems showed lower environmental impacts than BSF and BAF, except for Fw-Eu and M-Eu impacts (**¡Error! No se encuentra el origen de la referencia.**). This can be explained by the lower burdens allocated to milk with respect to meat in dairy farms, while specialized beef meat systems account for the entire environmental burdens of reproductive animals. Enteric fermentation and manure management are the leading causes of impacts in the evaluated systems, although their contribution varies depending on whether the breeding or fattening phases are involved (**¡Error! No se encuentra el origen de la referencia.**). Imported raw ingredients and transportation play significant roles in certain impact categories. These findings align with O'Brien et al., 2020. Transportation and meat processing stages contributed minimally to the impacts, as observed by Mogasen et al. (2015). The uncertainty analysis highlights the variability of the systems, particularly in climate change and acidification, emphasizing the importance of optimizing system design to mitigate their environmental impacts.

4. CONCLUSIONS

The study underscores the complexity of beef production's environmental footprint and shows the advantages of mixed beef production systems in Spain, particularly those integrating dairy calves (DN and DA), which exhibit lower impacts in most categories compared to specialized beef systems (BSF and BFU). Our findings highlight the need for tailored sustainable practices, mainly as concerns feed production and manure management, to further reduce environmental impacts.

5. ACKNOWLEDGEMENTS

The authors acknowledge PROVACUNO's assistance in surveying stakeholders and express gratitude to Salvador Calvet and Gabriela Clemente for their valuable input in improving the manuscript.

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Table 1. Environmental impacts of the four beef production systems per functional unit (1 kg carcass).

Impact category	BSF	BAF	DN	DA
Climate Change [kg CO_2 eq.]	$2.08\cdot10^{+01}$	$2.09\cdot10^{+01}$	$9.25\cdot10^{+00}$	$9.27\cdot10^{+00}$
Terrestrial Acidification [kgSO_2 eq.]	$8.62\cdot10^{-02}$	$8.62\cdot10^{-02}$	$3.57\cdot10^{-02}$	$3.58\cdot10^{-02}$
Marine Eutrophication [kg N eq.]	$1.03\cdot10^{-02}$	$1.03\cdot10^{-02}$	$1.32\cdot10^{-02}$	$1.32\cdot10^{-02}$
Freshwater Eutrophication [kg P eq.]	$1.09\cdot10^{-03}$	$1.09\cdot10^{-03}$	$1.42\cdot10^{-03}$	$1.42\cdot10^{-03}$
Stratospheric Ozone Depletion [kg CFC-11 eq.]	$2.50\cdot10^{-04}$	$2.50\cdot10^{-04}$	$1.05\cdot10^{-04}$	$1.05\cdot10^{-04}$
Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	$2.12\cdot10^{-02}$	$2.13\cdot10^{-02}$	$1.59\cdot10^{-02}$	$1.61\cdot10^{-02}$
Photochemical Ozone Formation, Human Health [kg NOx eq.]	$1.75\cdot10^{-02}$	$1.77\cdot10^{-02}$	$1.52\cdot10^{-02}$	$1.54\cdot10^{-02}$

Abbreviations: BSF= Beef single farm; BAF: Beef abroad farm; DN: Dairy national; DA: Dairy abroad.

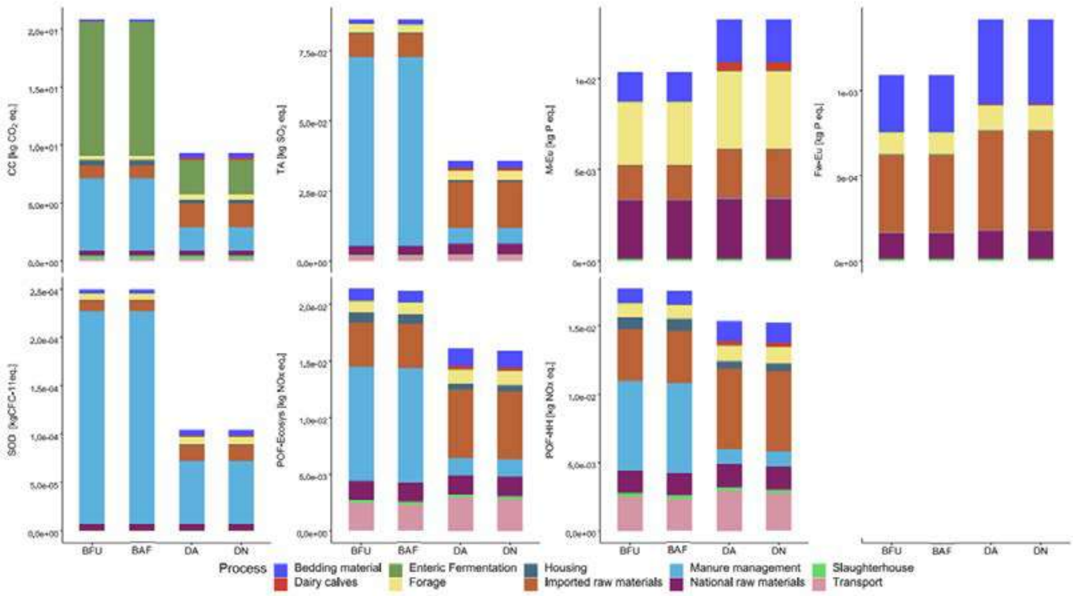

Figure 1. Environmental impacts (climate change (CC), terrestrial acidification (TA), freshwater eutrophication (Fw-Eu), marine eutrophication (M-Eu), photochemical ozone formation- human health (POF-HH), photochemical ozone formation- ecosystems (POF-Ecosys), and stratospheric ozone depletion (SOD)) of the four beef production systems per functional unit (1 kg carcass).

Abbreviations: BSF= Beef single farm; BAF: Beef abroad farm; DN: Dairy national; DA: Dairy abroad.

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Strategies for mitigating the carbon footprint of milk production in the South and Southeast of Brazil

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1. INTRODUCTION

Livestock production faces the challenge of reducing greenhouse gas (GHG) emissions without compromising productivity. Brazil has the third-largest milk production in the world; however, animal productivity is low, with around 2600 kg milk/cow/year (Andrade et al., 2023). The country's climate regions and social and economic diversity influence the environmental impact of dairy production in Brazil. Despite this, it is necessary to improve milk production efficiency, such as increasing individual productivity and optimizing herd composition by increasing the proportion of dairy cows. The construction of environmental metrics for milk production is the way to identify strategies to reduce the carbon footprint of milk. The estimate of a milk's carbon footprint is complex because it relates a large amount of direct and indirect data associated with the product system. Life Cycle Assessment (LCA) is a standardized and internationally recognized method that supports science-based decision-making and the development of strategies to reduce environmental impact (IDF, 2022). This study aimed to estimate the carbon footprint of milk from farms in southeastern and southern Brazil and to evaluate strategies focused on enteric CH_4 mitigation.

2. METHODS

The study used data from 400 farms in Brazil's southeast and south regions, which account for 67.7% of the country's milk production. farm data was collected from the research project carried out by Embrapa Cattle Dairy, between 2021 and 2023, considering diversified production systems. The study followed the ISO 14040 and ISO 1044 (ISO, 2006) guidelines for LCA and adopted the cradle-to-farm-gate boundary. The IPCC (2019) equations were used to estimate GHG emissions. The functional unit used was 1 kg of fat and protein-corrected milk (FPCM) (IDF, 2022).

To design the scenarios, identified critical points that affect the carbon footprint of milk production were considered, such as low individual productivity and the proportion of animals in production (% lactating cows) and other categories of the herd (% dry cows, heifers, and dairy calves). Therefore, it was hypothesized these factors could be used to achieve a reduced carbon footprint in milk production. The milking rate of cows achieved by better reproductive efficiency can leverage the reduction of methane emissions (Abreu et al., 2023). Based on the two factors, scenarios were applied to fixing the herd composition to 49% dairy cows, and to adjust 7% dry cows, 21% heifers, and 23% dairy calves, and a 10% increase in milk production per cow for the farms studied. The calculations were carried out using the OpenLCA version 1.11 software for impact analysis in the climate change category.

3. RESULTS AND DISCUSSION

Milk yield ranged from 5.05 to 43.7 kg FPCM cow^{-1}. day^{-1} (average 19.5 kg FPCM cow-^{1} day^{-1}). The proportion of lactating cows ranged from 25.2 to 67.3% (average 48.2%). The milk carbon footprint averaged 1.44 and a weighted average of 1.02 kg of CO_2 eq. kg FPCM^{-1}, a figure lower than that presented in the IFCN report, which was 2.16 kg of CO_2 kg FPCM^{-1} for Brazilian milk (IFCN, 2022). Enteric CH_4 emissions accounted for 69% (30-95%) of the total GHG emissions. The main sources of variability were herd composition, animal productivity, and diet quality. The data variability shows heterogeneity of the dairy systems and the opportunity to improve herd composition and cow's milk yield.

The CH_4 emissions were reduced by 35% caused by a reduction of 12% in the total number of cattle in the farms. However, emissions from feed production were less influenced, 11%, due to the higher food intake from the lactating cows (49% herd cattle). The milk carbon footprint ranged from 0.42 to 7,03 kg of CO_2 eq. kg FPCM^{-1}, with an average of 1.01 and a weighted average of 0.92 kg of CO_2 eq. kg FPCM^{-1}.

4. CONCLUSIONS

The study showed that in the proposed scenario, it is possible to achieve the objective of reducing CH4 emissions by more than 35%, reaching the goal of the Global Methane Pledge, and reducing the carbon footprint by 30%.

5. ACKNOWLEDGEMENTS

The authors are grateful to Brazilian Agricultural Research Corporation – Embrapa, Nestlé Brazil Ltda, and Lactalis of Brazil Ltda.

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ISO-International Organization for Standardization (2006b) Environmental Management - Life Cycle Assessment - Requirements and Guidelines ISO 14044.

Table 1. Carbon footprint and enteric CH4 emissions of milk in baseline and scenario for increasing yield per cow and optimizing herd composition.

	Carbon footprint (kg of CO2 eq. kg FPCM-1)			Enteric CH_4 emissions (kg of CO2 eq. kg FPCM-1)		
	Mean	**Weighted mean**	**Range (max-min)**	**Mean**	**Weighted mean**	**Range (max-min)**
Baseline	**1.44**	**0.92**	**9.63-0.43**	**1.01**	**0.65**	**3.57-0.39**
Scenario	**1.01**	**0.85**	**7.03-0.42**	**0.65**	**0.56**	**2.09-0.30**

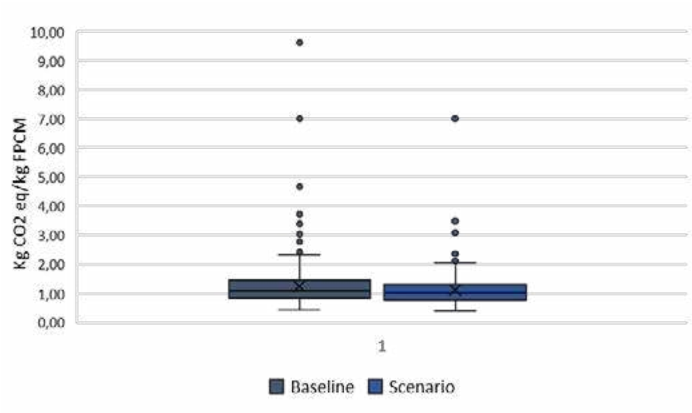

Figure 1. Box plot to show the variation in the carbon footprint of the milk production of the 400 farms in the baseline and scenario for increasing yield per cow and optimizing herd composition

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An environmental cost-benefit analysis of organic and non-organic sheep farming in Iceland

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1. INTRODUCTION

Approximately 30% of habitable land on the planet is used for livestock purposes that contribute to soil depletion, biodiversity losses, nutrient runoff, and greenhouse gas (GHG) emissions contributing to climate change (IPCC, 2022; Willett et al., 2019). The demand for meat and dairy products has never been higher and is expected to grow as global affluence increases (Falcon et al., 2022).Cost-benefit analysis can be used to evaluate the long-term merits of an investment decision, yet the outputs do not typically include eternal costs of environmental damage. Iceland, with its unique climate, abundant natural resources, agricultural traditions, and dependence on global supply chains for agricultural inputs, provides an interesting case study for exploring the economic aspects of sheep farming.

2. METHODS

This paper presents an environmental CBA comparing organic and non-organic sheep farming in Iceland, evaluated over three decades. Aggregate benefits included income from sale of edible meat and aggregate cost framework was based on the environmental life cycle costing (ELCC) method. Greenhouse gas emissions were monetized as an external cost. Data for this case study was collected from one organic and one non-organic farm and was compared to national average data from the Agricultural Research Institute in Iceland. The scale of each farm is quite different, so results were expressed per functional unit – kg of edible meat sold. System boundaries are equivalent to a life cycle assessment of the same system – cradle to farm gate.

3. RESULTS AND DISCUSSION

Net present value (NPV) and benefit-cost ratio (BCR) indicators reveal both systems as unprofitable over thirty years without subsidies. Depending on the discount rate, the organic farm's BCR ranges from 0.26 to 0.38, with a NPV between (-2.4) and (-1.1) million euros. The non-organic farm's BCR ranges from 0.12 to 0.19, with NPV between (-8.6) and (-3.7) million euros. Greenhouse gas emission costs constitute 28% and 33% of total life cycle costs for organic and non-organic farms. Across three discount rates, the LCC and ELCC per kilogram of organic lamb ranged between €13.78 – 25.27 and €18.23 – 37.07, respectively. The LCC and ELCC per kilogram of non-organic lamb ranged between €9.75 – 18.05 and €13.80 – 28.82, respectively. Due to a shortened value chain, organic sheep farming demonstrated revenue advantages as compared to non-organic. The external cost of greenhouse gas emissions from sheep farming forms a significant portion of lifetime costs suggesting that policymakers could incentivize organic practices aimed at reducing greenhouse gas emissions.

4. CONCLUSIONS

This study represents a detailed CBA model that compares organic and non-organic sheep farming systems across economic and environmental dimensions. This analysis provides a deeper understanding of the long-term economic prospectivity of sheep farming at the farm level under different production methods and demonstrated the organic production method to have economic advantages. Sheep farming nations looking to encourage more sustainable food systems by discouraging meat consumption and production could restructure farm subsidies in favor of organic production methods to possibly reduce economic hardship to farmers at the same time as delivering environmental benefits.

5. ACKNOWLEDGEMENTS

This work has been supported by Rannsóknamiðstöð Íslands (Rannís) in relation to the Sustainable Healthy Diets project (grant no. 200221-5601).

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Development of the National Environmental Sustainability and Technology Tool (NESTT) for Canadian egg farmers

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Keywords: NESTT, egg, decision support, farm-level, benchmarking, footprint.

1. INTRODUCTION

In Canada, total egg production experienced an annual growth rate of 2.5% from 2013 to 2018, with egg production constituting around 2% of all cash receipts among farm operations in Canada. The Canadian egg industry is expected to continue growing while facing heightened societal expectations regarding sustainability measurement, management, and reporting. In response to these challenges, Egg Farmers of Canada (EFC), in collaboration with researchers at the University of British Columbia, has developed the National Environmental Sustainability and Technology Tool (NESTT) as the cornerstone of its long-term sustainability plan for the industry (EFC, 2021). NESTT is an online, farm-level sustainability assessment and management tool designed to provide farmers with easy access to sustainability evaluation of their farm operations. Its primary purpose is to empower and enable farmers to informed make business decisions through a sustainability lens, while simultaneously supporting EFC in developing industry-wide sustainability initiatives, targets, and milestones.

2. METHODS

Sustainability assessment within NESTT is supported by an ISO 14040/44-compliant Life Cycle Assessment (LCA) framework. NESTT employs one tonne of eggs as the functional unit, defines system boundaries from cradle-to-farm gate, and bases co-product allocation on feed energy utilization. The primary inventory data collected in NESTT focuses exclusively on layer facilities for each completed flock, while inventory data for other foreground processes (such as pullets, hatcheries, and breeders), feed inputs, and background processes is sourced either from previous Canadian LCA studies (Pelletier 2017) or third-party inventory databases. Manure-related emissions were estimated in NESTT following IPCC Tier 2 protocols. NESTT uses six Impact World+ categories for impact assessment – climate change, land occupation, biodiversity, water scarcity, fossil and nuclear energy use, terrestrial acidification, and freshwater eutrophication. Based on the categorization of impact sources in previous LCAs of Canadian egg production and the input variables from farmers that are key influencing factors in the environmental outcomes of egg production, six life cycle impact sources – pullets, feed, energy, manure, water, and transportation – are defined. An approach to modelling in which each of these six defined impact sources for egg production are modelled as discrete, stand-alone modules is used in NESTT. Further, NESTT integrates various green technologies such as solar/wind energy generation and ammonia scrubbers, with farmers able to see the potential for these technologies to mitigate their farm's environmental impacts.

3. RESULTS AND DISCUSSION

Key resource use and efficiency metrics identified through analysis of previous LCA studies of Canadian egg production are displayed in a scorecard (Figure 1). Life cycle impact assessment results are provided, along with a contribution analysis, in the footprint results page (Figure 2). When a green technology is selected, farmers will be able to see the changes in LCIA results overall and with respect to the specific module that each alternate technology is associated with. Farmers can compare their farm's performance to robust national, regional and housing system-relevant benchmarks for both the scorecard (inventory) indicators and footprint (impact assessment) results. For each indicator, farmers are also categorized into low, medium, or high sustainability rankings depending on their performance relative to other farms with the same housing system type. Farmers can also create action plans, track their farm's performance over time, and access an in-built library that includes information on various aspects of egg farming such as environmental management and animal welfare.

4. CONCLUSIONS

The National Environmental Sustainability and Technology Tool (NESTT) seeks to estimate the life cycle environmental impacts of Canadian egg farm operations, assist farmers in analyzing the mitigation potential of promising green technologies and strategy alternatives, and aid farmers in interpreting the data through decision support features such as benchmarking.

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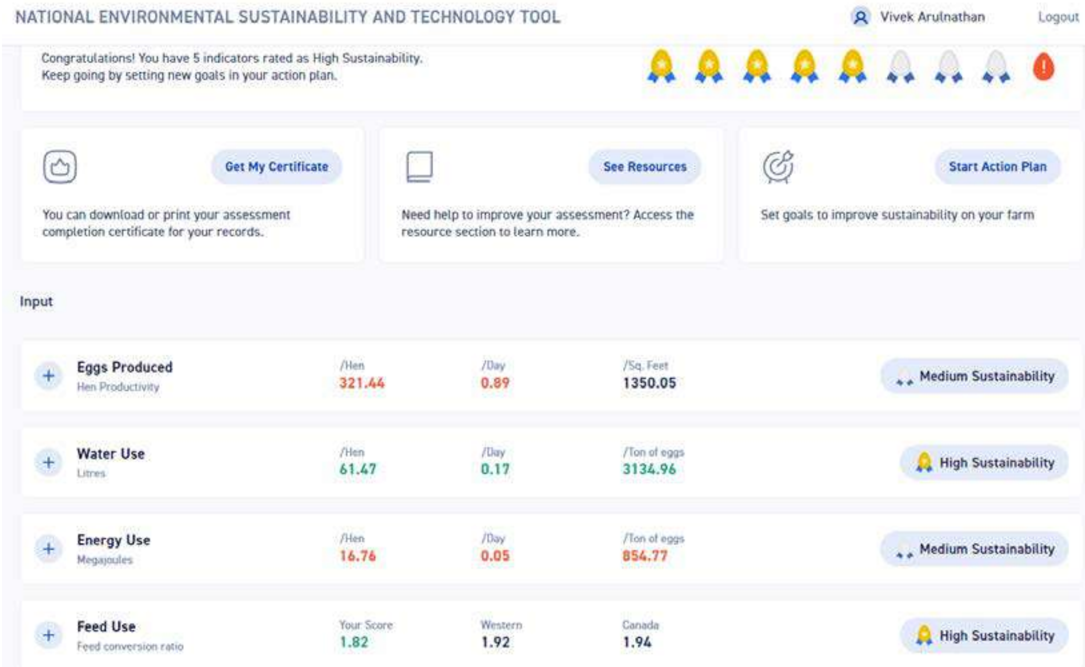

Figure 1: Screenshot of the scorecard in NESTT

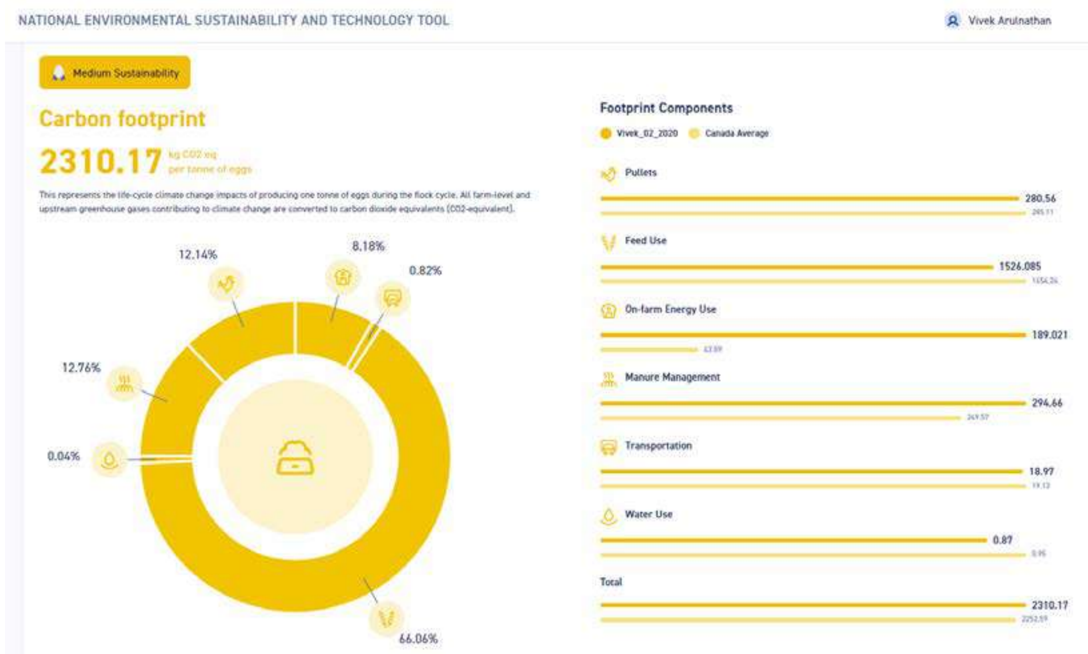

Figure 2: Climate change impacts (carbon footprint) for an imaginary farm as displayed in NESTT

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Effects of early season drought on carbon footprint of milk in northern latitudes

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1. INTRODUCTION

Dairy sector contributes significantly to global greenhouse gas emissions. Meanwhile, climate change exposes challenges to dairy production, and is expected to influence the environmental impacts of the dairy products. For instance, Europe experienced severe drought in the spring and summer of 2022, resulting in substantial agricultural losses. In spring, northern Europe will more often have lower soil moisture levels compared to past averages. (Ruosteenoja et al., 2019). Early summer droughts cause yield losses of forage crops that cannot be compensated for later in the growing season (Peltonen-Sainio et al., 2021).

The lower yield of forage crops leads to extra off-farm feed inputs and alternative feed composition in the dairy system. However, the resources invested to the cultivation system, such as nitrogen fertilizers, seeds and pesticides are not decreased accordingly. Those may affect the carbon footprint of milk life cycle via on-farm cropping, resources input and the feed uptake by dairy cows. Therefore, this study aims to explore the hypothesis that early season drought conditions may elevate the carbon footprint of milk production. Furthermore, the study will explore how different farming practices and adaptive strategies might mitigate effects of drought.

2. METHODS

Data were primary collected from the Viikki Research Farm at the University of Finland (2017-2023). The farm has a research dairy barn with 60 dairy cows, whose average milk production is 10 000 kg per year. The barn is equipped with GreenFeed system for real time methane emission measurements. Feed is mainly produced on the farm, and it consists of grass silage, feed grain and protein crops (rape and fava bean).

Various carbon footprint calculators have been developed for assessing the carbon footprint of milk production following technical specifications on LCA. However, only three carbon calculators out of 64 tested were suitable for farm level carbon audits, as they are scientifically robust, comprehensive and practical (Leinonen et al. 2019). The carbon footprint of milk was analysed using the Solagro carbon footprint calculator developed by the European Commission (https://solagro.com/works-and-products/outils/carbon-calculator), and the Cool Farm Tool developed by the Cool Farm Alliance (https://coolfarm.org/). The weather data were obtained from the Finnish Meteorological Institute.

2. RESULTS AND DISCUSSION

Drought conditions at the beginning of the growing season have reduced oat and barley yields on several occasions (Figure 1). However, for grass silage production, later rains in the growing season mitigated the impact on yields (data not shown). In particular, there was an increase in temperatures in June compared to the long-term averages (Figure 2).

LCA results on the impact of changing crop yields on the carbon footprint of feed and milk are not yet available. Possible ways to mitigate the effects of drought could include soil moisture retaining farming techniques (eg. adjustable underground drainage systems) or changes in forage production. Additionally, irrigation has been identified as a potentially economically viable option for future feed production in Finland (Peltonen-Sainio et al. 2021).

3. ACKNOWLEDGEMENTS

COVERE² has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under Horizon Europe, the EU Framework Programme for Research and Innovation.

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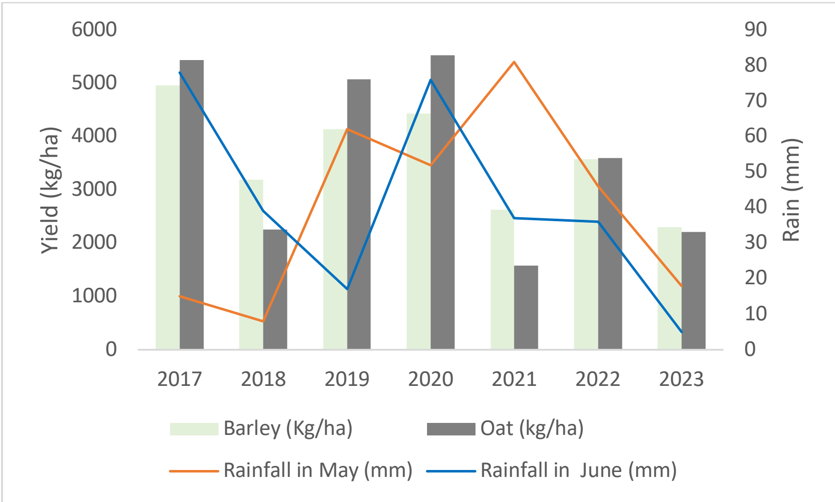

Figure 1. Oat and barley yield levels in 2017-2023 at the Viikki research farm. The red line shows the precipitation in May and the blue line shows the corresponding amount in June.

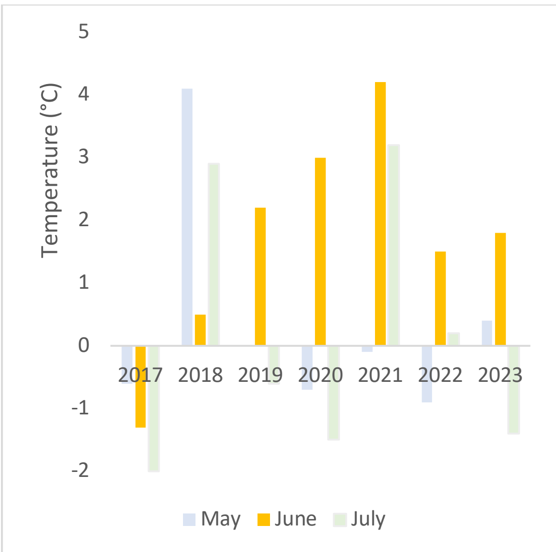

Figure 2. Temperature deviation from the 1991-2020 average (degrees). Location: Helsinki, Finland. Data from Finnish Meteorological Institute.

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Improving the sustainability of livestock system by using low carbon trace mineral sources

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1. INTRODUCTION

The present challenge of livestock production is to meet the growing demand for animal products at low environmental impact. Available life cycle assessment (LCA) studies have shown that feed production significantly contributes to the environmental footprint of edible animal products and therefore an important element to take into account when considering mitigation options. For this reason, the Product Environmental Footprint (PEF) Category Rules (PEFCR, 2018) of animal feed was approved by the EU commission in 2018, with the feed industry being the first sector to have its PEF (PEFCR, 2018). However, for feed additives such as trace minerals, the assessment related to the models of their production process are still being improved. In this line, the feed industry's commitment to generate high-quality data on PEF for feed additives will be important in the near future.

Thus, the objective of this study was to develop a comprehensive dataset for a potentiated zinc (Zn; HiZox®), a monovalent copper (Cu; CoRouge®), and a purified manganese (Mn; ManGrin®) sources in compliance with PEFCR requirements, and to simulate the contribution of the use of these sources in animal feeds to carbon emissions.

2. METHODS

The first step of this study was to perform the PEF study, based on the method as described in the PEFCR Feed for food-producing animals, and the experimental unit was 1 kg of zinc, copper or manganese used in animal nutrition. The system boundaries were from cradle-to-plant (Figure 1), and the environmental indicators included all PEF impact categories, as well as the toxicity ones. The modelling was performed in the SimaPro version 8.5 and the latest PEF datasets were used (PEFCR, 2018).

The second step of the study was to use the values of carbon emissions obtained by the PEFCR study in the simulations of carbon emission, per kg of feed, for different animal species. One of the simulations considered a European scenario of piglet production, where the piglet feeds were supplemented according to EU regulation, meaning 150 mg Cu/kg feed, 150 mg Zn/kg feed and 50 mg Mn/kg feed. The second scenario considered a non-EU scenario for broiler production, where Cu is used to growth promoter reasons, meaning 150 mg Cu/kg feed, 120 mg Zn/kg feed, and 120 mg Mn/kg feed.

3. RESULTS AND DISCUSSION

The results of LCA for the three sources are presented in the Table 1. The carbon footprint of potentiated Zn, monovalent Cu and purified Mn were 4.32, 2.48 and 3.07 kg of CO_2-eq. per kg of product, respectively. These values increased when we consider the impact per kg of mineral supplied in the diet, as the products have, on average, 75% of mineral concentration. The impact on freshwater ecotoxicity were 12, 40 and 27 CTUe per kg of product for Zn, Cu and Mn sources, respectively.

As expected, the values of LCA found for the trace minerals are higher the ones reported for feed crops (usually values are lower than 3 kg CO_2-eq; see Agri-footprint database), because of the more complex process used in the production of feed additives. However, these values are in line with these for other feed additives, as L-lysine (3.18 kg CO_2-eq) or L-threonine (3.93 kg CO_2-eq), also reported in the Agri-footprint database. Although most of customers are concerned by carbon footprint, metals are the greatest contributors to ecotoxicity (Plouffe et al., 2015), which makes the assessment of this category by the trace minerals industry important.

The simulations for the two scenarios showed that the inclusion of these sources presented the lowest carbon footprint among the trace mineral sources (sulfates and hydroxy chlorides). When used combined, they reduced the carbon emissions by 29% in piglet feed compared to sulfates, and by 12% in broiler feed, compared to hydroxy chlorides.

These results can be linked to the high concentration of the three products evaluated (around 75%) compared to sulfates (around 25-35%) and hydroxy minerals (around 54-58%). Other reasons may explain the results, but as the comparison used sources from database (black box), it is not possible to know what is contributing to the impact.

4. CONCLUSIONS

This study provided a high-quality PEF related dataset for trace minerals, to be used by the feed industry in their own PEF assessments.

The results showed that to provide the same Cu, Zn and Mn amounts, HiZox®, CoRouge® and ManGrin® have less environmental impact than sulfates and hydroxy chlorides. These products can help to the decarbonization roadmap for the European feed sector.

As perspective, the animal production system, as well as the speciation of zinc and copper in animal wastes, could be accounted in the boundaries of the LCA. This would be relevant because of the high contribution of metal speciation to the toxicity impact.

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Table 1. Carbon footprint and freshwater ecotoxicity impact of trace mineral sources per kg of product and per kg of mineral provided in the diet

	Carbon Footprint, kg CO2-eq		Freshwater Ecotoxicity, CTUe	
	/kg product	/kg mineral	/kg product	/kg mineral
HiZox®	4.32	5.70	12.0	15.8
CoRouge®	2.48	3.30	40.3	53.6
ManGrin®	3.07	3.98	27.8	36.1

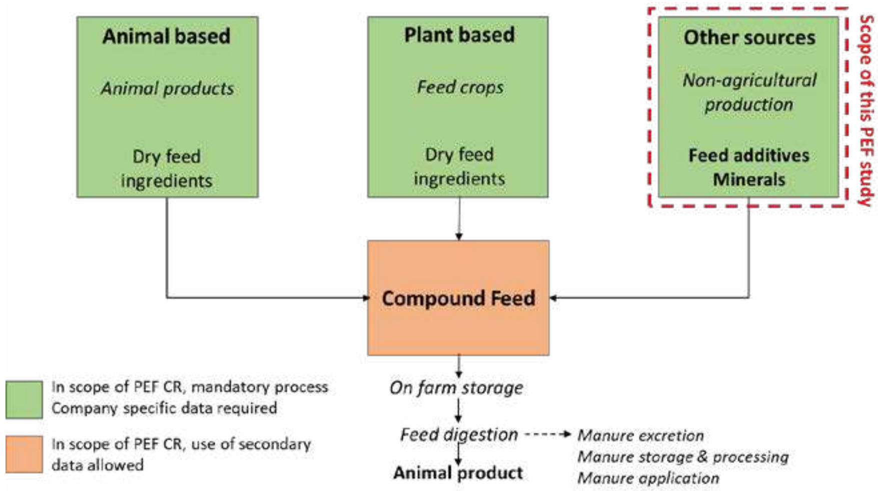

Figure 1: System boundaries considered in this PEF study (based on PEFCR, 2018)

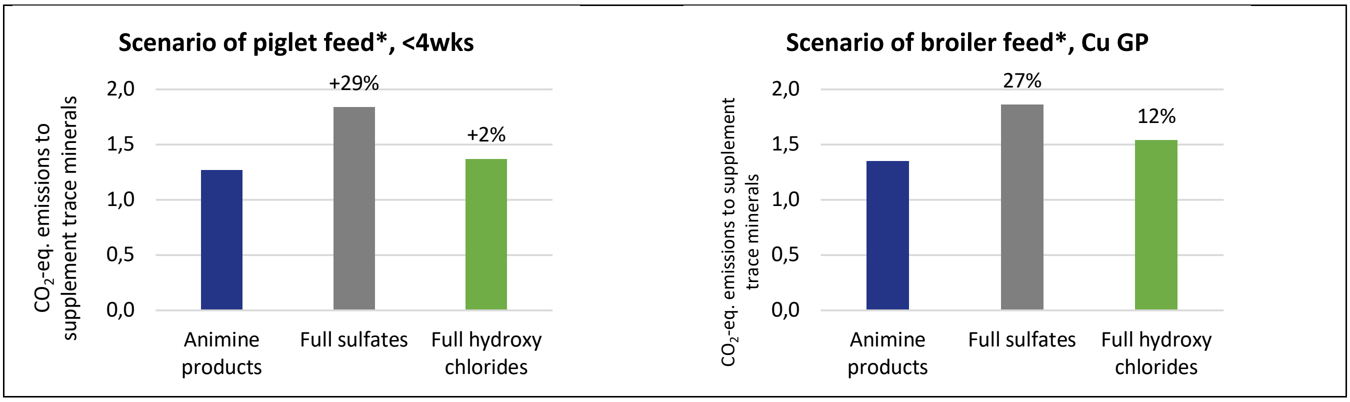

Figure 2. Simulations of the impact of the inclusion of trace mineral in the diet of piglets after weaning (EU context) and growing broilers (outside EU context) on carbon footprint of the feed. Piglet feed (150 ppm total of Cu and Zn, 50 ppm of Mn) and broiler feed (120 ppm of Zn and Mn & 150 ppm of Cu)

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Carbon footprint of Basque dairy farms under different production systems

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1. INTRODUCTION

Greenhouse gas (GHG) losses are an increasing global environmental concern, whose reduction will have to be addressed by all economic sectors in the next future. As Mazzetto et al. (2022) stated, GHG emissions from dairy sector may vary according to the production systems, farm-level practices, and site conditions, and their contribution need to be accounted for by using sound methodologies. Among the different methods to assess the environmental impacts of dairying activity, in which the climate change impact is included, life cycle analysis (LCA) has widely been used (Cortés et al. 2021). The objective of this study was to calculate the carbon footprint (CF) of 10 dairy farms from The Basque Country (northern Spain) by using the LCA approach, and to analyze the main factors contributing to such impact under different production systems.

2. METHODS

Ten dairy farms from The Basque Country (northern Spain) were selected to study their CF. The farms were selected according to the farm typification work previously carried out from a database of 85 dairy farms. Table 1 shows the main features of each farm typology. A cradle-to-gate LCA approach was utilized to assess the CF. All the processes related to milk production were included: farm activities, herd and slurry/manure management, concentrate and forage purchase, fertilizers, bedding material, electricity and fuel use, cleaning and chemical products, paper, plastics, seeds, and transport. The life cycle inventory (LCI) was performed through on-farm surveys, minimizing as much as possible the use of secondary data. The reference year was 2022. Methane (CH_4) and nitrous oxide (N_2O) emissions from enteric fermentation, slurry/solid manure management, and their application as organic fertilizers were estimated by using Tier 2 IPCC guideline (2019). Ammonia losses, which were calculated to estimate the indirect N_2O losses from manure storage and application stages, were calculated by EMEP/EEA (2019). Carbon footprint assessment was carried out by using SimaPro 9.5 software, in which the IPCC 2021 GWP100 impact method was selected. In accordance with the IDF guidelines for dairy systems (IDF, 2015), 1 kg of fat and protein corrected milk (FPCM) was taken as the functional unit. The biophysical allocation method was chosen to split the environmental impact between milk and meat. Overall, milk accounted for ≈ 94% of the CF impact in these farms. The cut-off rule was set at 1%.

3. RESULTS AND DISCUSSION

Table 2 shows the CF values of the pilot farms. Climate change impact ranged from 1.30 to 2.74 kg CO_2 eq kg^{-1} FPCM, which suggests a high heterogeneity among the selected farms. When CF was referred to the farm typology, group1 and group 2 (*extensive*) averaged 2.02 kg CO_2 eq kg^{-1} FPCM, while group 5 (*intensive*) had the lowest mean CF with 1.82 kg CO_2 eq kg^{-1} FPCM. Nonetheless, high variability was also observed within typologies. As Figure 1 shows, enteric CH_4 losses (29%), concentrate purchase (23%), CH_4 losses from manure storage (17%), N_2O losses from field application (4%) and diesel consumption (4%) were the main contributors to climate change impact. On-farm activities accounted for 53% of the CF, while upstream processes did at 47%. The relative contribution of the enteric CH_4 tended to be higher in more extensive farms, while the burden of the concentrates was lower for them. The opposite trend was observed for intensified dairy farms. The use of soybean meal in the concentrates, which was estimated to be 24.2% (SD. 8.4%) of the ingredients, was the principal factor contributing to the off-farm CF impact. Mean CF of the concentrates was estimated to be 1.71 kg CO_2 eq kg^{-1} concentrate (SD. 0.2)

4. CONCLUSIONS

We conclude that large variability of CF exists among studied dairy farms, which suggest that there is a significant margin to improve practices which contribute to abate CF. Abatement strategies should especially be focused on either on-farm (dairy herd nutrition and manure management) or off-farm (concentrate formulation) mitigation strategies. Further farms should be studied to have more accurate figures on the CF of the different farm typologies in the region.

5. ACKNOWLEDGEMENTS

Authors sincerely thank all the farmers who were involved in this study because of their support.

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Table1. Main features of the farm typologies.

Features	Group 1	Group2	Group3	Group 4	Group 5
Farmer's age	> 50	< 50	> 50	> 50	< 50
Nº cows	< 30	31 to 99		> 100	
Milk yield (kg cow^{-1} year^{-1})	< 7,000	< 10,000		> 10,000	
Milk yield (kg ha^{-1})	< 10,000	< 15,000	> 15,000	> 15,000	
TMR	No	No	Yes (78%)	Yes (100%)	
Milking robot	No	No	No	Yes (45%)	
Grazing period milking cows (%)	30	17	0	0	

Table 2. Carbon footprint (kg CO_2 eq kg^{-1} FPCM) of the pilot farms.

	CF (kg CO_2 eq kg^{-1} FPCM)	Group
Farm1	1.72	4
Farm2	1.30	1
Farm3	2.18	4
Farm4	1.79	3
Farm5	1.88	5
Farm6	2.08	2
Farm7	1.99	2
Farm8	2.74	1
Farm9	1.76	5
Farm10	2.10	3

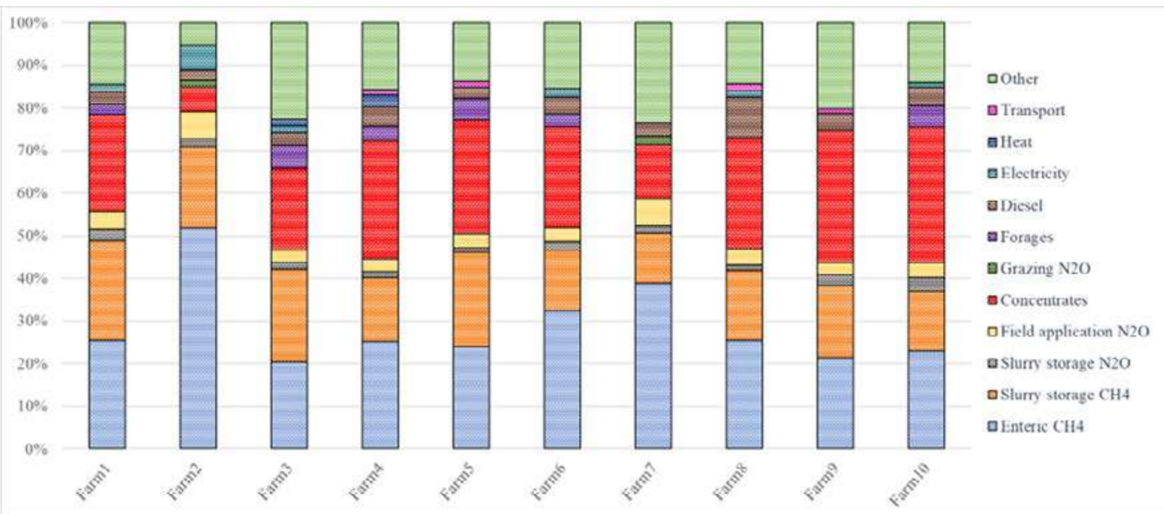

Figure 1. Contribution (%) of the different processes to the carbon footprint

Food loss and waste: environmental impacts and solutions

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Circling the sandwich: A characterisation of food waste and its drivers in UK commercially-prepared sandwiches

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1. INTRODUCTION

Sandwiches are the cornerstone of British food culture. British consumers purchase 3.8 billion sandwiches per year, eating 18,304 in a lifetime (BAS, 2012, Scott, 2017). Half of all sandwiches eaten in the UK are bought from retail environments and consumed outside the home, and distancing in the food chain means that environmental and social impacts, like food waste, are little known to both consumers and academics (EatingBetter, 2022) despite being a ubiquitous and familiar food item. While food producers and manufacturers show increasing concern for food waste within their operations, studies exploring food waste burdens of individual products are rarely undertaken. To understand more about the food waste contribution of this culturally significant food item, we therefore undertook to explore the food waste arisings within a commercial food manufacturing environment.

2. METHODS

We use the Food Loss and Waste Standard (Hanson, et al., 2016) to build an inventory of food waste within an industry leading sandwich manufacturer, and to structure an inquiry into its characterisation, impact, and drivers.

3. RESULTS AND DISCUSSION

We combine food waste data from six months of manufacture runs with observational data and embodied knowledge from wider actors within the industry, in our analysis of chicken salad, one of the most popular sandwich types (Figure 1). Through a rigorous exploration of both food waste arisings and its drivers, we enumerate the food waste burden of the individual sandwich as 34.64 g, or roughly 14 % of a whole sandwich's weight (Figure 2). Further, we intend to supplement the food waste inventory with social (nutrient), economic (cost) and environmental impact (CO_2eq) assessment [results under development].

4. CONCLUSIONS

Through an analysis of key characteristics and drivers within the sandwich manufacturing operation, thereby increasing the understanding of food waste inventories on both a granular and systemic level, we seek to offer recommendations to increase the sustainability and circularity of the food manufacturing industry and wider food system.

5. ACKNOWLEDGEMENTS

This research was funded by UKRI BBSRC FoodBioSystems Doctoral Training Partnership (DTP), grant number BB/T008776/1.

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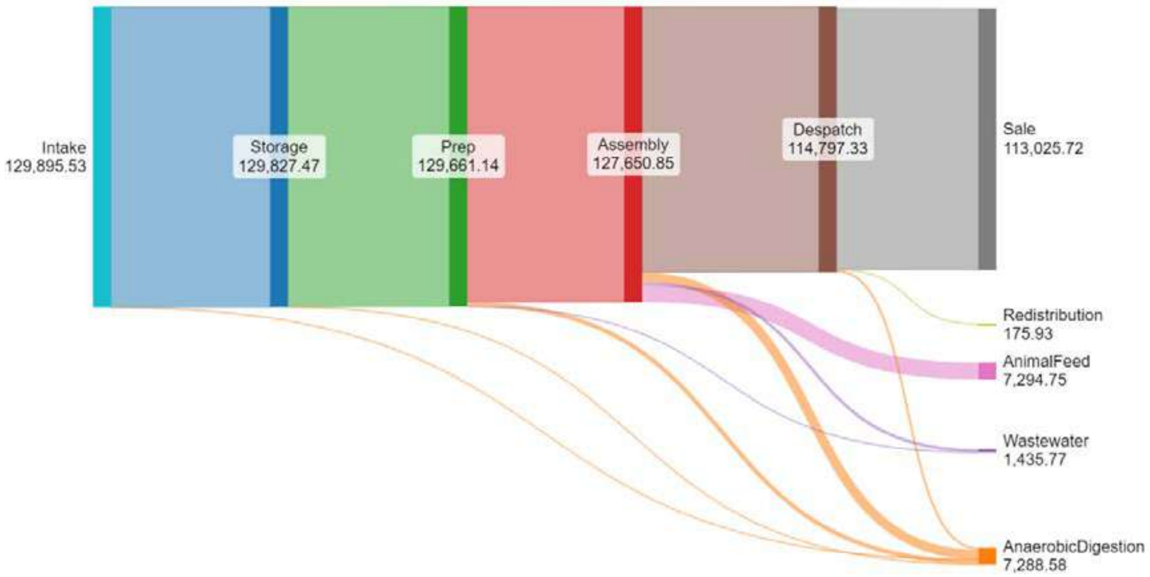

Figure 1.
Material flows of finished product and ingredients in kg, over 6 months of sandwich manufacturing operations. [Preliminary results].

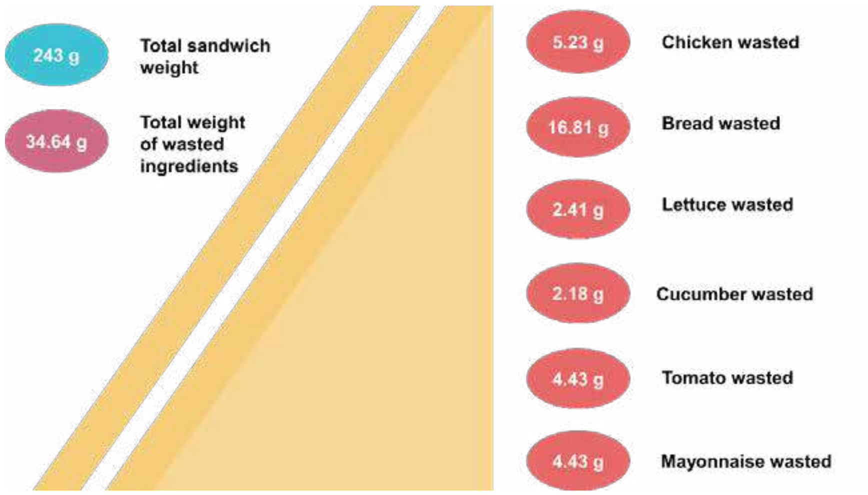

Figure 2. Volumes of food waste generated in the production of a single sandwich, derived from 6 months of operations. [Preliminary results].

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Exploring sustainable approaches to mitigate food waste and reduce environmental impact at the Ortomercato wholesale fruits and vegetables market in Milan

Andrea Casson[1]*, Abhishek Dattu Narote[1], Giovanni Ferrazzi[2], Carlo Bellettini[3], Manuela Rollini[4], Sara Limbo[4], Riccardo Guidetti[1]

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1. INTRODUCTION

Food waste has become a critical global issue, with around 14% of the world's food lost between harvest and consumption. Despite sufficient global food production, over 3.1 billion people still struggle to access adequate nutrition, with 690 million suffering from chronic hunger (FAO, 2022). This waste incurs significant annual costs for the environment, economy, and society. Addressing food losses and waste is essential for sustainability. While hunger is prevalent in low-income countries, food waste is more significant in middle and high-income countries, although both can coexist within regions. Policies and technological innovations target supply chain efficiency and waste reduction, including circular economy approaches and food redistribution initiatives. However, challenges such as short shelf life and logistical barriers exist. Comprehensive studies, including life cycle assessments, are needed to fully understand the environmental impact of food donation and waste management. This case study aims to quantify and evaluate the environmental impacts of managing food surpluses within the Milan Wholesale Fruits and Vegetables Market through LCA analysis. The study underscores the importance of organized interventions and objective measurement methods to address food waste while ensuring food security for vulnerable populations.

2. METHODS

The environmental impact assessment focused on a non-profit in Milan's Wholesale Fruits and Vegetables Market, aiming to recover unsold produce for redistribution to those in need. Using Life Cycle Assessment (LCA) and ISO standards, it analysed collecting and sorting operations for unfit fruits and vegetables. Suitable items were donated, while unsuitable ones underwent waste disposal. The study, spanning from September 2022 to July 2023, aimed to quantify environmental benefits and social support. The functional unit was 1 kilogram of saved and redistributed product annually, compared to 1 kilogram saved from waste streams. The assessment included production, logistics, waste management, and distribution, with data collected from various sources and Ecoinvent database utilisation for inventory. LCIA employed the EF 3.0 methodology for impact evaluation.

3. RESULTS AND DISCUSSION

The results of the quantitative and environmental impact analysis suggest that an organisation operating within the market is highly successful in food recovery, saving over 136 tonnes of food during the 49 days of operation at the market alone and generating environmental carbon credits equivalent to 55 tonnes of CO_2 eq in a year. The detailed analysis highlighted how some products are more likely to be donated, while others, such as the peach fruit, despite being one of the most donated products, represent the most discarded product at the screening stage, accounting for approximately 21% of the total food (most likely due to the perishable nature of the product). Within the environmental impacts, the analysis shows that food production is the leading cause of impact in almost all categories, accounting on average for 63% of the total impact. Food transport is the second most important factor, contributing 27% on average. When analysing the individual impact categories, cucumbers, peaches, peppers, artichokes, and tomatoes were identified as the products with the highest environmental impact among the stored products.

4. CONCLUSIONS

This work provides a solid basis for arguing the effectiveness of this model in reducing food waste, redistributing food surpluses and contributing positively to the environment in contexts where protecting the value of the food product must be a priority.

5. ACKNOWLEDGEMENTS

The Authors would like to express their sincere gratitude to Fondazione Cariplo and Milan Food Policy for their financial support of the project “VALORE” under the Call for Ideas “Foody Zero Sprechi”, Bandi 2021 Ricerca Scientifica.

This scientific work is also part of a PhD project funded by PON – National Operational Programme - Research and Innovation 2014-2020 – Action IV.5 - PhDs on green topics..

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Exploring sustainable approaches to mitigate food waste and reduce environmental impact at the Ortomercato wholesale fruits and vegetables market in Milan

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Comparative Life Cycle Assessment of surplus food waste prevention through reuse and upcycling

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1. INTRODUCTION

Rising global food demand has led to increased food waste, with one-third of all food produced lost annually, posing ethical, economic, and environmental challenges. In the EU, large volumes of food waste highlight the need for efficient reduction strategies. The EU aims to significantly cut food waste by 2030, aligning with a circular economy approach.

This study presents the results of implementing food waste prevention solutions in the main kitchen of Jespers Torvekøkken (JTK), a catering company in Denmark. The study assesses the environmental footprint savings obtained by introducing reuse and food upcycling technologies to prevent surplus foods from being downcycled to the waste sector. Recycling was also assessed and compared with reuse and upcycling, as the baseline of the study.

2. METHODS

An attributional life cycle assessment was conducted using SimaPro 9.4 and Ecoinvent 3.8, following ISO 14040/14044 guidelines, to compare the different methods of food surplus management. The impact assessment used ReCiPe 2016 Midpoint (H) for Global Warming, Marine and Freshwater eutrophication, Water consumption, and Land use. The functional unit is 1 tonne of food surplus generated. Three systems were assessed in this LCA study:

System 1: 1 tonne of food surplus from JTK kitchen is sent to a biogas plant, representing the baseline for handling food surplus in Denmark.

System 2: 8.1% of the surplus is reused in JTK's kitchen, and the rest goes to the biogas plant. This reflects JTK's efforts since 2021 to reuse surplus bread, fruits, and vegetables in their recipes.

System 3: Hypothetical scenario where 15.1% of the surplus (carrot peels) is upcycled into carrot flour, substituting 50% of wheat flour in cake recipes. In this system, 15.1% is upcycled, 8.1% reused, and the rest goes to the biogas plant.

System 3+green energy: Sensitivity analysis within System 3 using wind electricity and heat from wood chips for the upcycling process.

The system boundaries start at surplus generation and include transportation, anaerobic digestion, heat and power co-generation, drying, and grinding. Upstream food production and cooking emissions are excluded. Footprint savings from substituting food, electricity, inorganic fertilizers, and wheat flour production are included in the calculations. Data about the types and percentages of food surplus reused and upcycled was obtained from JTK, where monthly food surplus characterization defines specific surplus categories and amounts.

3. RESULTS AND DISCUSSION

The results show that System 2 had the best environmental performance in Global Warming, with a net negative score of –11 kg CO_2 eq, while System 3 demonstrated the worst performance at 55 kg CO_2 eq due to the energy-related GHG emissions from drying. System 2 had the lowest footprint in Marine and Freshwater eutrophication and Land Use, however System 3 showed a better performance in Water consumption at -8 $m^{3,}$ mainly due to avoided water consumption from substitution of wheat flour. Applying green energy showed a significant improvement of System 3, with a net negative Global Warming score at - 13 kg CO_2 eq.

4. CONCLUSIONS

Recycling combined with reuse (System 2) showed the least environmental impact overall. The upcycling scenario (System 3) had significant benefits in marine eutrophication and water consumption. Using green energy for upcycling further reduced its environmental footprint, especially for global warming and freshwater eutrophication. These results highlight the importance of integrating circular economy principles in food waste prevention, demonstrating the effectiveness of combining recycling, reuse, and upcycling to mitigate environmental impacts.

5. ACKNOWLEDGEMENTS

This research was performed in the scope of the FOODRUS project that has received funding from the European Union's Horizon 2020 research and innovation program (grant agreement no. 101000617).

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Graph 1: Global Warming impact in kg CO2eq for the 3 studied systems and the sensitivity analysis scenario with the green energy.

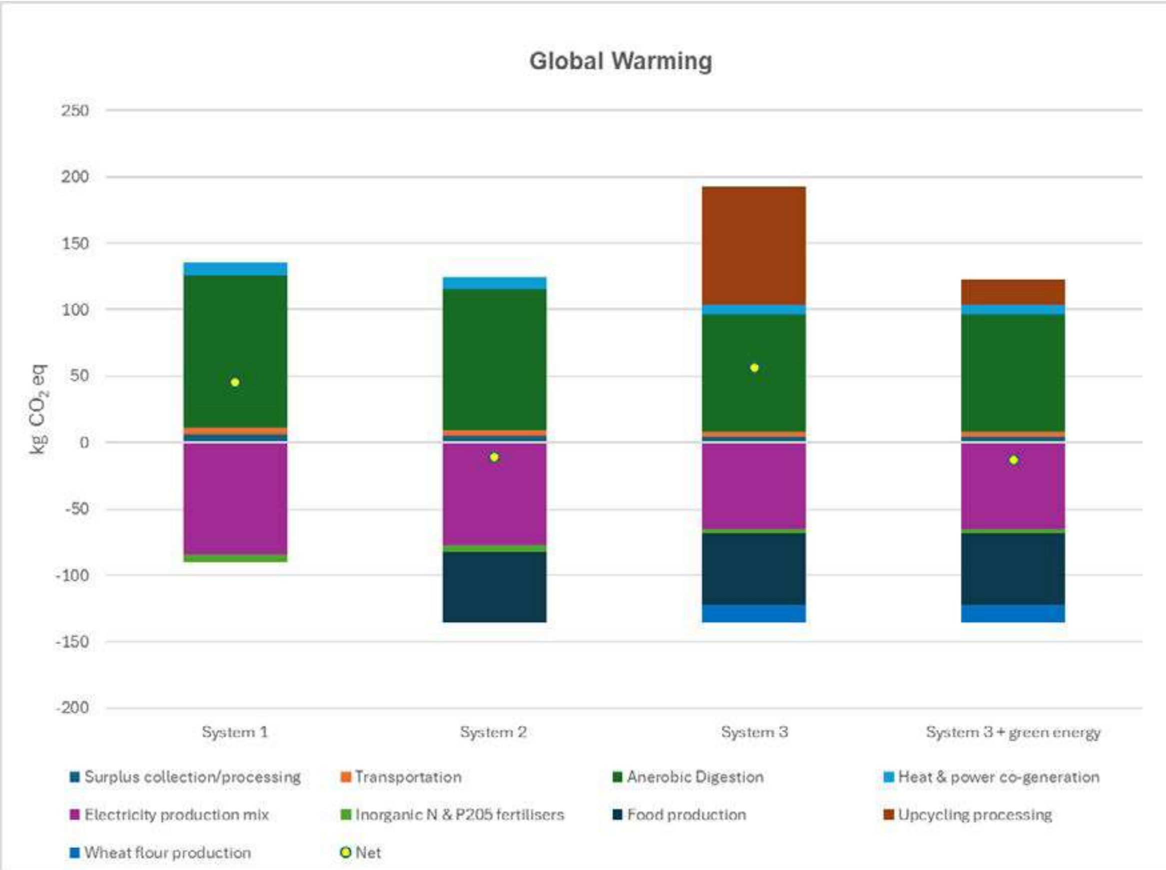

Table 1: The results of the 3 studied systems and the sensitivity analysis scenario within the rest of the impact assessment categories.

Impact category	Units	System 1	System 2	System 3	System 3 + green energy
Freshwater eutrophication	kg P eq	-0.03	-0.04	0.01	-0.03
Marine eutrophication	kg N eq	-0.001	-0.072	-0.104	-0.106
Land use	m^2a crop eq	-24	-76	-55	24
Water consumption	m^3	-2	-5	-8	-9

Sustainability of the food supply chain: Impacts assessment of food losses at primary production stages of plant-based food products

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1. BACKGROUND AND MOTIVATION

The mitigation of food waste and losses is recognized as a sustainability challenge, and the promotion of its reduction aligns with the objectives outlined in Sustainable Development Goal 12.3. The assessment of the magnitude of food losses (FL) at primary production stage and its associated environmental impacts is, hence, essential.

The impacts that could be associated with FL at primary production stage are defined as follow: i) impacts associated with resources consumed by the fraction of food that ended up lost, ii) impacts due to field operations corresponding to the fraction of FL, iii) impacts associated with food that was lost and left on the ground, and iv) on-farm treatment of the FL.

To best of our knowledge, in most commercial databases, current food products impacts do not consider all the impacts associated with FL at primary production stage, namely: impacts resulting in degradation of food products left on the ground besides the impacts due to the FL treatments taking place in-farm are not considered the current life cycle off food products. Regarding the impacts associated with resource consumptions and field operations, the reported results are aggregated and do not distinguish the contribution of impacts associated with FL from the overall impact of the commercialised food product (Figure 1).

In FOLOU project, the primary objective is to assess the impacts associated with food losses at primary production stage of food products. FOLOU aims to propose a starting point to fulfil this normative gap by proposing a PEF-compliant methodology in a form of Product Category Rules (PCR) for the assessment of food losses burdens at primary production stage. This objective is driven by the need to develop an approach on defining the impacts associated with FL, assess the sustainability of FL at primary production stage and provide a holistic approach on how to calculate each impact considered for the food groups under assessment.

2. FORMAT OF THE SESSION AND SCHEDULE

The session will start with an introduction to the FOLOU project, highlighting the primary objective of assessing impacts associated with food losses at the primary production stage, where the PCR delivered as D5.1” D5.1 – Product Category Rules for the assessment of sustainability burdens of food losses” will be presented. The methodology, combining models, LCA methodological choices, and inputs from PEF-compliance sources along with case studies from the FOLOU project and relevant literature, will be presented in the methods section. This will be followed by the expected results and discussion, providing insights into the contributions of each impact to the overall sustainability of the food system.

3. MAIN DISCUSSION POINTS

- **Impacts categorization:** explore multifaceted impacts associated with food losses, covering resource consumption, field operations, degradation of abandoned food, and treatment on the farm.
- **Quantification challenge:** uncover the complexities of quantifying resources consumed during the production of diverse food products and the subsequent allocation of these resources among both products and their losses.
- **Calculation methodologies:** navigate the impact calculation methods, leveraging a sophisticated blend of models, approaches, and inputs. Insights from FOLOU project case studies and relevant literature serve as invaluable compass points in this intellectual journey.
- **Innovative resource allocation:** explore the innovative approach of extracting resource consumption impacts from food losses, steering away from conventional methodologies focused entirely on commercialized food products and broadening the scope beyond just the food produced.

4. EXPECTED OUTCOMES/TAKE HOME MESSAGES

- **Holistic insights:** anticipate detailed insights into how each impact contributes to the broader sustainability of the food system.
- **Methodological refinement:** look forward to the refinement of sustainability assessment methodologies, a pivotal outcome that promises to enhance precision in understanding the interaction between environmental, economic, and social impacts.
- **Comprehensive framework:** envision the emergence of a more nuanced and comprehensive framework for understanding sustainability implications, particularly in the context of food losses at the primary production stage.
- **Creation of a working group:** bringing together diverse perspectives, ensure a comprehensive review, providing valuable insights, identifying areas of improvement and recommending revisions to enhance the overall quality of the PCR.
- **Significance of FOLOU:** recognize the significance of the FOLOU project in contributing substantively to the ongoing discourse on sustainable food systems, promising relevant insights that will reshape food sustainability evaluations.

5. CHAIR'S COMMITMENT

Imane Uald Lamkaddam: CONFIRMED
Daniel Franscisco Egas Galarza: CONFIRMED
Joan Colon Jorda: CONFIRMED
Audrey Rimbaud: CONFIRMED
Ana Isabel Novo de Barros: CONFIRMED

6. ACKNOWLEDGEMENTS

The authors acknowledge the FOLOU project (Horizon Europe research and innovation programme under grant agreement No 101084106). The authors acknowledge the WATELESS project European Union's Horizon Research and Innovation Action (HORIZON-CL6-2022-FARM2FORK-01) under Grant Agreement No. 101084222. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Research Executive Agency (REA). Neither the European Union nor the European Research Executive Agency (REA) can be held responsible for them. Joan Colón has received funding from the 2018 call for Ramón y Cajal grants from the Ministry of Science, Innovation and Universities (ref. RYC-2018-026231-I) co-financed by the State Research Agency and the European Social Fund.

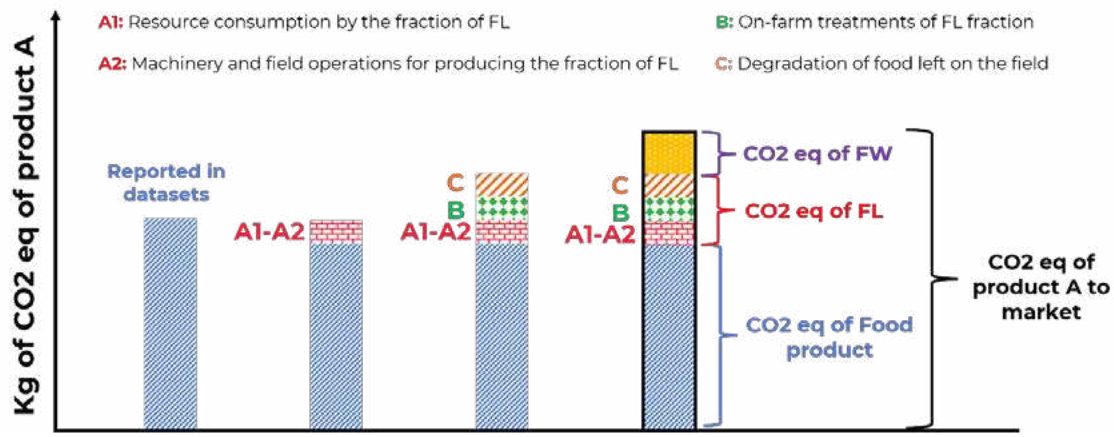

Figure 1. Actual food product impact allocation and proposed impact after accounting the impacts of side flows (E.g., CO2 eq).

22

Farm level dominates losses in Swedish beef supply chain

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1. INTRODUCTION

Food loss and waste (FLW) is a major environmental problem, where global FLW accounted for about half of the global annual GHG emissions from the whole food system (Zhu, J.; *et al.,* 2023). Although animal-based food is lost or wasted in low quantities compared to other commodities, the higher impact associated with producing them still makes it worth addressing (Lipinski, B., 2020). This holds particularly true for beef, which has an outstandingly high impact on global greenhouse gas emissions (Xu, et al., 2021). Losses of Swedish beef at farm level was found to be high, with an average loss rate of 9 % of the initially produced weight (Strid, et al., 2023). To put this into perspective and to guide action, an overview of the losses and waste along the entire beef supply chain would be a help. The aim of the present study was therefore to map out such an overview.

2. METHODS

The method used was a material flow analysis, with data sources from scientific and grey literature. Some flows and loss rates have robust sources, whereas others had to be approximated from similar processes in combination with process specific assumptions. The study does therefore not claim high accuracy, especially not for the consumption stage, but can contribute with a perspective on beef losses along the supply chain. Main data sources include: Strid et al, 2023 and Swedish Food Administration, 2023; more sources in footnotes of Table 1.

3. RESULTS AND DISCUSSION

3.1 Results

The beef losses was clearly largest at farms, followed by butcheries and households. Restaurants, farms and public catering had the highest loss rates. See Table 1.

3.2 Discussion

Considering that the majority of the environmental burden from beef is attributed to the first stage (animal production at farms), farm losses is a true environmental problem, compared to e.g., potatoes where the burden builds up along the supply chain and farm losses become less severe. Based on this, and the size of the farm losses, it seems reasonable to firstly address this sector. However, wasting beef at late stages of the supply chain infer that also the early losses have occurred in vain, as they are built in in the product's "backpack". Therefore, also measures targeting later stages can be effective, and could be more cost efficient as a smaller amount needs to be handled. In the wait for these losses to drastically reduce, LCAs of beef need to acknowledge them and include them in calculations to not underestimate the impact of beef.

4. CONCLUSIONS

Beef losses at farm level outnumbers all the following supply chain stages together, and should be a priority for measures. However, also measures in later stages could be effective, as they will bring their upstream losses with them. LCAs of beef need to acknowledge and account for the farm stage losses.

5. ACKNOWLEDGEMENTS

The study was part of a research project funded by the Swedish research council for sustainable development - FORMAS under the grant number: 2021-02324.

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Table 1. Flows and losses of beef in the Swedish beef supply chain [ton bonefree meat]

	Live animals	Farms[1,2]	Slaughter[3,4,5]	Butchery[6]	Retail and wholesale[7]	Consumption		
						Households[8,9]	Public catering[10,11,12]	Restaurants[11,13]
Share of beef purchases						85%	4%	11%
Swedish domestic beef								
Beef purchases						89 000	3 900	
Produced Swedish beef	109 000	96 000	96 000	94 000	93 000	88 000	3 600	
Home slaughter		3 300						
Losses		9 200	200	1 900	1 000	1 600	300	
Loss rate of incoming flow [%]		9%	0.2%	2%	1%	2%	8%	
Imported beef								
Beef purchases						64 000		8 600
Produced Imported beef	84 000	75 000	75 000	74 000	73 000	63 000		8 000
Home slaughter		1 400						
Losses		7 100	100	1 500	700	1 000		700
Loss rate of incoming flow [%]		9%	0.2%	2%	0.9%	2%		9%
Total domestic and imported beef								
Beef purchases						153 000	3 900	8 600
Produced beef	192 000	171 000	171 000	168 000	166 000	151 000	3 600	8 000
Home slaughter		4 700						
Lost beef		16 400	300	3 400	1 600	2 800	300	700
Loss rate of incoming flow [%]		9%	0.2%	2%	1%	2%	8%	9%
Lost beef [kg per capita and year][14]		1.6	0.03	0.3	0.2	0.3	0.03	0.07

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Sustainable cropping systems

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

Assessing Land Use of an Indoor Vertical Farm, Microgreens production through Life Cycle Assessment

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1. INTRODUCTION

Exacerbated by climate change pressures on food production systems, projected hunger highlights the urgency of addressing land degradation and its economic, social, and nutritional implications[(1)]. Urban agriculture (UA) emerges as a potential solution, offering year-round access to safe, nutritious food[(2)]. Microgreens, a nutrient-dense vegetable type, suitable for hydroponic cultivation, present health benefits with minimal resource demand[(3)]. Conducting a Life Cycle Assessment (LCA) analysis on broccoli microgreens grown in an Indoor Vertical Farm (IVF) aimed to evaluate environmental performance, particularly focusing on land use impacts, to highlight IVFs' potential in mitigating land use issues, utilizing the LANCA model[(4)].

2. METHODS

This work aimed to study the environmental impacts of a prospective indoor farming method integrating Controlled Environment Agriculture (CEA), Building-Integrated Agriculture (BIA) and Plant Factory with Artificial Lighting (PFAL) technologies, applied to the production of microgreens vegetables (*Brassica oleracea*). The IVF installation, situated in a basement of one of NOVA University's campus buildings, in Portugal, was not yet producing plants (and hence the term "prospective"). Two scenarios were studied with a variation in the energy source, where the first used only the national electricity grid mix (GD), and the other implemented a photovoltaic system mix (PV). LCA system boundaries were set from cradle to farm-gate with a functional unit (FU) of 1 kg of fresh weight microgreens produced and delivered daily. The impacts were calculated through the Environmental Footprint (EF) 3.0 and the LANCA assessment methods. Normalization for the first method was conducted using EF 3.0 standardized factors, while for LANCA, the factors calculated by Farago et al.[(5)] were selected.

3. RESULTS AND DISCUSSION

EF 3.0 results showed a 20% less impact when replacing 70% of the energy consumption with a photovoltaic system. The GM scenario displayed 21.30 kg of CO_2eq./FU, while PV values accounted for 17.20 kg of CO_2eq./FU. Normalizing the results with the EF 3.0 factors (Figure 1), it was possible to notice the higher impact of the PV on *Resource Use, minerals and metals* category. Overall, *Human toxicity, cancer* and *Water Use* resulted to be the most impacted categories. The hotspot analysis showed the relevance of the climate change category over the other ones. When deepening the contributions we saw significant impacts coming from the *Cauliflower seeds* (19.39%) and the *Coconut fibre* (16.24%) inputs. Similar findings can also be seen using the

LANCA method. Exploring the normalized values, the categories more impacted were *Biotic Production Loss Potential*, *Erosion* and *Physicochemical Filtration*. Examining deeply the results it was found that the *Coconut fibre* resulted to be the most impactful process representing at least a 60% of the contributions to all the *Occupation* categories (Figure 2 - LCIA LANCA normalized values for the GM and PV scenarios.
Table *3*).

4. CONCLUSIONS

The purpose of this study was to compare the environmental and energetic efficiency of the emerging IVF system and emphasize the importance of integrating renewable energy sources to address challenges like high electricity consumption in UA. Additionally, it highlighted the adverse effects of chosen substrates and seeds on land use within the LANCA model. While LCA is crucial for assessing system sustainability, it may not address all aspects, particularly those concerning food safety and security amidst climate change challenges, where IVFs emerge as a promising solution.

5. ACKNOWLEDGEMENTS

Thanks to Filipe Dourado, Duarte Leal Azevedo and Ricardo F.M. Teixeira for their support.

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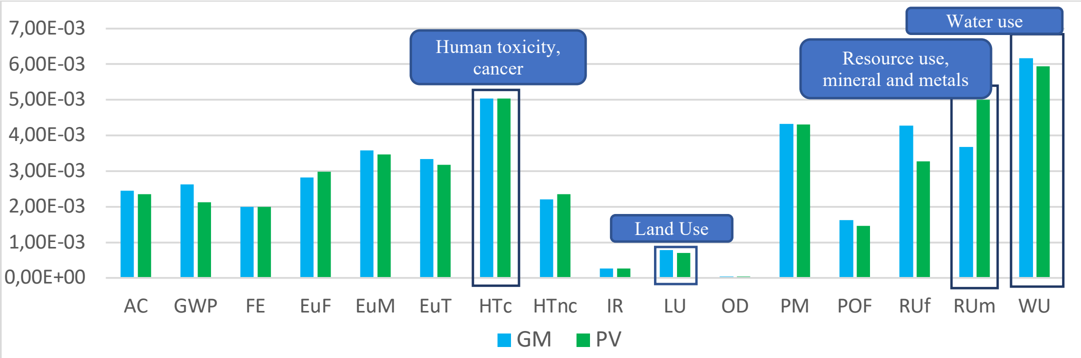

Figure 1- LCIA EF 3.0 normalized values for the GM and PV scenarios.

Table 1- LCIA EF Hotspot analysis for GM and PV scenarios.

Categories	GM	PV
Climate Change - total	18%	16%
Water use	16%	14%
Particulate matter	12%	12%
Ecotoxicity, freshwater - total	12%	12%
Resource use, fossils	11%	12%
Resource use, mineral and metals	8.6%	8.7%
Acidification	4.7%	4.7%

Table 2- LCIA EF Hotspot analysis for GM and PV scenarios.

Process	GM	PV
Infrastructure	5.4%	6.6%
Electricity	34%	18%
Packaging + Transport	5.0%	
Coconut fibre, substrate	16%	
Seeds	19%	

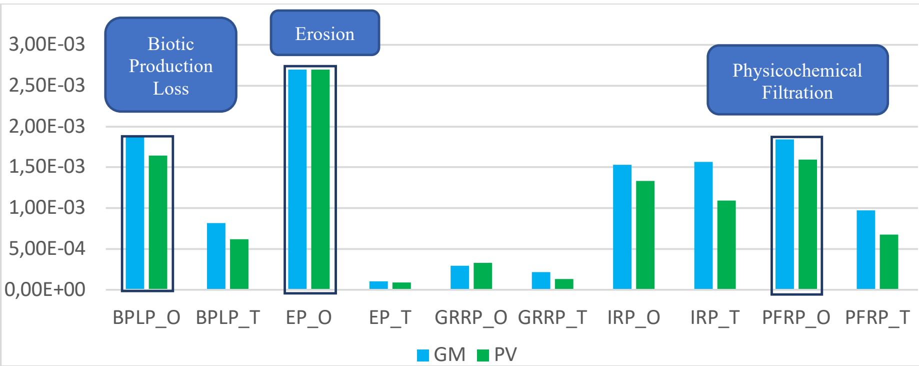

Figure 2 - LCIA LANCA normalized values for the GM and PV scenarios.

Table 3 - Relative contributions from the Coconut fibre to the LCIA LANCA results.

Categories	GM	PV
Biotic Production Loss Potential (Occupation)	67%	77%
Erosion Potential (Occupation)	99%	99%
Groundwater Regeneration Reduction Potential (Occupation)	121%	107%
Infiltration Reduction Potential (Occupation)	62%	71%
Physicochemical Filtration Reduction Potential (Occupation)	63%	72%

Improving environmental impacts of apple

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1. INTRODUCTION

French apple production for the fresh market represents 60% of the total fruit production in France with a potential of 1,6 million tons per year for a total fruit production of 2,3 million tons. The apple remains the leading fruit purchased by households with 16 kg per year according to the Kantar panel. French apple professionals wanted to assess their contribution to climate change to reduce the impacts of production with a framework program (Green Go). This program, piloted by the ANPP (National association for apples and pears), Blue whale, Pink Lady and AFIDEM (Association for processed fruits) which concerns table apples and apple sauce, covers production in the orchard, upstream, and the post-harvest stages of the fruit from the fruit station to the consumer, downstream. This study carried out by CTIFL (Applied research institute for fruits and vegetables), CTCPA (Agrifood technical centre), INRAe Transfert and Ecolysis analysed the main gas emitters at orchard level and throughout the value chain, evaluated different action levers to reduce carbon footprint and the management of orchard biomass at the end of the cycle.

2. METHODS

The upstream agricultural part was studied through the analysis of ten orchards. Life cycle assessment (LCA) calculations were carried out using the Means-InOut tool and then using SimaPro® software and the EF Environmental Footprint reference method. The impact of post-harvest phases was assessed using the 3EP calculator (Loiseau et al., 2020). For apple sauce, the study was conducted with industry stakeholders based on individual portion-sized applesauce sold in the retail distribution circuit. The action levers to reduce climate change impacts at the orchard, at the processing level, as well as in logistics and transportation were evaluated through multi-stakeholder workshops.

3. RESULTS AND DISCUSSION

At the orchard, the climate change represented 87 g CO_2 eq./kg of apple (98 g CO_2 eq. if considering commercialised kg of apple) and was mainly due to mechanization, which accounted for 46% to 75% of greenhouse gas emissions: use of lifting platforms for pruning, thinning, harvesting, installing hail-netting. The figure 1 shows the GHG emissions of fresh apples sold for each stage from orchard to the consumer with a total of 550 g CO_2 eq./ kg of apple: the orchard represented less than 20% of GHG emissions, the cardboard packaging nearly 25% and the movement of consumers to the shop was the biggest emission (40%).
At orchard level, different action levers must be evaluated with a reduction on climate change indicator from 0.3 to 20.4%: impact of disease-resistant varieties, fertilization management, electric platform (Table 1). For the individual portion-sized applesauce, the GHG emissions were 900 g CO_2 eq./ kg of apple sauce. The packaging was the main emission with 44% of the climate change impact.
Around 87 tons of CO_2 eq./ ha were stored in woody part and grass-covered for 20 years. This carbon storage compensated for 86% to 169% of GHG emissions (Canaveria et al. 2018, Chenu et al., 2014). However, at the end of its life, the orchard is uprooted, and most often the trees are burned in the field. The management of orchard biomass at the end of the cycle is important for the carbon balance.

4. CONCLUSIONS

This project has identified priority subjects for apple professionals. It has also allowed a better understanding of the environmental impacts through a multicriteria analysis. The next steps will be to develop a methodology for a "Low Carbon Label," support the implementation of improvement actions, and identify topics for experimentation.

5. ACKNOWLEDGEMENTS

This study was co-funded by the French Agency for Environmental and Energy Control (Ademe).

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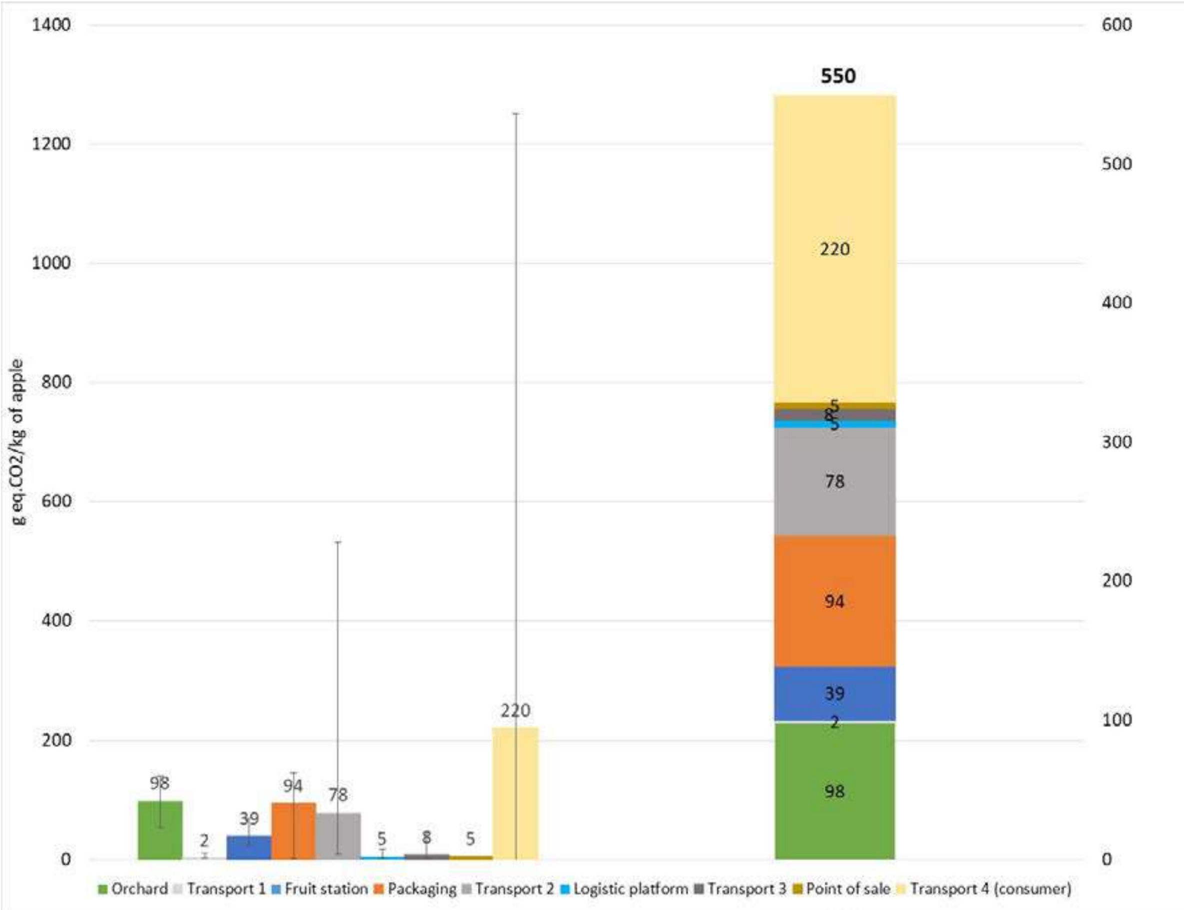

Figure 1. GHG emissions of fresh apples sold for each stage from orchard to the consumer

	GHG Reduction/reference orchard [%]
Energy-efficient driving techniques (tractor or platform)	- 2 %
Stop and start on platform	- 8,2 %
Electric platform	- 20,4 %
Fertilization management	- 4 %
Variable speed drive for irrigation pumps	- 0,3 %
Using organic nitrogen instead of mineral nitrogen	- 1,5 %
Reducing organic amendments at planting	- 3,3 %
Disease-resistant varieties	- 3,3 %

Table 1. Action levers

Ex-ante LCA of Rooftop Greenhouse Vegetable Production in Barcelona

Diego Maximiliano Macall[1]

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1. INTRODUCTION

Most Life-cycle assessment **(**LCA) studies are conducted *ex-post* to systematically evaluate the environmental impacts of a product, process, or service that is already in the market. However, evaluated at this stage, these assessments cannot help researchers, policy makers, or entrepreneurs determine the environmental sustainability of technologies or systems that do not already exist in the market (Cucurachi et al., 2018; DOE, 2012). The twenty-first century, due in large part to climate change, will be characterized by transitions from the *status quo* to new states in all aspects of human existence on Earth. New technologies and systems that are more environmentally-sound than current ones, will be needed in this transition period. Therefore, *anticipatory* or *ex-ante*, LCAs of technologies or systems could help guide their environmentally-sound scale-up (Tischner et al., 2000; Villares et al., 2017; Wender et al., 2014).

In 25 years, 68 per cent of humans will be living in an urban area (United Nations, 2018). Given that food is a fundamental necessity and most human activities are increasingly concentrated in urban centres, it becomes important to research the embedding of food production systems within these cities. Specifically, the *ex-ante* environmental impact of scaling food production within a city.

This study evaluates the environmental and energy impact of tomatoes grown in rooftop greenhouses (RTGs) within Barcelona throughout their life cycle, i.e. from its origins as a raw material until its end as waste.

2. METHODS

This *ex-ante* energy and environmental analysis was conducted in accordance with the global standards specified in the 14040 series (ISO, 2006).To analyze this agricultural production system, the limit of the study is the area of public building rooftop area in Barcelona i.e., 65 ha (BCNecologia, 2010). The study compares the output from a RTG situated within the city of Barcelona with that of a traditional multi-tunnel greenhouse system, focusing on a cradle-to-farm gate analysis framework. This comprehensive approach includes considerations of the greenhouse structure, input resources, and waste management strategies. For a conventional comparison, the research employs tomato farming in Almeria's multi-tunnel ground-level greenhouses, highlighting its substantial impact on the local vegetable market.

This analysis contrasts the traditional approach with a RTG setup located in Barcelona. The differing locations of the RTG and the multi-tunnel system in Almeria lead to variations in their respective growing seasons, influenced by the distinct climatic conditions of each area. In Almeria, tomato growth is typically a nine-month cycle, avoiding the overly hot summer. In contrast, the RTG in Barcelona can potentially extend the growing period to 11 months by incorporating two cycles: winter-summer and autumn-winter. This is made feasible by harnessing residual building heat to warm the greenhouse during the colder months.

For assessment purposes, the study uses the production of 1 kilogram of tomatoes over an annual cycle at the farm gate as the functional unit for evaluation.

3. RESULTS AND DISCUSSION

Rather than predicting what will happen, ex-ante LCA explores various potential future scenarios. It evaluates a spectrum of possible outcomes to understand the operational context of the technology in question. In this case, the use of RTGs to produce part of demanded tomatoes in the city of Barcelona. For one kilogram of tomatoes produced in a RTG, the environmental footprint is $1.42x10^3$ as measured by the normalized ReCiPe index (Huijbregts et al., 2017). This includes a global warming potential (GWP) of 226 grams of CO_2 equivalent and a cumulative energy demand (CED) of 6.32 MJ. A considerable fraction of the environmental footprint, as measured by the ReCiPe indicators, which varies between 27% and 68.6%, is linked to the greenhouse infrastructure. Nonetheless, this pattern is not consistent across all categories. For instance, the majority of marine ecotoxicity is driven by nitrate leaching from fertilizers, accounting for 90% of the impact. The transformation of natural landscapes is chiefly due to the production of growing mediums, contributing to 55% of the total effect.

4. CONCLUSIONS

This study on RTG systems in Barcelona shows how ex-ante LCA can effectively guide the development of sustainable urban agriculture, identifying key areas where environmental impacts can be minimized. The findings reveal that RTGs have a lower environmental footprint in key categories such as the GWP, and Norm-ReCiPe indicator compared to traditional multi-tunnel systems.

5. ACKNOWLEDGEMENTS

The project that gave rise to these results received the support of a fellowship from “la Caixa” Foundation (ID 100010434). The fellowship code is LCF/BQ/DI21/11860055.

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Category	Norm-ReCiPe [Pt]	GWP [kg CO2 eq.]	CED [MJ]
Rooftop Greenhouse (RTG)	3.34E-03	8 E-01	6.32E+00
Agriculture production	1.42E-03	2.26E-01	3.74E+00
Distribution	2.97E-07	4.77E-05	4.86E-04
Multi-tunnel (M)	4.29E-03	1.49E+01	3.27E+01
Agriculture production	1.36E-03	2.45E-01	2.37E+00
Distribution	7.56E-04	1.71E-01	3.27E+00

Table 1. Assessment of ecological metrics for RTG tomato production, juxtaposed with the standard multi-tunnel production system, across each

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Controlled Environment Horticultural Production in Barcelona

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1. INTRODUCTION

Modern commercial agriculture depends on knowledge, information, machinery, and service technologies to be productive (Schultz, 1960; Tweeten and Zulauf, 1998), and its sustainability and future productivity will be driven in large part by its technological transformation and big data use (Goedde et al., 2020). However, agriculture faces an array of challenges both in the medium and long-term. Ortiz-Bobea et al. (2021) show that an approximate 1˚C increase in global temperature since 1970 has decreased agriculture's total factor productivity by 21% globally.[1] An increasingly adverse climate is compounding a series of abiotic constraints that agriculture is contending with and which Stamp and Visser (2012) highlight, *viz*. dwindling amount of arable land, increasing water and phosphorus scarcity, and an increasing number of protein-based diets worldwide, *inter alia*. In its current state, the world food system is responsible for approximately one-third of global greenhouse gas (GHG) emissions, with agriculture being a main driver of this trend (Crippa et al., 2021). Moreover, increasing urbanization of higher income-societies, which creates increasing demand for different foodstuffs, is transforming agriculture by increasing its land, water, and energy requirements (Haddad et al., 2016; Reardon et al., 2016).

In 25 years 68 per cent of humans will be living in an urban area (United Nations, 2018). That is, throughout the remainder of the 21st century most human activity will take place in cities or urban centers. Therefore, basic human needs must be cornerstone of all policy decisions and governance arrangements of current and future city management and development (Caprotti, 2018). A basic human need that is threatened by the impending effects of climate change and an increasing city population is the access to nutritious food. A potential activity that could help address both pressures on the current food system is the movement of its productive component into the city. That is, undertaking urban horticulture (UH) at the city-level.

This study empirically measures the total production of tomatoes, bell peppers, and cucumbers that can occur in rooftop greenhouses (RTGs) within Barcelona. Assessing the viability and expected performance of this high-tech UH system *ex ante* generates valuable insights into its potential productivity, which is crucial to address the obstacle of insufficient information when considering to scale-up this agricultural production modality (Qiu et al., 2024; Raneng et al., 2023).

[1] Productivity here is understood as produced output from total economic resources used in its production.

2. METHODS

To project the total amount of tomatoes, bell peppers, and cucumbers that can occur in RTGs in the city of Barcelona, first the available rooftop area of 650,000 m^2 from public buildings was determined from public records (BCNecologia, 2010). Then, a linear knap-sack optimization model is developed and solved for based on the consumer price and yield for each of the selected crops to determine how to distribute available rooftop area (Equation 1). Once this distribution is determined, crop yields inside a RTG is projected based on the results obtained by Rufí-Salís et al. (2020).

$$\text{Maximize} \sum_{i=1}^{n} f_i(\text{x}, \text{y}, \text{z})$$

$$\text{s.t.} \sum_{i=1}^{n} g_i(x_i) \leq b \qquad \text{Equation 1}$$

3. RESULTS AND DISCUSSION

The resolution of the linear programming model shows that crops should be allocated in RTGs as follows: 312,500 m^2 to tomatoes, 205,882 m^2 to cucumbers, and 131,617 m^2 to bell peppers in order to maximize the total revenue. Given this area allocation, RTGs can produce about 10% of the yearly consumed quantity of each of these vegetables, or about what Barcelona's citizens consume in one month. That is, 0n 650,000 m^2 of rooftop, the city of Barcelona could supply one moth of its demand for tomatoes, bell peppers, and cucumbers.

4. CONCLUSIONS

Beyond the clear consumer benefits of moving part of the productive component into a city, there are environmental externalities that indirectly benefit the Spanish environment. Less nitrogen will flow into water systems, pesticides will not be needed to produce these three crops, and water use can be optimized in controlled environment agriculture within the city. As climate change intensifies and demographic trends play out, UH appears to be a clear way with which to address these two emerging challenges.

5. ACKNOWLEDGEMENTS

Diego Macall would like to thank the project that gave rise to these results received the support of a fellowship from "la Caixa" Foundation (ID 100010434). The fellowship code is LCF/BQ/DI21/11860055.

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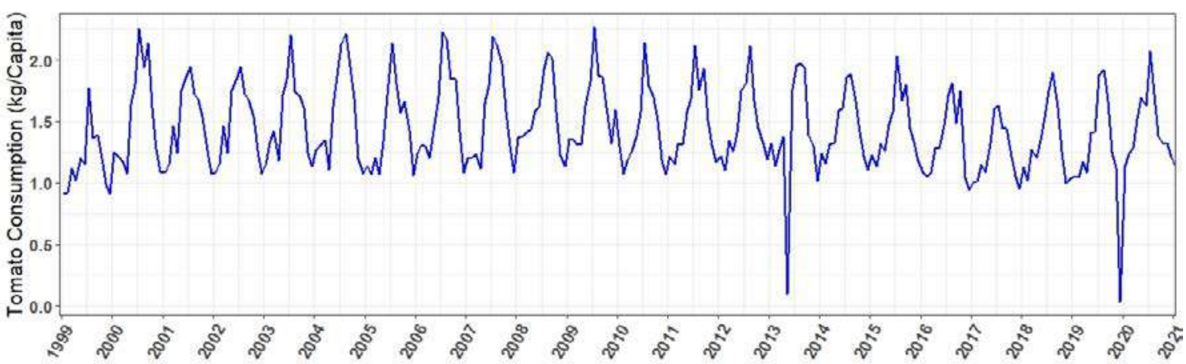

Figure 1 Catalonian Monthly per Capita Tomato Consumption 1999-2021

Source: Author based on MAPA (2023)

Notes: The per capita tomato consumption of Catolonia is used in lieu of disaggregated information at the city of Barcelona level. Between 1991 and 2021, the average person in Barcelona consumed

Life cycle assessment of a building-integrated rooftop aquaponics farm

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1. INTRODUCTION

Aquaponic systems are often described as providing food production with lower environmental impacts. However, there are few studies providing empirical evidence of commercial aquaponic systems, with many studies examining pilot and lab scale systems. This study aims to assess the environmental performance of a building-integrated aquaponics system and the implications of the synergistic possibilities of building integration.

The case examined is a building-integrated, decoupled aquaponics farm at a supermarket in Germany producing tilapia and basil. The basil (630 000 pots/year) is produced in a greenhouse covering the entire area of the supermarket, while the aquaculture room is located inside the supermarket building. The aquaculture room contains a typical Recirculating Aquaculture System (RAS) with 13 tanks, with an annual production of 4 000 kgs of whole, gutted fish. From the RAS system, water is pumped to water tanks on the floor below the greenhouse, and warm, CO_2-rich air is ventilated into the greenhouse. The greenhouse production utilizes vertically stacked shelves for germination, followed by growth of the plants until it reaches marketable size on ebb-and-flow tables which are filled from the water tanks on the floor below, to which the water then drains back again. The greenhouse and aquaculture room utilize residual heat generated by the supermarket's cooling units. Artificial lighting is used in the greenhouse during the dark months of the year. Electricity is sourced from a company producing renewables with a guarantee of origin.

2. METHODS

The environmental performance was assessed employing LCA, with the modelling conducted in OpenLCA and Excel. Datasets used were primarily from Ecoinvent v. 3.9 with additions from Agribalyse with the use of the Environmental Footprint v3.1 LCIA method. The data was collected for the calendar year 2022. The functional unit was 1 kg of produce, 85% basil and 15% tilapia. Impacts were allocated based on mass and displayed per kg of product, i.e., basil and tilapia respectively, and per pot of basil and per gutted tilapia. An additional allocation with basil as the only output and using system expansion to represent replaced tilapia was also conducted. Electricity use was modelled using several sources, including an average German mix, renewable mix according to electricity supplier, and European mix. Several modelling alternatives were also presented for the heat used. As the greenhouse is exposed to varying conditions over the year, it uses electricity and heat differently over the seasons.

As such we also modelled the impact per month.

3. RESULTS AND DISCUSSION

The results suggest that the basil produced has comparable or lower GHG emissions than conventionally imported varieties. Electricity was the largest contributor to total GHG impacts, with artificial lighting contributing largely. The results were also found to be sensitive to the electricity sourcing, where substituting the German mix for a renewable mix reduced GHG impacts considerably. Consumable inputs were the second most influential contributor to the GHG impacts, and the most influential contributor to several other impact categories such as water use, land use and ecotoxicity. Major contributors to the consumable inputs category were the peat part of the hydroponic substrate and the fish feed. Packaging for outgoing products also presented significant impacts, with the lion's share coming from cardboard boxes. Heat use was strongly influenced by source of heat and allocation of impacts between the supermarket and the aquaponic farm. Indeed, it was shown that the synergies with the supermarket had large benefits for the system. Finally, the monthly impacts due to seasonality have not yet been performed as of the writing of this abstract. Comparisons with other systems will be added.

4. CONCLUSIONS

Energy-intensive systems of growing plants with artificial lighting are overall strongly influenced by the impact of the grid mix. Use of residual heat and shared allocation of heat impacts is an efficient way to reduce the impacts of heating a greenhouse in a cold climate.

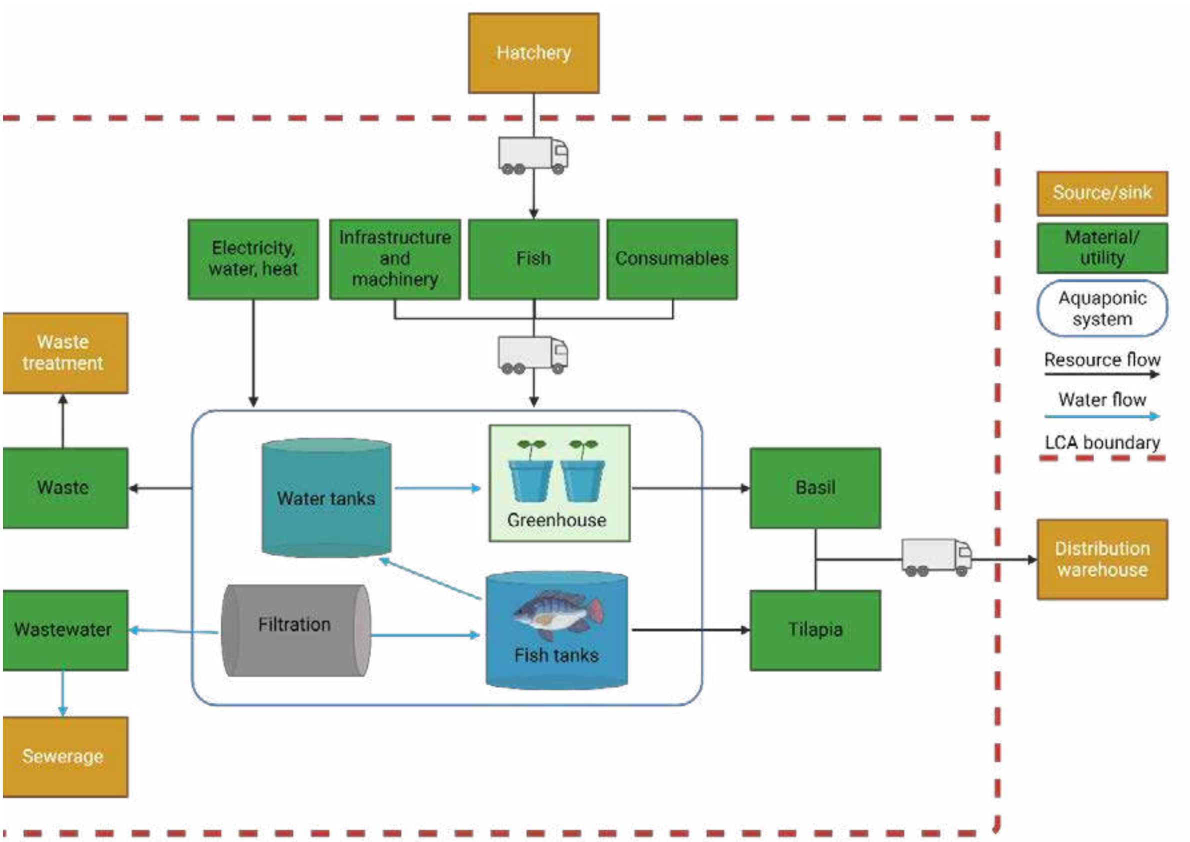
5. ACKNOWLEDGEMENTS

Thanks to ECF Farmsystems, especially Jasper Arendt and Jannis Grothaus for their collaboration in data gathering and for hosting us for a study visit. This study was funded by Formas.

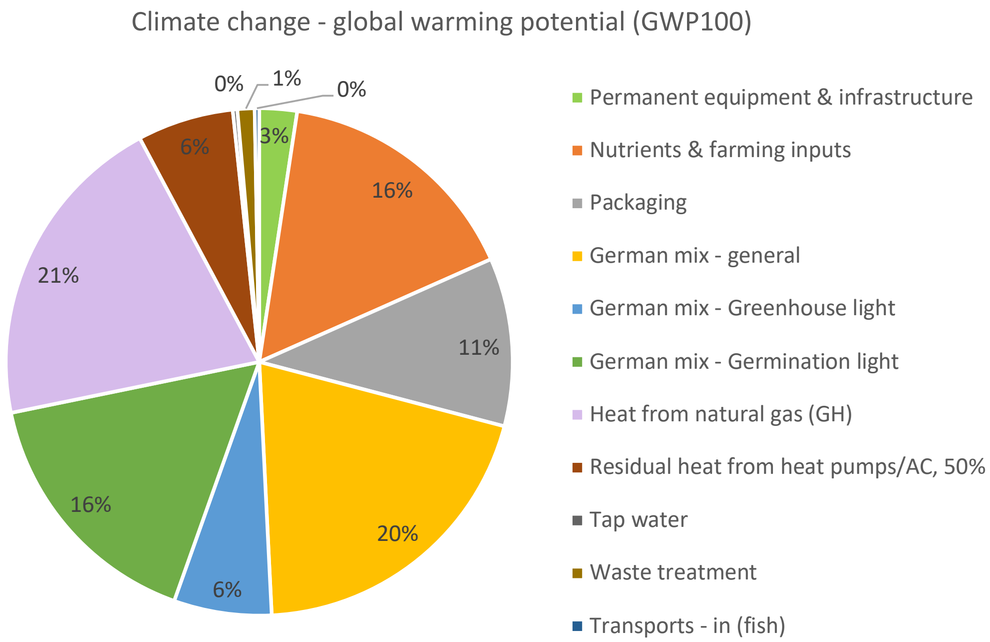
6. REFERENCES – WILL BE ADDED

. FIGURES

System boundary graph (Created with BioRender.com)



ninary results, percentage share of contribution to GHG impacts (GWP100)



Life cycle assessment of mycorrhizae production

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1. INTRODUCTION

The production of mycorrhizae is gaining importance in modern agriculture (Rouphael et al., 2015) due to the search for more environmentally friendly practices. Mycorrhizae are fungi with a symbiosis with plant roots and are used as biostimulants. They have been shown to boost the development and productivity of various plant species (Berruti et al., 2016). These symbiotic associations play a fundamental role in the functioning of terrestrial ecosystems by improving nutrient uptake (Clark & Zeto, 2000; Zakaria M. Solaiman et al., 2014), increasing disease resistance, and improving soil quality. Consequently, its application reduces the dependence on chemical fertilizers and enhances efficiency in using natural resources (Jansa et al., 2003; Noceto et al., 2021). Research on life cycle assessment in the production of mycorrhizae for use as biostimulants needs to be better developed. The main goal of this study is to assess the environmental impacts of mycorrhizal production *in vivo* for four scenarios.

2. METHODS

The functional unit considered was the production of 10,000 spores. Four scenarios were assessed, the main differences being the mycorrhiza strain, the host plant, the type of substrate, and the fertilization plan. The system boundaries comprise all the processes and inputs needed to produce the inoculum, namely seed disinfection, substrate production and sterilization, fertilizers' production, and the energy to irrigate and light the plants. For the development of the inventory (Table 1), data were collected from scientific literature. Ecoinvent v3.9 and Sphera database were used for the background processes, and ten impact categories were evaluated with Environmental Footprint 3.1.

3. RESULTS AND DISCUSSION

The impact scores of the four scenarios show slight differences for most of the impact categories (Table 2), with the exceptions commented below. Acidification scores range from 0,007 to 0,015 mole of H+ eq· FU-1, the difference due mainly to higher water use and fertilization in scenario 2. The excessive use of fertilizer causes an increase in scenario 2 in climate change, the values are between 0.4 to 4.32 kg CO2 eq·FU-1; whereas for land use, the results vary between 2 and 26 pt · FU-1 due to the different substrate and fertilization. The scores of fossil resources range from 5.8 to 60.4 MJ· FU-1, although it is mainly due to the electricity production, differences are due to the resources used for fertilizers manufacturing. Water use is to 1.3 and 21 m3 world eq · FU-1 due to different irrigation doses.

4. CONCLUSIONS

From the results, it can be concluded that even following similar processes, changes in the substrate used and t he fertilization plan are crucial to decrease the impacts of mycorrhizae.

5. ACKNOWLEDGEMENTS

We thank the Ministry of Universities for the support of the "Margarita Salas" program for the training of young doctors. The study forms was supported Partnership for Research and Innovation in the Mediterranean Area (PRIMA) funding for the New AGRoecological approach for soil fertility and biodiversity restoration to improve ECOnomic and social resilience of MEDiterranean farming systems.

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Table 1. LCA inventory for each scenario

		Scenario I	Scenario II	Scenario III	Scenario IV
Authors	Units	(S.C. Miyasaka et al., 2003)	(Habte et al., 2001)	(Kadian et al., 2018)	(Cuenca et al., 2007)
Seeds		02-06	corn	10 sorghum	bean
Total time weeks	weeks	14	14	13	16
Days	Days	98	98	90	112
Disinfection	hypochlorite	5%	5%	5%	5%
Substrate /pot		(1:3) v/v*	(1:1) w*	(1:3) w*	(1:1)v/v*
Soil	kg		1	1	
Peat moss		1			
Silica sand	kg		1	1	1
Clay					1
Vermiculite		3			
Inoculum	Spores	3704	1040	130	1110
Specie		Glomus aggregatum	AMF	Glomus mossae	
Energy consumption Sterilization	kWh	5,69	5	0,83	1,78
Energy LED lamp	kWh	3,57	3,13	0,488	1,28
Irrigation Water (L)	L	44,84	49,15	7,65	3,56
Fertilization	L	0,08	1,86	0,036	0,028
Emission					
NH3	Kg N	0,00000014	0,0000113	0,0000013	0,0000005
NO2	Kg N	0,00000008	0,0000067	0,0000008	0,0000003
N2O	Kg N	0,000003	0,000221	0,000025	0,0000095

Table 2. LCA results for each scenario

	Scenario I	Scenario II	Scenario III	Scenario IV
EF 3.1 Acidification [Mole of H+ eq.]	0,007	0,016	0,001	0,002
EF 3.1 Climate Change - total [kg CO2 eq.]	2,84	4,32	0,43	0,95
EF 3.1 Ecotoxicity, freshwater - total [CTUe]	13,00	131,00	3,51	4,42
EF 3.1 Eutrophication, freshwater [kg P eq.]	0,000033	0,000451	0,000011	0,000015
EF 3.1 Human toxicity, cancer - total [CTUh]	0,0000000013	0,0000000023	0,0000000002	0,0000000004
EF 3.1 Ionising radiation, human health [kBq U235 eq.]	0,83	0,88	0,12	0,27
EF 3.1 Land Use [Pt]	13,40	26,30	2,23	4,74
EF 3.1 Ozone depletion [kg CFC-11 eq.]	0,000000019	0,000000246	0,000000006	0,000000007
EF 3.1 Resource use, fossils [MJ]	38,50	60,40	5,87	12,80
EF 3.1 Water use [m³ world equiv.]	21,60	6,12	1,08	1,36

Transitioning from Conventional to Zero Chemical Nitrogen Grass Production: Promoting Healthier Food Systems in the Republic of Ireland

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1. INTRODUCTION

The use of chemical nitrogen (N) fertilisers in grassland has been instrumental in meeting farm feed demand and enhancing livestock productivity. However, this reliance on synthetic fertilizers may lead to a multitude of environmental challenges, ranging from water pollution due nutrient leaching, leading to eutrophication and water pollution. Moreover, the volatilization of nitrogen compounds from fertilizers contribute to climate change by serving as greenhouse gases. In response to these challenges, there has been burgeoning interest in alternative approaches to grassland management that eliminate the need for chemical N fertilizers. Zero Chemical Nitrogen (Zero-Chem N) grass production systems represent one such alternative, emphasizing sustainable practices such as organic fertilization and biological nitrogen fixation to maintain soil fertility and productivity while minimizing environmental impacts. This study evaluates the environmental implications of transitioning from conventional to Zero-Chem N grass production systems on Irish farms.

2. METHODS

A comparative life cycle assessment is applied to quantify and compare the impacts associated with these two management approaches, drawing on data from experimental fields, peer-reviewed literature and technical reports. Emission factors provided by IPCC (2019) serve as the primary basis for quantifying ammonia and greenhouse gas emissions. P emissions were assumed to be 0.01 of the P applied (Styles et al., 2016). Land based and dry matter based functional units are applied. A Sensitivity analysis is conducted to evaluate the effects of the rate of N application and grassland productivity. The inventory for the two systems is presented in (Table 1).

3. RESULTS AND DISCUSSION

For the Zero-Chem N baseline scenario, we assumed that 10% of the nitrogen (N) will be recovered from fixation, with the remaining complemented as slurry. The results, presented per tonne of dry matter, show that for global warming potential (GWP100a), conventional and Zero-Chem N systems had values of 273.21 kg CO_2 eq and 202.63 kg CO_2 eq, respectively. This reduction in N fertilizer use also contributed to a lower impact on abiotic depletion (fossil fuels), with values of 1027.73 MJ and 677.23 MJ for conventional and Zero-Chem N systems, respectively. A similar trend was observed for the eutrophication impact category, with conventional grassland production presenting 5.56 kg PO_4 eq, while Zero-Chem N production presented values of 5.44 kg PO_4 eq. However, the increased use of slurry in Zero-Chem N production resulted in higher emissions of acidifying compounds, leading to an acidification potential (AP) of 10.56 kg SO_2 eq, slightly higher than the conventional production's 9.56 kg SO_2 eq. The adoption of the Zero-Chem N baseline scenario demonstrated environmental benefits compared to conventional grassland production. The significant reduction in global warming potential (GWP100a) and abiotic depletion underscores the effectiveness of minimizing nitrogen fertilizer usage. Similarly, the decrease in eutrophication potential. However, the increased use of slurry in Zero-Chem N led to higher emissions of acidifying compounds, indicating the importance of considering trade-offs in environmental impacts when implementing alternative agricultural practices.

4. CONCLUSIONS

The adoption of Zero-Chem N grassland production presents a promising pathway to mitigate environmental impacts in Ireland, while also facilitating the production of organic grass for potential processing in biorefineries to yield high-value proteins, thereby offering farmers opportunities to diversify their sources of income. The work is ongoing and other scenarios will be included in the final version.

5. ACKNOWLEDGEMENTS

This work is supported by the project Life Farm4More.

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Processes	Unit	Zero Chemical N	Conventional
Occupation, grassland/pasture	m2a	10000	10000
Materials/fuels			
Manure (cow), at farm {RER} Economic, U	kg	11527.08	9209
Urea,N	kg	0	6.69
Calcium ammonium nitrate, N	kg	0	13.41
P2O5	kg	6.92	5.53
K2O	kg	13.23	13.23
Lime	kg	400	400
Grass clover seed	kg	3.2	3.2
Clover seed	kg	0.2	0.0
Transport	tkm	309.78	309.78
Herbicide	kg	0.1	0.1
Fungicide	kg	0.1	0.1
Electricity/heat			
Diesel burned in machinery	MJ	2901	2901
Emissions to air			
Carbon dioxide, fossil lime	kg	176.00	176.00
Carbon dioxide , fossil urea	kg	0.00	21.11
Dinitrogen monoxide, direct fertilizer	kg	0.00	1.73
Dinitrogen monoxide, indirect fertilizer	kg	0.00	0.57
Ammonia, fertilizer IE	kg	0.00	3.21
Nitrogen monoxide, fertilizer IE	kg	0.00	3.41
Nitrogen monoxide, IE	kg	10.85	8.67
Dinitrogen monoxide, direct manure	kg	2.08	1.66
Dinitrogen monoxide, indirect manure	kg	1.94	1.55
Ammonia, manure IE	kg	52.67	42.08
Dinitrogen monoxide, crop residue	kg	0.34	0.34
Dinitrogen monoxide, crop residue	kg	0.08	0.08
Emissions to water			
Nitrate Fertilizer, IE	kg	0.00	73.03
Phosphorus Fertilizer, IE	kg	0.00	0.01
Nitrate, manure IE	kg	233.92	186.88
Phosphorus, manure IE	kg	0.07	0.06
Nitrate, crop residue IE	kg	28.73	28.73

Table 1. Life cycle inventory for the production of 1 ha grassland

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What is the climate and environmental impact of organic food? A meta-analysis of food LCA studies

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1. INTRODUCTION

In recent years, there has been a growing interest in investigating the climate and environmental impacts of organic food in comparison with conventional food. To assess and compare the environmental impact of organic with conventional food, as well as to evaluate the impact of methodological choices of Life Cycle Assessment (LCA) for food products, we conducted a meta-analysis that systematically examined a large number of LCA studies on either organic food or a comparison of conventional and organic food considering both mass and area functional units.

2. METHODS

A systematic review of the scientific literature on organic food LCA identified 2177 publications, after screening out irrelevant studies, a meta-analysis was performed on 100 published studies on both animal and plant products. This was done by investigating eight impact categories of global warming, acidification, eutrophication and eco-toxicity potential plus potential biodiversity loss, and energy, water, and land use for both mass- and area-based functional units from cradle-to-farm gate.

3. RESULTS AND DISCUSSION

The review shows that most studies were from North America and Europe and focused mainly on global warming potential with few studies considering soil carbon sequestration. There was also little focus on potential biodiversity loss and eco-toxicity potential. The meta-analysis showed no significant differences in global warming, acidification and eutrophication potential and energy use per kilogram of organic and conventional food, but higher land use. Furthermore the analysis showed a significantly lower global warming potential, eutrophication potential and energy use per hectare of organic food compared to conventional food. All studies that compared biodiversity found organic farming to have higher potential biodiversity per kilogram and hectare, and most of the studies that compared eco-toxicity potential in organic and conventional food found lower impacts from organic farming.

4. CONCLUSIONS

There are still methodological challenges in LCA of food products regarding i) improving the methods for assessing biodiversity, toxicity, and land degradation; and ii) improving models for better estimation of changes in soil carbon and nitrogen stocks resulting from different land management options. Furthermore, the choice of the functional unit can affect the policy decisions. What may seem as an effective option to reduce a given impact at the global scale (assessed per kg) may not be an efficient option at the local scale (assessed per ha) or when looking at the effect on other impact categories. Therefore, including several functional units (per kg and per ha) and impact categories for LCA of organic food are important. Including results both at the product and dietary levels may further provide insights towards more holistic assessments that can form the basis for comprehensive decisions.

5. ACKNOWLEDGEMENTS

This study was part of the Climate friendly and SUSTAINable ORGANIC food and diets (SustainOrganic) project as part of the Organic RDD 4 program, which is coordinated by International Centre for Research in Organic Food Systems (ICROFS). It has received grants from the Green Growth and Development Program (GUDP) under the Danish Ministry of Environment and Food.

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Life cycle assessment of peat substitutes: sustainability of Danish growing media

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1. INTRODUCTION

Peat moss (sphagnum) extraction is associated with greenhouse gas emissions and leads to the destruction of sensitive ecosystems. For this reason, efforts are being made in Danish horticultural and vegetable growing industries to reduce peat consumption. One such efforts is development of available alternative growing media that meet the requirements of plant cultivation and at the same time lead to an improved environmental impacts. An understanding of this can be obtained by analyzing the environmental sustainability of various peat substitutes via life cycle assessment (LCA).

2. METHODS

The potential greenhouse gas emissions of peat, bio-based peat alternatives (extruded wood fiber, degassed manure fibers, willow-based compost, willow-based hydrochar) and their mixtures (75% peat with 25% peat alternative) were investigated using an LCA approach. To perform this, foreground data (collected from both industry and literature) was used together with background data from Ecoinvent V3.8. The chosen functional unit was 1 m^3 of growing media and the system boundary was from cradle to the use in greenhouses (including the processes: raw material extraction, substrate production, transport, and use).

3. RESULTS AND DISCUSSION

The global warming potential (GWP) of all the peat alternatives showed significant reduction per m^3, varying between 89 and 109% compared to sphagnum. When incorporating 25% of each alternative with peat, the carbon footprint of the mixture was reduced by 16 to 33% compared to pure peat. Thus, there are very large climate prospects of replacing peat with bio-based alternatives, and this underlines the relevance of being able to increase the proportion of the bio-based components in their mixtures with peat beyond the 25% and towards 100% replacement. GWP of peat substitutes is low because they are produced locally and processed with low consumption of materials and energy and without extraction associated with greenhouse gas emissions like in the case of peat use.

4. CONCLUSIONS

Wood fiber is superior to the other alternative growing media components in terms of low GWP, but its availability depends on the demand and price of biomass in other sectors such as the energy industry that may limit its use in growing media industry. Willow-based compost also competes with use for energy but is expected to be readily available for horticulture in the future and can be manufactured without significant negative environmental impacts. Similar to compost, availability of the willow-based hydrochar can be affected by energy use, however it can be produced locally with readily available materials and its similarity to peat in terms of consistency and properties makes it an attractive peat alternative. Growing media components such as degassed manure fibers made from renewable, secondary residues or waste products with little competition for other uses can also be potential alternatives to peat.

5. ACKNOWLEDGEMENTS

This study was part of Biosubstrate project funded by the Danish Green Development and Demonstration Program (GUDP) (Grant number34009-18-1435).

Life Cycle Assessment on Semi-closed Lettuce Greenhouses

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1. INTRODUCTION

In the rapidly changing world of today, where sustainability is no longer an option, but a necessity, the need for sustainable food is growing. While there is debate about different growing systems and their sustainability, cultivating crops in controlled environments has gained significant attention. High-tech greenhouses provide a controlled environment for growing crops, resulting in more yield and also more control over water, fertilizer and pesticide use. However, to build and operate high-tech greenhouses, more materials, energy and CO_2 are required. The Life Cycle Analysis (LCA) of greenhouses has been studied previously by many researchers, however, the majority of studies lack detailed greenhouse construction data. Also, the difference between the environmental impact of a semi-closed greenhouse and a traditional Venlo greenhouse is overlooked. This study aims to address the gaps by conducting an LCA on an automated semi-closed greenhouse operating in a dry-cold climate. The results of this study are also used to identify the environmental hotspots, both in terms of constructing the greenhouse and operating it and finding solutions to improve.

2. METHODS

In this study, the LCA boundary is a cradle-to-grave. The greenhouse is treated as a lettuce production system. So, the functional unit is one kg of lettuce. There is no PEFCR available for vegetables in the horticulture sector, however, there is a shadow PEFCR, called the Hortifootprint Category Rules (HFCR), on which this study is based. The life cycle stages are divided into greenhouse construction and greenhouse structure, as depicted in Figure 1. The greenhouse construction stage consists of all the materials needed to build a greenhouse and the operational stage is defined based on the HFCR (Helmes, 2020). The end of life of the greenhouse for both construction and operational stages are included. Using and disposing of lettuce is not included in the study, as it is not related to the production process. Based on HFCR, the lifetime of the greenhouse is assumed to be 15 years (Helmes, 2020). The LCA is modelled using SimaPro software, version 9.5.0.2.

The foreground data for the construction phase were collected from the bill of materials. The foreground data for the operational phase were collected from the greenhouse owner/operator and for the data gaps, the FVO guideline (FVO, 2023) and greenhouse modelling tools were used. For the background data, the Ecoinvent version 3.9.1 cut-off was used. For the impact assessment method, the adapted EF v3.0 was used, since SimaPro is not fully compatible with the EF method (FVO, 2023), and all 16 impact categories were applied (Helmes, 2020). To find the most relevant impact categories, normalization and weighting factors from the EF LCIA method were used. The study also includes a data quality assessment.

3. RESULTS AND DISCUSSION

The results of the study are first analysed per construction and operation phase and then the overall environmental impact. In the construction stage, the materials used in the substructure and the greenhouse cover, including the sandwich panels, steel and aluminium bars, and glass contribute to the biggest impact within most impact categories. In the operational phase, the impact of energy is the greatest. The overall results show that energy consumption outweighs other processes and has the biggest impact, however, this outcome is location-dependent, as the modelled greenhouse requires heating and artificial lights. In the case of growing crops in traditional Venlo greenhouses, the overall environmental impact is expected to be bigger, as more resources are used to produce 1 kg of lettuce. It is worth noting that the final results await the reviewing process and will be later published in detail.

4. CONCLUSIONS

To reduce the environmental impact of the greenhouse, transitioning to renewable energy is the most important step. For the construction phase, using materials with sustainable resources and environmental product declaration is an essential first step. In conclusion, in the studied climate, semi-closed greenhouses are relatively sustainable food production systems and efficient use of renewable energy could significantly improve their impact. For a thorough understating, a similar analysis will be conducted on greenhouses in other climate regions in the future.

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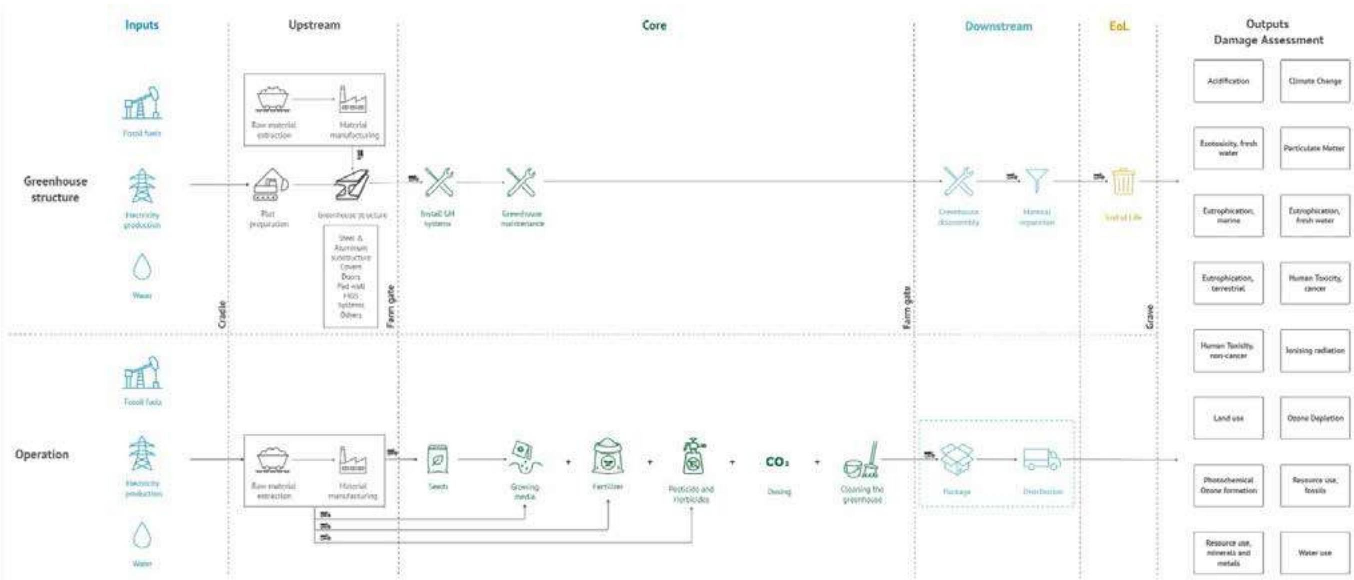
Figure 1. Life cycle stages included in the study



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Life Cycle Assessment (LCA) of seed-to-fruit tomato to promote renewable energy sources and sustainable agricultural production

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1. INTRODUCTION

Climate crisis and the simultaneous excessive growth of the population, intensifies the need for sustainable food production and satisfactory yields. An effective tool to evaluate the sustainability of cultivation practices is the LCA method [1]. Tomato cultivation is particularly widespread in Europe, while its intensive cultivation may lead to significant environmental impacts. For this study, the environmental impacts from all stages of tomato production were studied and evaluated. The main purpose of the study was to identify the hotspots for each of the two production stages, with the aim of finding alternative cultivation practices.

2. METHODS

The examination of the environmental performance of tomato production system in Greece, was carried out using the LCA method. The first stage of tomato seedlings production in a greenhouse and the second stage of their transplanting and cultivation in open-field until the harvest of the final product and its transport to the processing plant, were studied. Primary data and climate data were collected via personal interviews and a smart device. The boundaries of the first system were defined as cradle-to-nursery gate and the second as cradle-to-farm gate. Two functional units were used, 1 tomato seedling for the first production stage and 1 kg of tomatoes for the second stage. The study of the effects of the two systems were examined in the environmental indicators, showcased in Table 1, using the method CML-IA baseline v.3.07/EU25 implemented in SimaPro v.9.4.0.2 software.

3. RESULTS AND DISCUSSION

Regarding the effects of the first stage of cultivation, it emerged that diesel fuel had the highest impact on all indicators (except AD and ODP), that ranged between 28.0-79.0%. Peat used as a substrate had the second largest effect on GWP100 (26.0%) and ODP (23.9%). Greenhouse infrastructure had the biggest impact on AD (55.6%), but its effect in other categories was low (3.0-19.0%). LCIA results are presented in Figures 1 and 2. The aforementioned inputs have been shown as hotspots in other similar studies as well [2], which emphasizes the importance of optimization of their usage. Using photovoltaics instead of fossil fuels constitutes an effective way to meet the energy needs of greenhouses, mixing peat with perlite could be an equally efficient solution [3], while it is important to optimize the greenhouse structure. For the tomato cultivation in open field, it emerged that nitrogen fertilization occupies the first place on almost all indicators with an effect of 17.5-29.0% and phosphates occupying the second place with 9.0-18.1% contribution. The only variation is observed in the OD index, where the use of pesticides has the greatest effect (24.5%) and in FAE, where irrigation is considered the greatest hotspot (19.7%), due to the electricity consumption for the operation of water drill. The rational use of fertilizers and use of renewable energy sources within a system of integrated production management is a necessary condition for reducing the effects of these parameters and be the solution for clean energy production with a reduced footprint.

4. CONCLUSIONS

From the present study it emerged that in the tomato seedlings production stage, diesel, peat and greenhouse infrastructure have significant impact in various environmental impact categories. In the open field tomato cultivation, high impacts were presented due to fertilization, plant protection and irrigation. Further research includes the implementation of alternative practices to mitigate hotspot effects and enhance the performance of tomato production system.

5. ACKNOWLEDGEMENTS

This research was carried out as part of the project «Direct calculation of carbon footprint per unit product in greenhouse crop production to promote renewable energy sources (RES) and sustainable agricultural production» (Project code: KMP6-0279604) under the framework of the Action «Investment Plans of Innovation» of the Operational Program «Central Macedonia 2014 2020» that is co-funded by the European Regional Development Fund and Greece".

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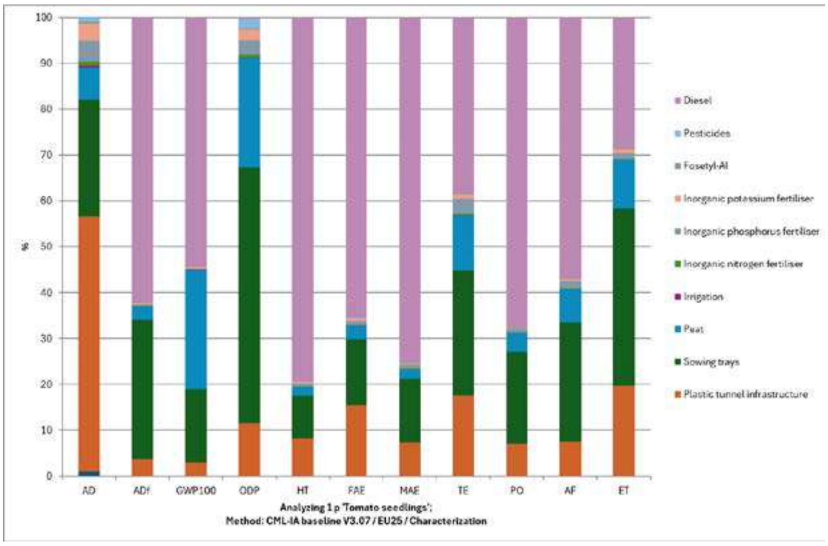
Table 1. Impact assessment results for the two stages of tomato production

Impact category	Unit	Value – Seedlings production	Value – Open field cultivation
Abiotic Depletion (AD)	kg Sb-eq	3.10E-08	1.76E-06
Abiotic Depletion-fossil fuels (ADf)	MJ	2.80E-01	1.38E+00
Global Warming (GWP100)	kg CO2-eq	2.33E-02	9.91E-02
Ozone Layer Depletion (ODP)	kg CFC-11-eq	2.77E-10	1.28E-08
Human Toxicity (HT)	kg 1,4-DB-eq	1.36E-02	1.02E-01
Freshwater Aquatic Ecotoxicity (FAE)	kg 1,4-DB-eq	5.84E-03	6.68E-02
Marine Aquatic Ecotoxicity (MAE)	kg 1,4-DB-eq	1.94E+01	1.35E+02
Terrestrial Ecotoxicity (TE)	kg 1,4-DB-eq	1.69E-05	3.04E-04
Photochemical Oxidation (PO)	kg C2H4-eq	3.90E-06	3.08E-05
Acidification (AF)	kg SO2-eq	5.88E-05	6.66E-04
Eutrophication (ET)	kg PO4-eq	1.11E-05	1.58E-04



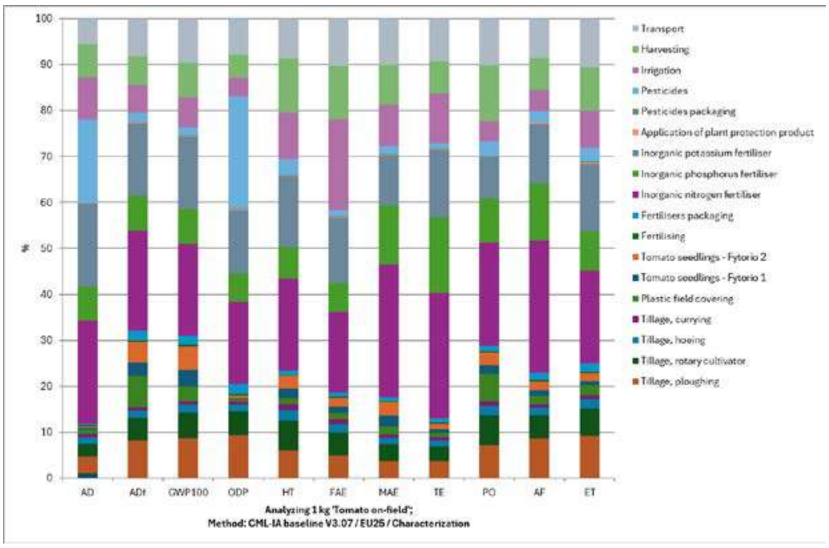


Figure 1. Contribution of each input in impact categories for seedlings production and open-field tomato cultivation

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Life Cycle Assessment of a Container Farm in Toronto, Canada

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1. INTRODUCTION

Indoor farming is considered a promising option to increase food security, by providing protection and reducing vulnerability due to extreme weather patterns, and reducing food supply chain disruptions and geopolitical instability. Canada imports a lot of fruits and vegetables and has faced supply interruptions, specifically with recent extreme weather conditions, prompting more serious consideration of indoor farms for food security and stable supply. A sustainable transition from imports to indoor farms will require an assessment of indoor farming environmental performance for the cold climate conditions of Canada. In this study, we used life cycle assessment (LCA) to evaluate and compare the environmental performance of imported field greens and greens produced in a retrofitted shipping container, assuming final consumption in Toronto, Canada.

2. METHODS

The container farm consists of a turnkey shipping container system with insulation and LED lighting (Figure 1). The study boundaries are cradle-to-retail gate. The functional unit is 1 kg of leafy greens (referred to as 'greens'). The container farm, located in Toronto, Ontario, uses electricity for LED lighting, nutrient solution pumping, and ventilation and cooling. Inventory data were obtained from utility bills. Major inputs are presented in Table 1 and the farm produces 56.70 kg greens/m^2. The reference system is field greens, modeled using global average production of lettuce from ecoinvent3.8 as a proxy. The yield for field greens is 2.7 kg/m^2. It was assumed that the greens were produced in Arizona and transported 2000 km to Toronto in a refrigerated truck to retail. It was also assumed that there would be 30% losses in the distribution chain based on food and waste loss throughout the supply chain (USDA, 2018). openLCA software and TRACI were used to estimate three impact categories: Global Warming Potential (GWP), Fossil Fuel Depletion (FFD), and Eutrophication Potential (EUP).

3. RESULTS AND DISCUSSION

The GWP, FFD and EUP were 3.40 kg CO_2eq, 7.43 MJ surplus, and 5.57*10^{-3} kg Neq per 1 kg container greens (Table 2). Electricity use contributed to ~99% of the impacts. The highest electricity consumption was for the heating/cooling system, with air conditioning required in the summer due to a combination of heat from high average external temperatures (~25-30°C) and heat generated by the LED system. In contrast, a previous study of greenhouse tomato production in Canada showed that heating during the cold winters was the hotspot (Dias et al. 2017), but overall GWP and EUP were similar (3.2 kg CO_2eq and 2.6*10^{-3} per 1 kg tomatoes).
The hotspots for the imported greens were transportation, which contributed to 90%, 94% and 55% of GWP, FFD, and EUP, respectively. The remainder of the impacts were associated with field greens production.
The GWP, FFD, and EUP impacts for container farms are 2.2, 2.7 and 1.4 times higher than those for imported field lettuce (Table 2). The field greens would have to be transported 4000 km by refrigerated truck to have similar impacts to greens grown in a container farm. Nevertheless, on-site (i.e. gate-to-gate) land occupation for container greens is 60% of the field greens (based on yields, 0.018 and 0.029 m^2a for container and field greens respectively), while on-site water use for container greens is 5.5% of that used in field green production (1.4 L/kg and 32 L/kg for container and field greens respectively).

4. CONCLUSIONS

Although Canada's cold climate requires high energy use for heating greenhouses to maintain desirable temperatures for crop growth during colder months, the situation is different with container farms. Container farms are highly insulated systems, with an extensive LED lighting system, which requires constant shedding of excess heat, regardless of the season. The extreme summer heat increases electricity consumption for cooling in container farm operation. When coupled with the current dependence of fossil fuels for electricity across most of Canada, greens produced in a container farm in Canada have higher GWP, FFD and EU impacts than imported field greens transported over long distances in refrigerated trucks. Future work should investigate options to redu ce energy consumption including the optimization of the lighting and energy use, the use of renewable energy so urces and/or waste heat and crops that can grow at higher temperatures.

5. ACKNOWLEDGEMENTS

Not applicable.

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Table 1: Inputs for the production of 1 kg of greens in a container farm located in Toronto, Canada

Inputs	Amount	Units
Electricity, Total	38.3	kWh
Nitrogen fertilizer, N	0.00122	kg
Phosphate fertilizer, P2O5	0.00122	kg
Potassium fertilizer, K2O	0.00122	kg
Water, Total	1.39	L

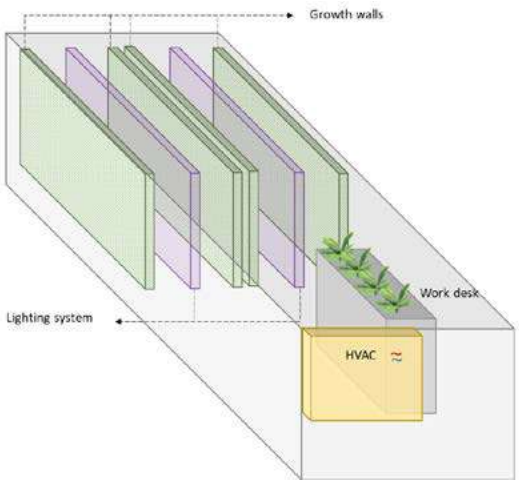

Figure 1: Schematic of container farm.

Table 2: Impact results comparing 1 kg of greens produced in a container farm located in Toronto, Canada and 1 kg of field greens transported 2000 km and with 30% loss in supply chain.

	GWP (kg CO_2eq)	*Fossil Fuel Depletion (MJ surplus)*	*Eutrophication (kg N eq)*
Greens, container, local transport (<10 km), ON grid	3.4	7.4	5.6E-03
Reference: Lettuce, field, refrigerated truck (2000 km)	1.5	2.8	3.9E-03
Ratio of Container impacts/imported field greens impacts	**2.2**	**2.7**	**1.4**

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Growing Green: Environmental Assessment of Struvite Fertilization in Hydroponic Tomato Cultivation

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1. INTRODUCTION

Tomato stands as one of the most popular and extensively cultivated vegetable crops globally. It plays an essential role in the agriculture sector and holds significant cultural and culinary importance for various populations. However, its cultivation is responsible for many ecological concerns, related to water consumption, use of mineral fertilizers and overall resource consumption[1]. The adoption of alternative fertilizers obtained from waste can reduce the environmental impact related to the horticulture system while also promoting circular economy strategies. Struvite ($MgNH_4PO_4$), a recovered salt from wastewater treatment plants, has shown to be a valid alternative for phosphate inputs to various horticultural crops[3]. This research aims to assess the impact of struvite fertilization on both yield and environmental performance of hydroponically grown tomatoes.

2. METHODS

Tomato plants (Solanum lycopersicum L., var. Montgrí) were grown from March to July 2023 in a Mediterranean integrated rooftop greenhouse (iRTG). Two different fertilization methods were employed: a) a control treatment, with all the nutrients provided by mineral fertilization through a fertigation system and b) a sector where plants received a nutrient solution lacking P, Mg^{2+} and NH_4^+ supplied to them through struvite grains, placed in the substrate. The Life Cycle Assessment (LCA) methodology used to evaluate the two fertilization models. Impact assessment was conducted with Simapro 9.4 software, with environmental information from Ecoinvent 3.8 database and the ReCiPe midpoint impact assessment method with a hierarchical approach. The chosen functional unit (FU) for this study was 1 kg of fresh tomato and the impact categories considered were the following: global warming (GW), freshwater eutrophication (FE), marine eutrophication (ME), terrestrial acidification (TA) and fossil resource scarcity (FRS) and mineral resource scarcity (MRS).

3. RESULTS AND DISCUSSION

The yield of the two sectors was almost the same, with 7.02 kg·m^{-2} produced by the mineral fertilization treatment and 7.12 kg·m^{-2} produced by the plants with struvite fertilization. Regarding the environmental impact, the sector with struvite fertilization showed to be less impacting in all categories compared to the mineral one, as show in Table 1. The impact related to FRS was reduced by 17% for the plants fertilized with struvite while, for MRS, the impact was 46% lower. Due to the adoption of a slow-release fertilizer, FE was reduced by 63% for plants with struvite fertilization while, regarding ME, the impact was 1.14 lower compared to the plants with mineral fertilization. The slightest difference between the two treatments were found among the GW and TA categories, where crops with struvite fertilization showed a lower impact of 12% and 7%, respectively.

4. CONCLUSIONS

The results of this study show that, both in terms of productivity and environmental impact, the adoption of struvite fertilization can be a viable alternative to produce greenhouse tomatoes in the Mediterranean region.

5. ACKNOWLEDGEMENTS

This study was funded by the Catalan Agència de Gestió d'Ajuts Universitaris i de Recerca (AGAUR) under the grant 2021SGR00734 Sostenipra and WEF4Build 2023 CLIMA 00041 BOOSTING BUILDINGS CLIMATE RESILIENCE THROUGH WATER-FOOD-ENERGY NEXUS BASED SOLUTIONS (WEF4Build).

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Table 1. Table with the environmental impacts related to the different fertilization methods.

Impact category	Unit	Mineral fertilization	Struvite fertilization
Global warming	kg CO_2 eq	6.35E-01	5.61E-01
Terrestrial acidification	kg SO_2 eq	4.43E-03	4.14E-03
Freshwater eutrophication	kg P eq	5.04E-04	1.89E-04
Marine eutrophication	kg N eq	2.09E-04	1.82E-04
Mineral resource scarcity	kg Cu eq	4.64E-03	2.53E-03
Fossil resource scarcity	kg oil eq	1.57E-01	1.30E-01

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Applicability of LCA to analysing the biodiversity impacts of different coffee production systems

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1. INTRODUCTION

Biodiversity is deteriorating rapidly, with species extinctions accelerating (IPBES, 2019). Food production is the biggest contributor to biodiversity loss (WWF, 2020). From single food products coffee has a relatively high biodiversity impact in Finnish food consumption (Sandström et al., 2017). Literature suggests that coffee agroforestry is more biodiversity friendly compared to conventional coffee production (Caudill et al., 2015), but LCA studies on this are lacking. Also, LCA has difficulties in analysing the impacts of different farming systems and it tends to favor intensive farming systems (van der Werf et al., 2020).

This study compares the biodiversity impacts of conventional coffee production to coffee agroforestry. It is investigated if life cycle impact assessment (LCIA) methods can recognize differences between these coffee production systems. Recommendations will be made for method development and data quality.

2. METHODS

A SimaPro model for conventional coffee production and coffee agroforestry in Colombia is created based on literature data. Inventory data for both production systems is sourced from Acosta-Alba et al. (2020), and background process data from the Ecoinvent 3.9.1 database. LC-IMPACT by Verones et al. (2020) is used as the LCIA method. Biodiversity impacts of land use are also calculated using characterization factors (CFs) from Scherer et al. (2023) to analyse the effect of land use intensities. Ecoregion specific CFs are used when applicable. The analysis is limited to gradle-to-farm gate.

3. RESULTS AND DISCUSSION

Preliminary results of the impacts of conventional coffee production and coffee agroforestry on terrestrial ecosystems are presented in Figure 1. The preliminary results indicate that the impacts of coffee agroforestry are 41 % lower than those of conventional coffee production.

4. ACKNOWLEDGEMENTS

This research has been funded by the Strategic Research Council project “Biodiversity Respectful Leadership (BIODIFUL)” (grant number 345884).

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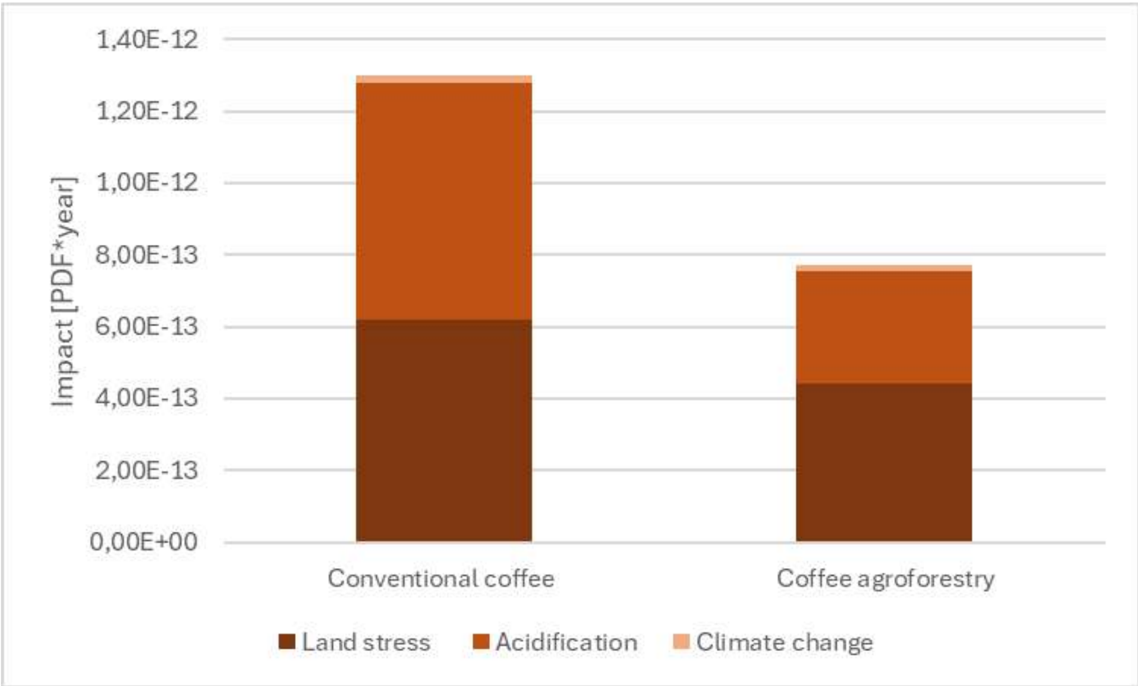

Figure 1. The biodiversity impacts of conventional coffee production and coffee agroforestry on terrestrial ecosystems based on land stress, acidification and climate change impacts calculated using LC-IMPACT method by Verones et al. (2020). It seems that the impacts of coffee agroforestry are around 41 % lower than the impacts of conventional coffee production.

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Displacing imports and impacts with peri-urban agriculture: An integrated assessment of local produce in the Metropolitan Area of Barcelona

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1. INTRODUCTION

Cities face a greater reliance on food imports amid urbanization. Urban areas are often expanded at the expense of agricultural land transformation[1], decreasing local production capacity. As urbanization progresses, food production is disconnected from where it is consumed[2], implying environmental impacts associated with lengthier supply chains. Further impacts and degradation come from mineral fertilizers[3], instrumental to meet the demand in conventional food systems. An alternative to this is peri-urban and urban agriculture (UA) combined with nutrient circularity, which can provide local crops fertilized with nutrients recycled from various urban residues. Life Cycle Assessment (LCA) has been applied to compare the environmental impacts of local versus imported produce[4] and assess the sustainability of nutrient circularity in UA[5]. However, many food system studies have focused on the carbon footprint, prioritizing transport over assessing nutrient circularity.

This study addresses this gap by performing a full LCA using geographically explicit eutrophication characterization factors, inventory data representing specific geography, as well as focusing on more than one or two crops by delving into the self-sufficiency of the produce basket of an urban area. We determine what and how much imported produce is being displaced with UA production, quantifying the impacts of the different local produce compared to imported, and identifying the benefits and trade-offs of improving the sustainability of UA by replacing mineral fertilizers with nutrients circularity based on current local needs. With this study, we aim to understand the sustainability of the current food system and provide decision makers with an appropriate strategy to improve it by identifying hotspots and closing the loop of local nutrient sources while reducing environmental impacts.

2. METHODS

The Metropolitan Area of Barcelona (AMB) serves as the area of study for its aims to expand the total surface area dedicated to UA, the commitment to develop sustainable urban food systems, and the potential of meeting UA fertilizer needs with nutrients recovered from urban residues[6,7]. To assess the self-sufficiency of UA in the AMB we contrasted the crop production data from the URBAG agricultural map[3] with official household food consumption records, ensuring local dietary patterns. With this we determined the amount of produce needed to be imported to satisfy the current demand, while the import origins were identified by analyzing official import statistics from AMB´s distribution market of the last 9 years (2015-2023).
The environmental impacts of local and imported produce will be quantified with an attributional LCA with a cradle-to-gate approach (from the production of materials for cultivation to the distribution market for retail), which we will apply to the most produced and consumed produce of the food basket. Moreover, the sustainability of the current food system and the nutrient circularity strategies applied will be assessed by upscaling the LCA to the total consumption of the produce in the AMB and comparing different local fertilization scenarios (e.g. current fertilization practices and replacement of mineral fertilizer with nutrients recovered from urban residues). The functional unit of the LCA will be the production of 1 kg of each produce, while for the upscaled food system will be its total consumption. As for the inventory data, we build from previous and current studies of our research group (URBAG) on the AMB and use regionalized data per type of crop for specific processes and elements when available (e.g. fertilizer and water requirements and mineral fertilizer use-on-land N_2O emissions). For the remaining processes, as well as for the inventory of imported crops, we prioritize the compilation and adaptation of life cycle data specific to the city or region from where the crops are imported (e.g. lettuce from the AMB versus lettuce from Murcia). The life cycle inventory of each of the nutrient recovery strategies applied is also considered in the local fertilization scenarios.

3. RESULTS AND DISCUSSION

Preliminary results indicate that the AMB has a low self-sufficiency of produce from its UA, as the current production does not meet the demand. In this regard, more analysis is yet to be performed to determine holistic reasons behind this. As for the LCA results, we expect local produce will outperform imports following lower impacts associated with food miles and food loss from the supply chain. Furthermore, we expect mineral fertilizer substitution through nutrient circularity will result in environmental benefits when upscaling the environmental assessment to the current food system.

4. CONCLUSIONS

Conclusions have yet been established.

5. ACKNOWLEDGEMENTS

Authors thanks the National Secretariat of Science, Technology and Research (Panama) for the grant awarded to J. Arosemena (contract 270-2021-156); the financial support of the European Research Council (ERC) Consolidator project: Integrated System Analysis of Urban Vegetation and Agriculture (818002-URBAG); the Spanish Ministry of Science, Innovation and Universities, through the “Maria de Maeztu” programme for Units of Excellence (CEX2019-000940-M); and the funding and recognition awarded to the research group Sostenipra (2021 SGR 00734) by the Department of Research and Universities of the Generalitat de Catalunya.

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The use of biochar to offset the lifecycle greenhouse gas emissions of sugarcane produced in Brazil

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1. INTRODUCTION

The agricultural sector contributes with over 30% of the greenhouse gas (GHG) emissions of the Brazilian economy (MCTI, 2023). To offset part of these emissions, the application of biochar in the field (**Fig. 1**) has been promoted as a promising method, due to suitable cost and logistics. Potential benefits of biochar as a carbon removal technique include the sequestration of carbon in the soil and reduction in N_2O emissions (Grutzmacher et al., 2018).

The sugarcane production chain presents a good fit for biochar use in Brazil. In addition to a planted area of 8.3 million hectares and a volume of 653 million tonnes of sugarcane harvested in the 2023/24 season, sugarcane production generates large amounts of bagasse (10.4 dry tonne/ha.yr) and straw (2.9 dry tonne/ha.yr) (Silva et al., 2019) as residues, which can potentially be used to produce biochar via pyrolysis (**Fig. 1**).

In this study, we assessed the potential use of biochar, produced from sugarcane residues, to offset the lifecycle emissions of the sugarcane production sector in the state of Sao Paulo (largest producer in Brazil).

2. METHODS

We used the Ecoinvent database v3.9.1 to obtain the inventory of sugarcane production in the state of Sao Paulo (valid for 2012-2022) and the SimaPro v9.5.0.1 to assess the lifecycle impacts in terms of GHG emissions, according to the GWP 100-yr method (2022). For land use change (LUC) we used the BRLUC model v2.0 (Garofalo et al., 2022), which provided an impact value of 0.4 tonne CO_2e/ha.yr (2000-2019) for the state of Sao Paulo.

We used the study by Lefebvre et al. (2021) to estimate the credit for the carbon sequestration of biochar (0.39 kg C/kg biochar or 1.42 kg CO_2e/kg biochar). We took a conservative approach in this study by not accounting for other potential benefits as credits, such as reduced field N_2O emissions, reduced fertilizer need and electricity generation from the pyrolysis process.

3. RESULTS AND DISCUSSION

Table 1 presents the amounts of biochar needed to offset the lifecycle emissions of sugarcane production for each of the main categories considered. The combined value of 1.25 tonne biochar/ha needed to offset the emissions of field CO_2 and N_2O and agricultural inputs is comparable to the amount of agricultural correctives for the sugarcane crop typically applied in the field, which would facilitate the biochar application operations.

One tonne of dry sugarcane residue generates roughly 300 kg of biochar; therefore, the total offset value of 1.87 tonne biochar/ha would demand 6.23 dry tonne residues/ha, which seems compatible with the generation of bagasse and straw. These residues, however, are typically reserved for the generation of electricity used in the mills and/or sold to the grid, under contracts with the government. Outsourced residues from other biomass types might be an option to produce biochar for sugarcane crops.

4. CONCLUSIONS

Biochar has good potential to offset part of the emissions of sugarcane produced; however, the availability of biomass needed to produce biochar will be an obstacle.

5. ACKNOWLEDGEMENTS

Project 1028 FAPED/CNPMA/FINEP Renovacalc 01.22.0591.00 (1514/22) and Project 6822 FUNARBE/EMBRAPA/BAYER.

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Table 1. Biochar needed to offset the lifecycle emissions of sugarcane production in SP, Brazil

Parameter	Lifecycle GHG emission impacts of sugarcane	Biochar needed to offset the impacts of sugarcane	
	kg CO_2e/ tonne cane	kg biochar/ tonne cane[f]	tonne biochar/ ha[g]
Agricultural inputs[a]	6.39	4.50	0.32
Field N_2O emissions[b]	15.9	11.19	0.80
Field CO_2 emissions[c]	2.58	1.82	0.13
Diesel[d]	5.20	3.66	0.26
Land use change[e]	5.56	3.92	0.28
Other inputs and emissions	1.33	0.93	0.07
Total	**36.94**	**26.01**	**1.87**

[a]Emissions from the production and packaging of agricultural inputs (e.g. urea, glyphosate, superphosphate, pesticides).
[b]Direct and indirect N_2O emissions from fertilizers, and emissions from sugarcane straw burning (IPCC, 2019).
[c]CO_2 releases from urea and limestone application, according to IPCC (2006), plus emissions from fuel combustion (diesel 88%, and biodiesel 12%), using emission factors from Nemecek and Kagi (2007).
[d]Emissions from the production of diesel used in agricultural operations (e.g. application of fertilizers, planting).
[e]Obtained from the Brazilian Land Use Change (BRLUC) method v2.0 (Garofalo et al., 2022)
[f]Biochar credit of 1.42 kg CO_2e/kg biochar, calculated from Lefebvre et al. (2021), only considering the benefit of carbon sequestration.
[g]Considering a sugarcane productivity of 71.94 tonne cane/ha in the state of Sao Paulo.

Figure 1. Biochar pyrolysis system, external aspect, porosity, and application in the field

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Impact of installing a cashew orchard in an area with native vegetation in Brazil

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1. INTRODUCTION

Given the growing attention to environmental issues observed in recent years, international food supply chains are increasingly focused on sustainability and reducing environmental impacts. In this context, land use change (LUC) is an important driver of climate change, being responsible for 66% of CO_2 emissions in Brazil (SEEG, 2021). LUC is often associated with the expansion of agricultural land, and can increase GHG emissions in the carbon footprint (CF) of agricultural products by up to 30 times (CURTIS et al., 2018).

The quantification of carbon emissions through LUC is a process related to CF studies of agricultural products, such as cashew nuts. Cashew farming makes an important socioeconomic contribution to agriculture in Brazil, especially in the Northeast region, with the states of Ceará, Piaui and Rio Grande do Norte responsible for 91.8% of the total cashew cultivation area in the country (IBGE, 2021).

In this way, this work evaluates the FC resulting from LUC when moving from a forested area to an orchard with dwarf cashew trees (nut + peduncle) in the main cashew producing regions in Brazil.

2. METHODS

Carbon stocks were calculated for the three states in the Northeast region of Brazil: Ceará (CE), Piaui (PI) and Rio Grande do Norte (RN). The carbon balance in biomass considered the plant physiognomies of the Caatinga forest is applied (savannah steppe – Ta, Tp and Tg) – that is, 14.9 t C/ha (MCT, 2010) found in the main producing states, carbon in the adult plant of clone BRS 226 (63.5 kg C/plant) and the density of 208 plants/ha. The soil carbon balance considered soil stocks of: 26.2; 25.8 and 24.2 t C/ha for CE, PI and RN, respectively and management factors characteristic of permanent crops: factor of carbon alteration related to land use (FLU = 1.01), factor of carbon alteration related to management regime (FMG = 0.99) and factor of carbon alteration related to input of organic matter (FI = 1.04), provided by IPCC (2019). Furthermore, it was considered that 20% of above-ground biomass was burned, generating direct emissions (CO_2, CO, CH_4, N_2O and NOx) of greenhouse gases (GHG), calculated using the IPCC (2019) emission factors. The impact of LUC on climate change was assessed using the global warming potential of GHGs, with a 100-year horizon.

3. RESULTS AND DISCUSSION

It was observed that Ceará is the state where the LUC of native vegetation for cashew orchards had the lowest impact (0.0516 kg of CO2-eq/t of cashew). Although there is a difference in absolute terms, the maximum variation in the impact of LUC between the main cashew producing states was 9.7%. This small variation between states can be explained by the similarity between the vegetation physiognomy of these states (Caatinga forest (savannah steppe – Ta, Tp and Tg) – that is, 14.9 t C/ha (MCT, 2010). Regarding carbon stock in soils in these regions, the predominant soil classes in dwarf cashew production areas in CE, PI and RN are: Ultisols; Oxisols and Alfisols, 26.2; 25.8 and 24.2 t C/ha, respectively.

4. CONCLUSIONS

Climate changes resulting from LUC in the main cashew producing states (CE, PI and RN) in Brazil show non-significant variation. In the state of Ceará, the LUC of an area with native vegetation for a cashew orchard generates less impact on climate change.

5. ACKNOWLEDGEMENTS

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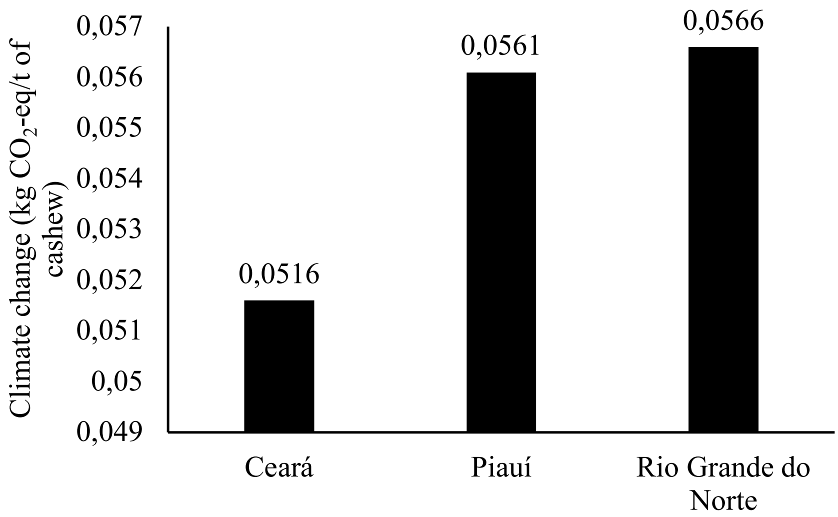

Figure 1. Impact of LUC on climate change in different cashew-producing states

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Addressing climate change, blue water scarcity and toxicity-related impacts of citrus tree nurseries

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1. INTRODUCTION

The cultivation of perennial fruits, especially citrus, requires a nursery stage. The growth of fruit tree seedlings in containers with substrates inside greenhouses leads to disease-free trees and facilitates the development of a robust root system (Castle, 1987). In Uruguay, citrus is the most relevant fruit crop in tonnes and area (MGAP, 2023). Published LCAs for food production in nurseries are centred on horticultural products, and nursery processes available in inventory databases correspond to open-field nurseries where seedlings are grown in the soil. Among the main challenges in LCA application in soilless crops grown in greenhouses are the modelling of water consumption and emissions from fertiliser and pesticide applications (Antón et al., 2019). This study aims to quantify climate change, blue water scarcity, and toxicity-related impacts of citrus fruit tree seedling production, evaluate their significance in relation to the impacts of the citrus production cycle, and address the methodological issues identified.

2. METHODS

The studied system is a Uruguayan citrus nursery, and the functional unit is one seedling at the nursery gate. The system boundaries are set from cradle to nursery gate, and data was obtained from 2017 to 2019. The inventory is detailed by month for the 15 multi-tunnel greenhouses studied. The life cycle stages considered can be seen in Figure 1. The cultivation process lasts up to 28-32 months and involves two main phases: sowing in seedbeds and transplanting into pots, where the seedlings are grafted with the corresponding citrus variety. Monthly balances of N and P_2O_5 were performed considering the nutrients provided by fertilisers and irrigation, seedling uptake, leaching, and air emissions, applying N_2O emission factor for peat from Pitton et al. (2021). Emissions from pesticide application were modelled following Antón et al. (2019), and Nemecek et al. (2022) and dissipation rates on plant matrix and vapour pressures were considered to model the plant-air secondary distribution. The water consumed by the crop was calculated from a water balance. AWARE and USEtox were used to quantify blue water scarcity and toxicity impacts, while IPCC characterisation factors were applied for climate change.

3. RESULTS AND DISCUSSION

The production of galvanised steel structures and peat transportation by ship constitute hotspots of the nursery stage, and results are summarised in Table 1. In the case of lemons, this stage accounts for 0.0-0.7% of the complete cycle impact scores, depending on the category, and for mandarins, 0.2-3.6%, except for HTc, which represents 14.4% of the impacts in the case of lemons and 50.3% in the case of mandarins. The impact scores obtained are greater than those of generic fruit seedling production from Ecoinvent 3.8 and clementine seedling production from Agribalyse® v3.0.1. as, in both databases nurseries are open-field, without irrigation, greenhouse structure, or substrate, which greatly differs from the typical citrus nursery.

4. CONCLUSIONS

The main hotspots detected are infrastructure production and substrate transportation, and the contribution of the nursery stage to the whole citrus productive cycle is negligible (0-3.6%). Significant differences were observed when comparing the results with commercial databases, highlighting the relevance of developing studies like this. Further research should address the estimation of crucial inventory data for soilless crops grown in greenhouses, such as water consumption and on-field emissions.

5. ACKNOWLEDGEMENTS

Maria Inés Cabot is the recipient of a scholarship (POS_EXT_2018_1_154319) from ANII (Uruguay) and a support scholarship (BFPD_2023_1#46477920) from CAP (Uruguay).

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Figure 1. System boundaries showing the life cycle stages included in the LCA of Uruguayan lemon and mandarin nursery production.

Impact category	Average score ± arithmetic standard deviation
Climate change (kg CO_2 eq.·seedling^{-1})	4.0 ± 0.1
Ecotoxicity (CTUe·seedling^{-1})	$1.3 \cdot 10^{4} \pm 4.1 \cdot 10^{2}$
Human toxicity, cancer (CTUh·seedling^{-1})	$9.0 \cdot 10^{-6} \pm 2.6 \cdot 10^{-7}$
Human toxicity, non-canc. (CTUh·seedling^{-1})	$1.9 \cdot 10^{-6} \pm 7.4 \cdot 10^{-8}$
Blue water scarcity (m^{3}eq.·seedling^{-1})	$1.5 \pm 4.7 \cdot 10^{-2}$

Table 1. Environmental impacts of producing one seedling in a citrus nursery (average scores and arithmetic standard deviation)

Identifying environmental hotspots in malting barley production: an Italian case study

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1. INTRODUCTION

Agricultural practices directly impact the environment and degrade resources like land, water, and fossil fuels (van der Werf et al., 2020). With growing consumer awareness about sustainability, it is paramount to provide accurate information on environmental impact and resource use in the food supply chain. Life Cycle Assessment (LCA) has been essential to quantify the environmental performance of widely disparate agricultural systems (Lago-Olveira S. et al., 2023). Therefore, this study aims to analyse, through LCA, the critical hotspots in the cultivation of barley in Central Italy for beer production, identifying which steps or processes of the agricultural stage could be modified to improve the sustainability of this raw material, especially considering the new path highlighted by the PAC (2023-2027) to let a real sustainable transition for agricultural systems.

2. METHODS

The LCA methodology (ISO 14040, 2006) was applied to estimate the environmental loads related to barley production, and 1 hectare was chosen as the functional unit for a land-oriented analysis. Information concerning the agronomic practices was provided by a local farmer in the Lazio area (Italy) and completed with literature (Lovarelli et al. 2020). The Ecoinvent® database v.3.10 (FitzGerald D et al., 2023) was used as a secondary data source. Direct and indirect emissions derived from the agrochemical applications were calculated following González-García et al. (2021). Figure 1 represents the system boundaries of the case study based on malting barley production. Environmental impacts were estimated considering the ReCiPe 2016 (H) midpoint method (Huijbregts et al., 2016), while Simapro® software v9.5. (PRé Consultants, 2023) was used to implement the life cycle inventory data.

3. RESULTS AND DISCUSSION

The environmental burdens associated with the cultivation of 1 hectare of malting barley are shown in Table 1. The use of fertilisers and phytosanitary products and their consequent emissions can be considered the primary environmental hotspot, contributing rates above 80%, as displayed in Figure 2. This is a common hotspot highlighted in other studies conducted in the field (Lovarelli et al., 2020). Conversely, mechanization activities involving diesel consumption and related tile pipe emissions have a negligible impact on the environmental profile. These results suggest that the application of fertilisers and phytosanitary products needs to be further optimised by identifying the appropriate dosage, selecting alternative products, or incorporating new cultivation strategies to reduce the environmental burden while maintaining crop yield efficiency. Additionally, an effective strategy to mitigate impacts could involve adopting Agriculture 4.0 solutions, such as Decision Support Systems, to aid in a truly sustainable transition of the primary sector. This approach aligns with the guidelines identified in the new CAP and the European Green Deal and can lead to agricultural systems less harmful to the natural environment.

4. CONCLUSIONS

This study highlights the environmental burdens associated with malting barley production as a preliminary step in the beer production chain. Attention should be paid to the application of fertilisers and phytosanitary products to improve the profile, as well as incorporating new cultivation strategies in line with the European Green Deal.

5. ACKNOWLEDGEMENTS

This research has been partially supported by the project Transition to sustainable agrifood sector bundling life cycle assessment and ecosystem services approaches (ALISE) (TED2021–130309B-I00) funded by MCIN/AEI /10.13039/501100011033 and by the European Union NextGenerationEU/ PRTR.

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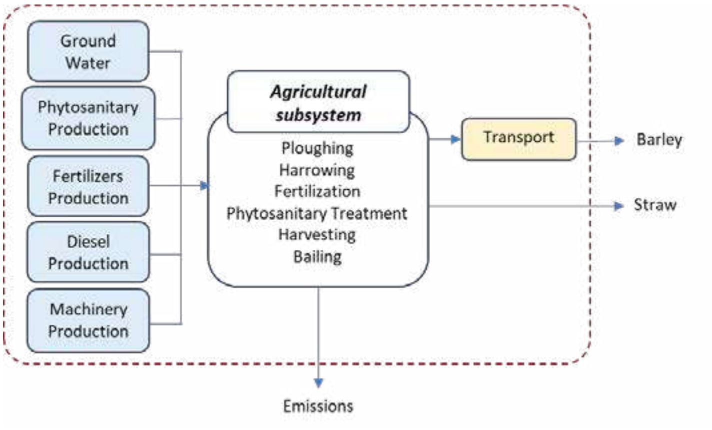

Figure 1. System boundaries of the case study

Table 1. Environmental profile of 1ha of barley cultivation.

Impact Category	Unit	Barley Cultivation
Global Warming	t CO_2 eq	2,94
Freshwater Eutrophication	kg P eq	17,2
Marine Eutrophication	kg N eq	10,3
Terrestrial Ecotoxicity	t 1,4-DCB	5,07
Freshwater Ecotoxicity	kg 1,4-DCB	43,4
Fossil Resource Scarcity	kg oil eq	488
Water Consumption	m^3	30,8

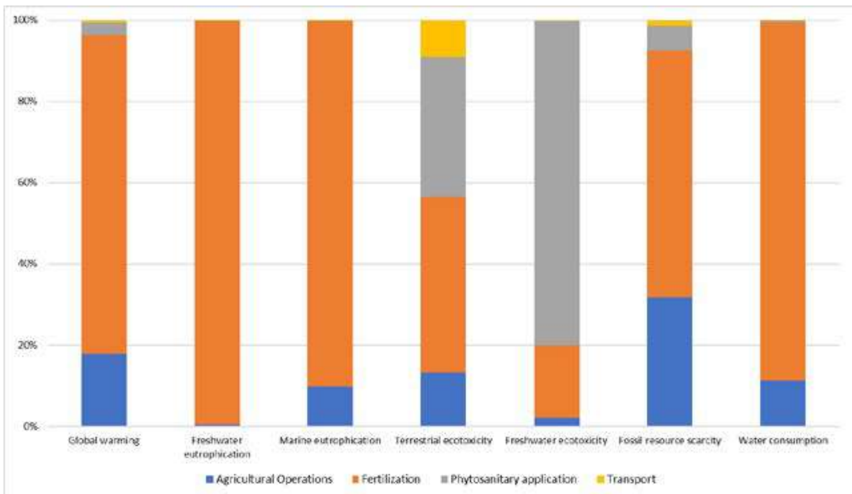

Figure 2. Distribution of burdens between involved processes

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Environmental impact scenarios for the introduction ofTrue Potato Seed-based starting material in ware potato cultivation practice

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1. INTRODUCTION

Potato cultivation is characterized by multiple years of seed tuber cultivation, high inputs and high yields in terms of mass, resulting in a climate change impact of around 100 kg CO2eq / metric tonne (Haverkort & Hillier, 2011). Potatoes are traditionally clonally propagated, but a system of a field transplanting nursery-raised potato seedlings is under development (ResPot, 2024). This allows faster introduction of new varieties from hybrid breeding, which yields true potato seed (TPS). Currently available varieties offer stacked resistance against Phytophtora infestans (PI), a major potato fungal disease. Several options exist for the introduction and cultivation of the new varieties, but the changes in environmental impacts thanks to TPS and PI resistance are unknown. This explorative life cycle assessment will help breeders, agronomists and their stakeholders to prioritize innovation efforts.

2. METHODS

The LCA focuses on ware potatoes harvested, including all required resources and their transport, specifically the seed tubers. The functional unit is 1 metric tonne of ware potatoes, with the same quality across the scenarios. Scenarios are based on conventional cultivation: 1) Non-resistant variety with traditional propagation: 6 years of seed tuber cultivation, 2) PI-resistant variety with traditional propagation, 3) PI-resistant variety with TPS-based propagation, requiring 2 generations of seed tuber (i.e. 2 years of cultivation) between transplant production and ware potato cultivation. The sensitivity analysis addresses high and low applications of animal manure or chemical fertilizer, high and low use of diesel and an optimized TPS scenario in which no seed tuber cultivation is required. The datasets on ware potatoes and seed potatoes on clay soil in the IJsselmeer polders from the "Quantitative Information Potatoes and Vegetables" (KWIN-AGV, 2022) were used to model an archetype of Dutch potato cultivation. This data was augmented with data from the Dutch farm accountancy data network, field trial & seedling data (ResPot, 2024), and expert validation (Kik, 2023). SimaPro 9.10, Agri-footprint 6 (Economic) and ecoinvent 3.9 (cut-off), the "Environmental Footprint"-method and new characterization factors from OLCA-Pest were used for modelling, raw material data and life cycle impact assessment.

3. RESULTS AND DISCUSSION

The reduced number of PI treatments results in a modest reduction (appr. 3%) in the climate change and terrestrial ecotoxicity impacts, mostly thanks to reduced diesel use. This contrasts with a reduction in the mass of applied plant protection active ingredients by 24%. The eliminated fungicides against PI have a limited climate change impact and, moreover, a relatively low toxicity. Furthermore, fertilizer production and diesel combustion contribute to more than half of the ecotoxicity impact, limiting the contribution of the fungicide reduction.

TPS-based seedlings substitute a limited mass of seed tubers 2 generations before ware potato cultivation. Hence, the climate change and terrestrial ecotoxicity impacts do not change (+/-1%). Across the three scenarios, just under half of the climate change impact is due to direct fertilization emissions and less than a quarter due to diesel combustion.

Sensitivity studies show that real-life variations in animal manure, chemical fertilizer and diesel consumption (under the same yield) can be significant and strongly affect the climate change and ecotoxicity impacts. It also stands out that if the seed tuber cultivation cycles can be eliminated from the TPS scenario, TPS-seedling introduction does affect the impacts of starting material but also of fertilization and mechanical operations during cultivation.

4. CONCLUSION

A significant reduction in the mass of PPP applied translates into a modest reduction of climate change and ecotoxicity impact at most. The change in impacts due to the introduction of TPS strongly depends on the propagation system implemented. The sensitivity analysis indicates that optimized agronomy, possibly aided by new TPS-based varieties with increased yield potential or nutrient efficiency, has great potential for environmental impact reduction.

5. ACKNOWLEDGEMENT

This study is part of RESPOT, funded by “TKI Uitgangsmateriaal”, project # LWV200237.

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Data science integration with LCA modelling: a review with a focus on spatial-temporal variability in agriculture

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Keywords: life cycle assessment, life cycle inventory, data science, big data, agriculture, spatial variability, regionalization

1. INTRODUCTION

Data science is the discipline of extracting meaningful insights from data, utilizing and combining elements of mathematics, statistics, computer science/engineering, and artificial intelligence. Although data science and analysis are well established and popular in many industries/domains, its integration with agriculture has begun to happen only recently (Sonka 2016, Lokers et al. 2016, Tantalaki et al. 2019). Advances in data collection and computing are expected to facilitate data processing to previously impossible levels, potentially enabling better dealing with the multidimension complexity and spatiotemporal resolution issues that are prevalent in life cycle assessment (LCA) research (Li et al. 2023). There is a notable lack of LCA studies which incorporate data science techniques despite the well-established advantages that data science brings to LCA (de Jesus et al. 2021). On the other hand, advanced machine learning and data mining are quickly becoming an integral part of the agriculture industry, especially for precision agriculture (PA), and are poised to be a key driver in meeting global challenges of agricultural productivity and environmental impacts (Tantalaki et al. 2019). A major unresolved issue in LCA revolves around spatial and temporal variability, thus making analyzing environmental impacts associated with PA using LCA even more challenging considering how imperative highly granular data is to PA applications (Li et al. 2023).

2. METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method (Moher et al. 2009) was utilized to identify and process relevant literature to answer the following questions:

- *What are the key opportunities to make use of big data in LCA, and what are the most appropriate ways to implement them?*
- *What are the data science techniques that can contribute to better addressing the spatial and temporal variability inherent to agriculture, especially in LCA modelling?*

Peer-reviewed journal articles were identified from the Web of Science Core Collection using keywords (life cycle assessment, life cycle inventory, data science, big data, agriculture, spatial variability, regionalization, etc.). Results were limited by year (2000-2024), document type (scientific article), subject type (open field crop agriculture), language (English), and assessed for inclusion/exclusion criteria defined for each research question.

3. RESULTS AND DISCUSSION

Results of the review highlight some promising data science tools/techniques; the Universal BigLCA Framework, where big data is incorporated as a main element in all four stages of a typical LCA (Li et al. 2023), the "data gap challenge", the incongruency of data availability contained in LCA databases (country level resolution, variety of sources and measurement methodologies) and farm-level data, often highly specific, distinct, and not easily scalable.

4. CONCLUSIONS

Tools and techniques which harness the power of data science are of utmost importance in terms of utility for improvements to LCA, especially for agricultural studies or other products/systems that involve spatial and temporal variability.

5. ACKNOWLEDGEMENTS

Thank you to colleagues of the PRISM Laboratory University of British Columbia – Okanagan.

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Environmental evaluation of digital and connectivity solution for agricultural application with LCA

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1. INTRODUCTION

Over the last years, the importance and need for broadband and high-speed connectivity has constantly increased. However, in Europe, a 13% lack of access persists, and mainly concerns the most rural and remote areas (Eurostat, 2022). The European-funded project COMMECT aims at bridging the digital divide by providing quality, reliable, and secure access for all in rural and remote areas.

The aim of the COMMECT project is to deploy connectivity solutions to support agriculture, viticulture, forestry, and livestock transport, sectors in rural areas, whilst paying attention to how these solutions contribute towards social, economic, and environmental improvements by quantifying their impacts and benefits. Several connectivity solutions are implemented in the COMMECT Living Labs (LLs) around Europe. Five LLs from Luxembourg, Norway, Denmark, Turkey, and Serbia will test different ICT (Information and Communication Technology) applications in the field.

In this study, environmental impacts are modelled for ICT equipment itself and its application in the different LLs. The goal is to find out which of the ICT applications have the most noteworthy overall impacts to the environment, especially to climate change. The data will be fed into a Decision-Making Support Tool, one of the project outcomes.

2. METHODS

The impact assessment will follow LCA-standards, such as ISO 14040, ISO 14044, and the Environmental Footprint (EF) method developed by the European Commission (EC). The life cycle impact assessment will include the 16 impact categories, including climate change, acidification, and resource use, per the recommendations of the EC for the EF methodology (Fazio et al., 2018). Normalization and weighting factors are used to facilitate interpretation and aggregate environmental impacts into one single score, which will be used as an environmental Key Performance Indicator (KPI) in the COMMECT project together with the KPI focusing on climate change (Sala et al. 2018). Based on these sector-specific instructions, impacts are categorized in first and second-order effects. First-order effects include the direct impacts of deploying ICT solutions, and second-order effects include indirect enabling effects in the sector of application.

3. RESULTS AND DISCUSSION

Environmental evaluation will be implemented for at least five different use cases from four different LLs. In these evaluations, the first and second-order effects will be modelled. By May 2024, the first-order effects in Luxembourg, Denmark, Turkey, and Serbia living labs were modelled. From the second-order effects for the reference case initial results are available for Luxembourg, Denmark, and Turkey. The rest of the first- and second-order effects will be modelled and the first-order effects will be related to the functional unit during 2025. The initial results can be seen in table 1. The final results will be calculated when all three parts of the calculation are complete, and they can be combined as shown in figure 1.

4. CONCLUSIONS

The key findings of this study assist in determining whether various ICT applications yield positive or negative environmental impacts, identifying which applications have the most pronounced effects in either direction, and assessing significant trade-offs between different EF impact categories. In this way, it will be seen whether the ICT applications are useful in agri-food production from an environmental aspect. With the insights and conclusions drawn from this study, the decision support tool will be equipped to provide information regarding the potential environmental effects of diverse ICT equipment applications.

5. ACKNOWLEDGEMENTS

COMMECT project has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement no. 101060881.

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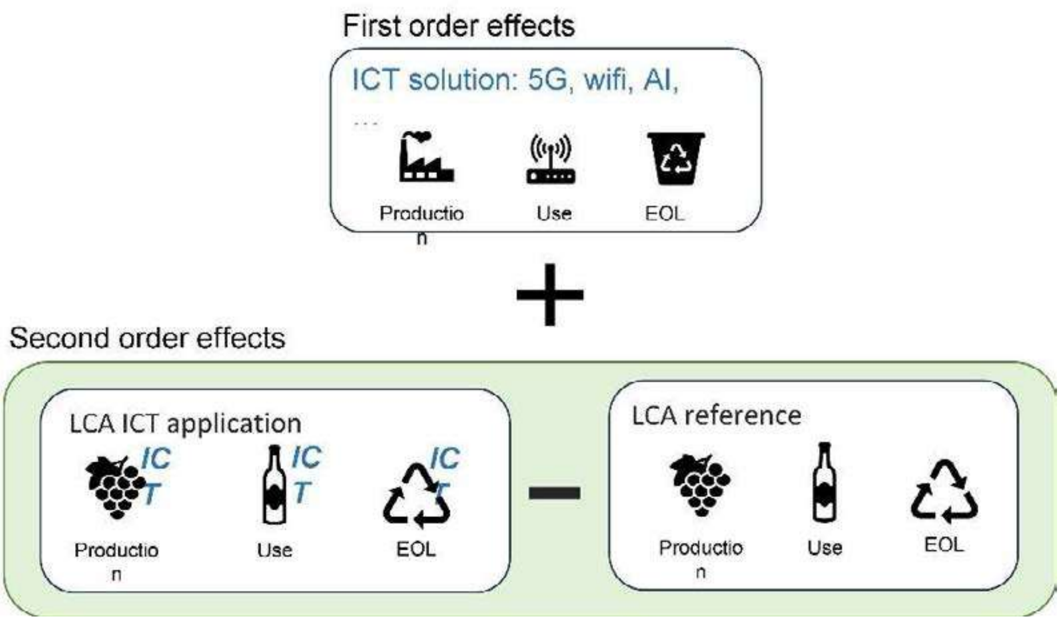

Figure 1. A visualization of the first- and second-order effects calculation

Table 1. Initial results of the COMMECT LCA.

Initial results	**First-order effects of the whole ICT application [kg CO_2-eq]**	**Second-order effects, reference, in relation to the functional unit [kg CO_2-eq per FU]**	**Second-order effects, with ICT application**
LL1: Luxembourg	141,46	0,03 (1 kg of grapes)	-
LL2: Norway	-	-	-
LL3: Denmark	29,95	29,95 (0,12 saved pigs)	-
LL4: Turkey - Antalya	1020,15	0,16 (1 kg of olives)	-
LL4: Turkey- Mersin	1020,15	0,27 (1 kg of olives)	-
LL4: Turkey - Izmir	1092,46	0,42 (1 kg of olives)	-
LL5: Serbia	122,39	-	

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Carbon and water footprints of an oat-based drink

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1. INTRODUCTION

The life cycle assessment team at IRTA and Liquats Vegetals SL., a plant-based drinks producing company, have engaged in a collaborative project aiming to quantify the environmental impact of the production of a oat-based drink in Catalonia, north-eastern Spain. Climate in Catalonia is dry and mild. The main objective of this ongoing project is twofold: 1) to quantify the carbon and water footprint associated with the cultivation of oat, for being the impact categories in the current spotlight; 2) The water and carbon footprints of growing oat are compared with the footprints of traditionally cultivated winter crops, namely wheat and barley. The study encompasses three plots of oat in different locations in the area of study, all cultivated in the season 2022-2023. All crops are rainfed, thus only blue water consumption of the inputs used in the agricultural activity are considered. The scope of the study is the primary production, from cradle to field gate. The carbon and water footprints from growing oat in Catalonia will be compared with a scenario of an oat supplier from Navarra, northern Spain, which has a colder and slightly more humid climate than Catalonia. This last scenario takes into account the transport until the facilities of the drink producer in Catalonia.

2. METHODS

To collect the primary data, a specific questionnaire was prepared for each scenario, and online surveys, phone calls, bibliographies and face-to-face interviews were performed. The water footprint and carbon footprint indicators recommended in the environmental footprint (PEF) method (European Commission, 2013) were applied to assess the environental impacts of water consumption (Boulay et al., 2018) and carbon emissions (Myhre et al., 2013). Secondary data are retrieved from Ecoinvent (Wernet et al., 2016) and Agribalyse (Asselin-Balençon et al., 2020). The LCA study is performed in Simapro v. 9.5 LCA desktop software (Wernet et al., 2016)(Asselin-Balençon et al., 2020) Multi-functionality has been handled following the PEF guidelines (European Commission, 2021).

3. RESULTS AND DISCUSSION

Preliminary results for the carbon and water footprints for the three base scenarios of oat production have been calculated. It is important to highlight that two scenarios are experimental microplots, while the third scenario is a conventional commercial field. This difference is important, as difference in management practices can influence the yield, thereby the resulting environmental impact. In **Tabla 1¡Error! No se encuentra el origen de la referencia.**, are the characterized results of the footprints per ton of oat grain produced and, in **Figure 1**, the graph of input contributions on the carbon footprint of the base scenarios.

Comparing the three oat cultivation base scenarios, scenarios 1 and 2 perform better than scenario 3. Lower impacts are due to higher yields of the microplots, around 4.000-6.000 kg/10.000 m^2, which is 50% greater than yields in the commercial field, and fewer inputs used, such as fertilizers, phytosanitary products, and diesel. Remaining task is calculating and comparing the footprints of the traditionally cultivated cereals (winter wheat and barley) as well as oat in Navarra against the footprints already calculated.

4. CONCLUSIONS

Footprints of scenario 3 were like or slightly lower than footprints from other studies on winter cereal crops (wheat, barley) that IRTA has carried out. Since this is the most representative of real conditions, I would add that the footprint of this scenario 3 will be the base scenario and the other 2 will serve to communicate best case scenarios.

5. ACKNOWLEDGEMENTS

Thanks to Liquats V. and Grans del Lluçanès for the support in collecting the primary data.

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Scenarios	kg CO^2 eq. / 1.000 kg of product	m^3 depriv. / 1.000 kg of product
Sce. 1	1,21E+02	9,00E+00
Sce. 2	3,57E+02	8,00E+00
Sce. 3	6,92E+02	1,29E+02

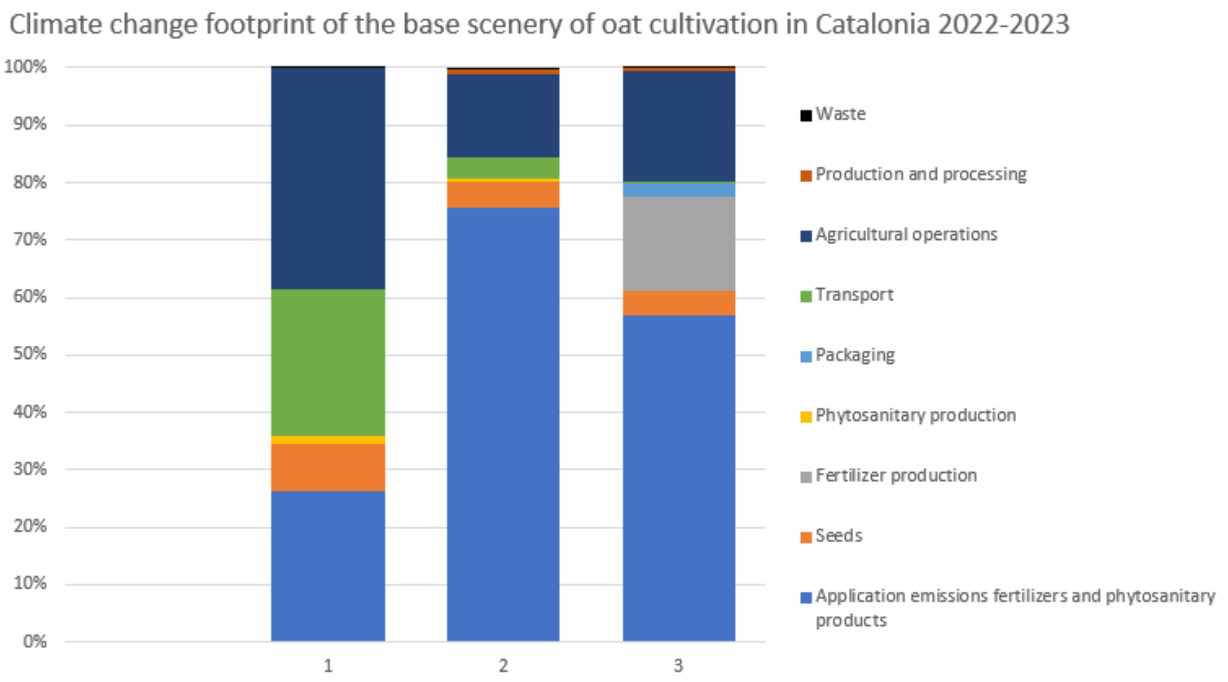

Figure 1. *Contributions (in percentages) to the carbon footprint for scenarios of oat studied .*

Innovations in food production beyond the farm gate

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Emerging technologies in agriculture – an Environmental and Social Life Cycle Assessment

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1. INTRODUCTION

The Horizon XGain project represents a significant step forward in promoting sustainable, balanced, and inclusive development of rural coastal and urban areas by facilitating access to relevant stakeholders to a comprehensive inventory of advanced connectivity and edge computing technologies. Examples of these technologies are visualized in Figure 1, e.g. drones operation in rural areas, precision agriculture, using cameras to observe livestock, water quality monitoring, remote oyster farming. The socio-environmental impact of adopting these technologies will be evaluated through Life Cycle Assessment (LCA) and social Life Cycle Assessment (S-LCA) for the selected use cases which will test the technologies (TRL 4-6). Next to that, a Knowledge Facilitation Tool (KFT) will be developed in which developing business models and supporting decision-making will be supported when choosing a suitable mix of connectivity options and edge-processing technologies, following a multi-actor and practitioner-oriented approach to assessing the social, economic and environmental impacts of these technologies.

2. METHODS

In this task of the project, we aim to calculate the socio-environmental impacts of the use phase of the technologies, as shown in Figure 2.

2.1 Social Life Cycle Assessment

We are applying the S-LCA methodology to evaluate the social impact of emerging technologies at farms. For the use cases, this indicates starting with a baseline assessment to understand the current social impact of the farm with and without adopting the technology. For farms where technology adoption is not yet (fully) completed at the time of the assessment, we will create scenarios and ask the farmers to provide data on how they think adopting the technology will change their social impact

For the KFT, we will follow another approach; the possible social impact of the proposed technology for the end user will be estimated by means of an automatic scoring system. The end user has to answer questions about their current performance per impact category and through country-specific reference scales the end user receives a score, as well as an indication whether this social impact will go up or down when the technology will be adopted.

Concluding, the social impact of the use cases will be determined with a very elaborate social assessment with a lot of stakeholder interaction, while the KFT requires a lot of automation to provide a rough social impact score for the end user

2.2 Life Cycle Assessment

The LCA method systematically evaluates the use of natural resources and the associated environmental pressures exerted by the technologies. The 'footprint family' comprises a set of indicators that track these pressures, including but not limited to carbon, energy, water and nutrient footprints. These indicators are essential for comprehending the environmental impacts of the technologies on various planetary boundaries, such as climate change, resource cycles, and biodiversity. The LCA measures the effects on 'Earth's biophysical systems. For each of these footprints, both the size, denoting the appropriation of natural capital flows and the depths, indicating the extent to which these natural capital flows are depleted or diminished, will be considered. While the size quantifies the exerted environmental pressures, the depth serves as a metric to quantify the consequential impacts arising from these pressures on biodiversity. The computation of biodiversity impact adheres to the LC-IMPACT 1.2 method. This facilitates the translation of resource use (e.g., impact per m^3 of water used) and emissions (e.g., impact per tonne CO_2 equivalent) into a measurable dimension of biodiversity impact (Potentially Disappeared Fraction of species; PDF).

3. RESULTS AND DISCUSSION

At the time of the LCA Foods conference we are able to present the socio-environmental impact of adopting emerging technologies at farms and present about possible trade-offs.

4. CONCLUSIONS

The XGain project is evaluating the socio-environmental impact of new connectivity and edge computing technologies in several use cases as well as in the KFT to help farmers understand the impact of adopting these new technologies. The KFT combines LCA and S-LCA outcomes to rank solutions that maximise benefits while minimising environmental impact.

5. ACKNOWLEDGEMENTS

Grant Agreement No. 101060294, programme: HORIZON-CL6-2021-COMMUNITIES-01-03.

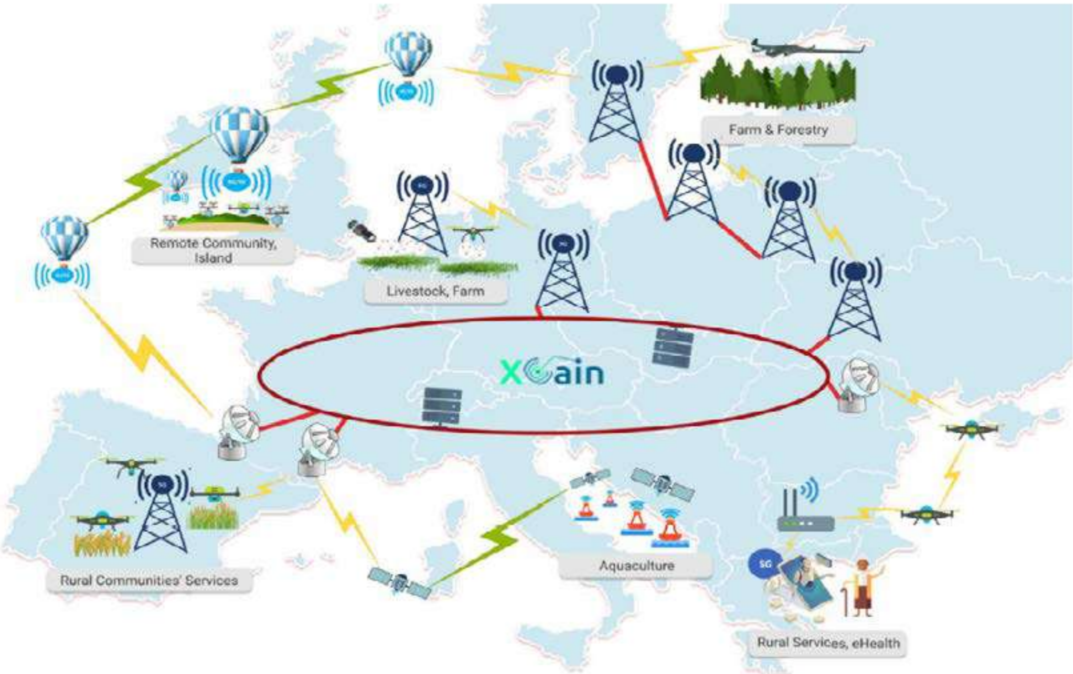

Figure 1 XGain's ecosystem of technologies applied in 6 use cases across Europe

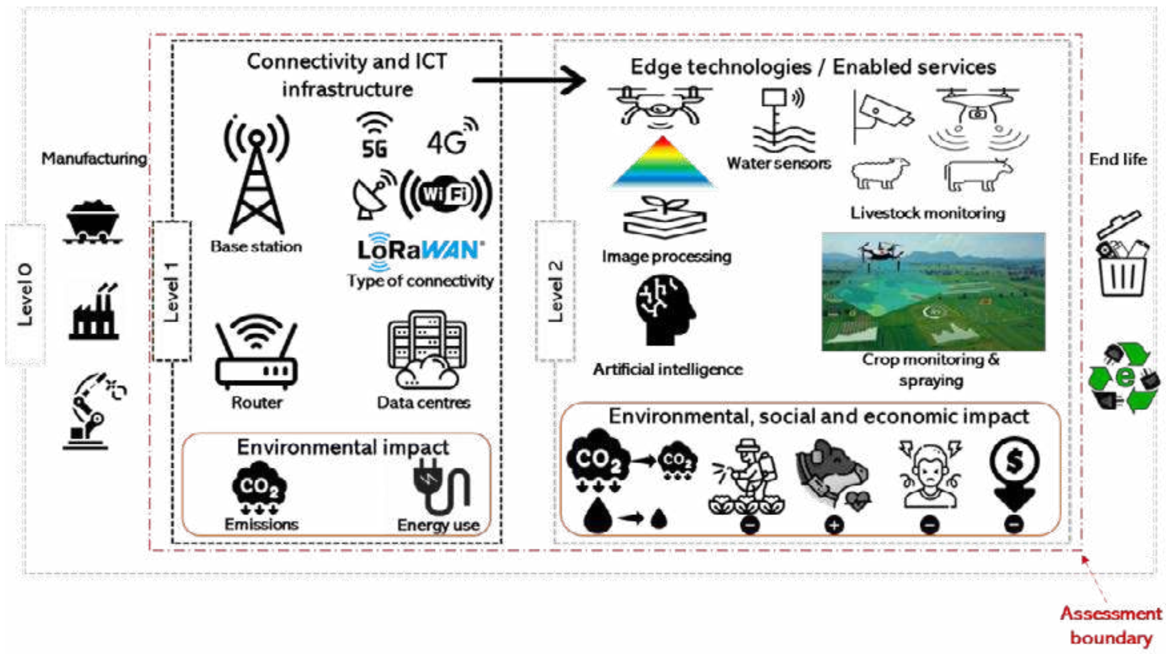

Figure 2 System boundaries and environmental, social and economic impact levels for connectivity and edge technologies

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Optimising Downscaled Food Chains for Sustainable Resource Use: A Comprehensive Case Study on Tomato Juice

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1. INTRODUCTION

Efforts to reduce food waste intensify, with Short Food Supply Chains (SFSCs) emerging as potential solutions. SFSCs offer social benefits but pose complex environmental challenges. This study evaluates the environmental impact of scaling down processing technologies within SFSCs, focusing on the transition from traditional thermal pasteurization to innovative methods like pulsed electric field (PEF) processing. The FOX unit, a mobile processing prototype, is assessed compared to traditional methods, exploring the practicality of mobile processing unit transportation. This research contributes to understanding how collaborative initiatives shape sustainable food chains, addressing key questions on technology impact and supply chain optimization.

2. METHODS

Utilizing ISO standards 14040-14044, a Life Cycle Assessment (LCA) compared the environmental impacts of traditional thermal pasteurization and novel pulsed electric fields (PEF) technology via the FOX unit. The FOX project (GA 817683) validated the FOX unit's performance with apples, later optimized for tomato juice production. A modified Thermal Pasteurization Juice Model, sourced from the Agribalyse database, compared scenarios of traditional pasteurization and FOX unit processing in Quakenbrück, Germany. SimaPro software (version 9.4.0.2, PRé Sustainability B.V., Amersfoort, the Netherlands) analysed data, with system boundaries set from cradle-to-processing gate. Additionally, two scenarios assessed the environmental impact of centralizing production versus relocating the FOX unit to countries of raw material origin (France, Italy and Spain), focusing on transportation impacts and processing at the source until scenario equivalence was reached.

3. RESULTS AND DISCUSSION

The yield of tomato extraction in the FOX unit was 78.52% (w/v), higher than the 54.04% (w/v) from thermal pasteurization, with 8.10% of tomato pomace generated. In Scenarios 1 and 2, the environmental footprint of tomato juice production was lower with PEF technology compared to thermal pasteurization (around 16%). The impact varied across categories, with notable reductions in energy consumption and emissions. Scenarios 3 and 4 explored the environmental impact of centralizing production versus local processing. The breakeven point where shipping raw materials to Germany equalled sending the unit to raw material origin countries was determined: the impact of keeping the mobile unit in Germany and processing 1t of tomatoes from the different countries, generated similar impacts to moving the unit to the different countries and processing different volumes there (approximately 200t of raw materials from France, 15t from Italy, and 45t from Spain). Environmental impacts were influenced by transportation and raw material production, with Spanish tomatoes having the lowest impact due to fewer inputs. Contribution analysis showed raw material production as the key contributor to environmental impact, suggesting a focus on improving cultivation methods and incorporating underutilized crop species. The geographical dimension highlighted the value of the FOX unit in optimizing SFSCs and reducing environmental impacts, particularly when employed by small-scale producers processing local raw materials for local markets. However, long-distance transportation of the final product may offset environmental gains during processing.

4. CONCLUSIONS

Implementing mobile processing units, like the FOX unit, optimizes Short Food Supply Chains (SFSCs) by situating processing near raw material sources, reducing losses and enhancing resilience. This aligns with Sustainable Development Goals (SDGs) and underscores the importance of raw material selection, with tomatoes from Spain showing the lowest environmental impact. Diverse agricultural practices, including underutilized crops, offer resilience and environmental benefits, emphasizing the need for sustainable farming. While focusing primarily on environmental impacts, broader economic and social benefits, such as supporting local economies, should be further explored to strengthen supply chains and policies.

5. ACKNOWLEDGEMENTS

This work was supported by European Union's Horizon 2020 research and innovation programme through the projects "Realising Dynamic Value Chain for Underutilised Crops" (RADIANT), grant agreement number 101000622 and "Innovative down-scaled FOod processing in a boX" (FOX), grant agreement number 817683.

Simplified parametrized LCA user-friendly tool to eco-design returnable bottles scenarios

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1. INTRODUCTION

Returnable bottles are one of the most promising strategies to reduce the environmental impacts of food packaging. Companies usually use the same generic values to justify their development (e.g., -79% GHG emissions compared to single-use (ADEME, 2018)). In addition, they rely on only a few parameters when speaking of optimize the environmental performances (mostly the return rate and the mass of the bottles). We developed a user-friendly tool to help stakeholders evaluate and optimize their returnable bottle systems. Based on simplified parametrized LCA models (Padey et al., 2013, Douziech et al., 2021), it combines the results' simplicity of use and scientific accuracy.

2. METHODS

To ensure the tool covers a realistic diversity of existing systems, we built a typology of configurations for returnable bottle strategies, helped by private companies (e.g., the drink producer can do the cleaning or not, which can potentially affect the environmental impacts). In parallel, we developed Python scripts to generate simplified parametrized LCA models from impact equations. This consists of simplifying the impact equations by (1) identifying the input parameters that make the results vary, applying Sobol' method (Sobol, 2001) on Global Sensitivity Analysis, and (2) setting the non-key parameters to the mean value in the equations (figure 1). The simplified models were applied with the stakeholders of H2020 FAIRCHAIN (https://www.fairchain-h2020.eu/) to optimize the implementation of returnable bottles strategies for a new innovative whey-based drink. We developed an interface for small and mid-sized stakeholders to include LCA results when developing local distribution strategies. Facing the difficulty of making decisions, expressed by the stakeholders, including a large number of – obscure – indicators, we also worked on the usability of the results presented in the tool to be used for decisions. This was done by selecting a limited number of indicators to display by looking at the correlations between impact categories when simulating thousands of random systems with simplified models.

3. RESULTS AND DISCUSSION

3.1 Simplified parametrized LCA models

The simplified models developed show an excellent ability to balance simplicity and robustness. For instance, the first simplified model developed in FAIRCHAIN helps to reduce the required data from 46 to 13, while explaining 90% of the total variability of the results for all impact categories of the EF3.0 method. It is, in addition, possible to discuss with the stakeholders the possibility of setting some other input data (e.g., in the case, it is difficult to collect) considering its impact on the results (as the share of variance due to each of the remaining parameters is known). We experimented with the search for trade-offs with project partners. We generated simplified models for the configurations considered in the research project and provided scripts and protocol to generate more.

3.2 User-friendly tool

We developed an interface that aims to (1) guide the user through the typology to the simplified model corresponding to its system and (2) produce LCA results with a limiting dataset. The expert version of the tool also allows the user to generate its own simplified models. The observation of correlations showed a good potential to reduce the number of indicators (from 16 to 5 for the first simplified model) to consider when comparing scenarios without compromising the whole environmental picture.

4. CONCLUSIONS

In the FAIRCHAIN research project, we explored the necessary trade-off between users' requirements ("we need it to be simple") and scientists' positions ("we want it to be robust"), and proposed an answer for the development of returnable bottle strategies: a user-friendly tool based on statistical simplification methods. The tool was developed and tested with future users, involved in the research project, involving practical constraints and ideas for future improvements, and large diffusion of the tool beyond the project.

5. ACKNOWLEDGEMENTS

This project received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 101000723. The authors especially thank the partners working on the distribution aspects of the French Case Study: Hugues Pelletier (PETREL), Muriel Charlet, Delphine Renevier and Mathieu Ganier (J'aime Mes Bouteilles).

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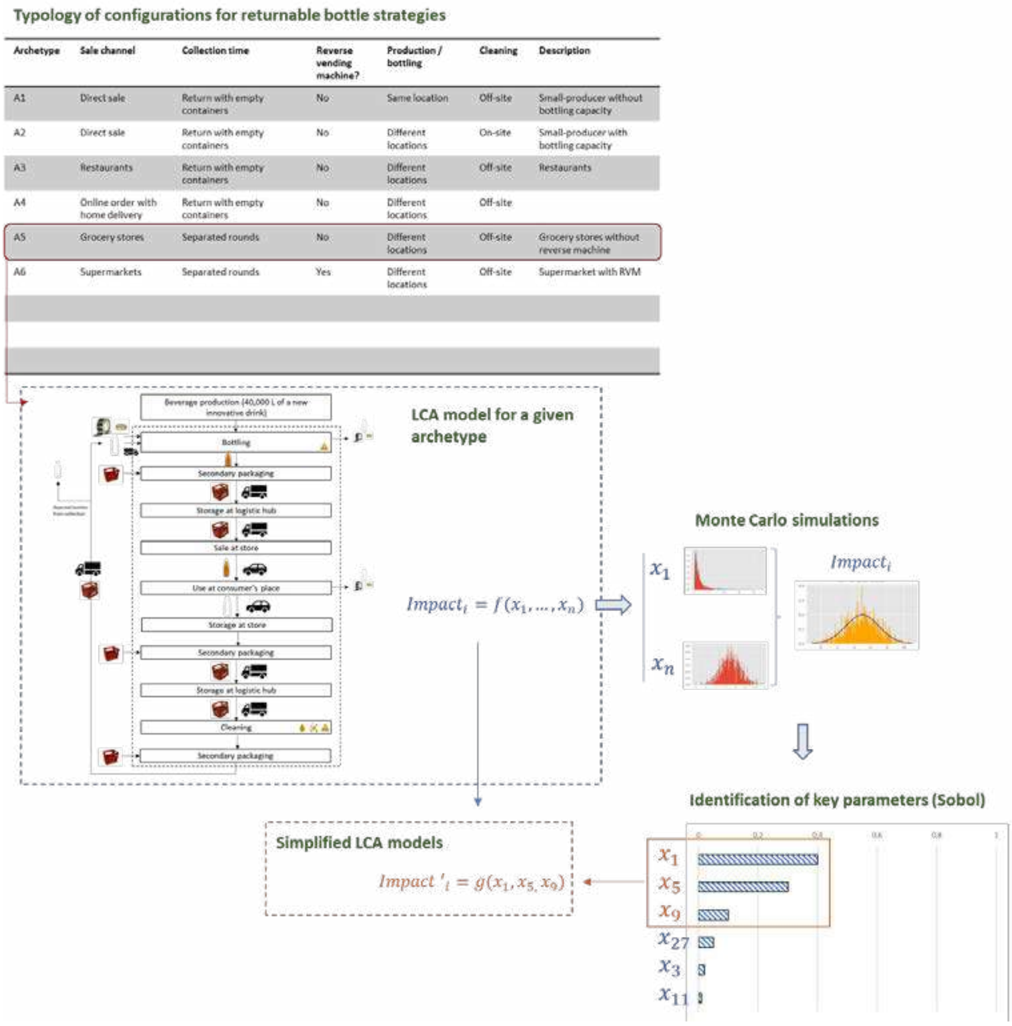

Typology of configurations for returnable bottle strategies

Archetype	Sale channel	Collection time	Reverse vending machine?	Production / bottling	Cleaning	Description
A1	Direct sale	Return with empty containers	No	Same location	Off-site	Small-producer without bottling capacity
A2	Direct sale	Return with empty containers	No	Different locations	On-site	Small-producer with bottling capacity
A3	Restaurants	Return with empty containers	No	Different locations	Off-site	Restaurants
A4	Online order with home delivery	Return with empty containers	No	Different locations	Off-site	
A5	Grocery stores	Separated rounds	No	Different locations	Off-site	Grocery stores without reverse machine
A6	Supermarkets	Separated rounds	Yes	Different locations	Off-site	Supermarket with RVM

Figure 1. Protocol used to generate simplified LCA models for a given archetype from the typology of returnable bottles systems. For a given archetype, the protocol is applied independantly to every impact category.

Optimizing FoodTransportation Boxes

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1. INTRODUCTION

According to IPCC 2023 [1], the transportation sector ranked as the fourth-largest contributor to global greenhouse gas emissions in 2019, contributing to 15% of the total emissions. Aligned with this imperative, the REDUCE Project included in the Green Agenda "Embalagem do Futuro" aims to rethink the design of food transportation boxes according to the circular economy principles. This contributes to optimizing the transport chain, focusing on logistical efficiency and material utilization. This research aims to compare the environmental performance of three different boxes used in the food value chain. Two of them already exist as monobloc and collapsible types, and another one is being developed in the REDUCE Project having as a baseline the results of the boxes already available in the market. Then, the major challenge of this study is to develop a novel collapsible box that obeys the circularity principles and presents a better environmental performance. At this moment, we seek to obtain valuable insights that will support sustainable decision-making for the project.

2. METHODS

This research uses the methodology presented by ISO 14040-44 [2, 3], which includes the following mandatory steps: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation. The project's main goal is to compare the environmental performance of the two existing boxes, monobloc and collapsible, with the newly designed polypropylene box developed according to the circularity principles. The functional unit (FU) considered was the production and distribution of one transportation box, and the system boundaries of this study follow a "gate to gate" approach, as described in Figure 1. The construction of infrastructures and equipment, end-of-life of capital goods, wastes from administration, laboratory, or offices, and end-of-life were excluded. The present study used a mass allocation and an attributional approach. The impact assessment was performed using SimaPro software (version 9.5.0.1), the main data used was provided directly by the Plastidom company and when necessary, background data was collected from the Ecoinvent database (version 3.9.1).

3. RESULTS AND DISCUSSION

The collapsible boxes showed better environmental performance for all impact categories, after using the Environmental Product Declaration method (EPD, 2018, V1.04), as illustrated in Figure 2. This method includes eight environmental impact categories, and all of them have been considered in this study. These results can be explained by the fact that collapsible boxes use less raw material, and occupy less space in the truck considered in the distribution stage when compared to the monobloc boxes. Moreover, within each impact category, it was the injection and thermoforming stage that contributed most to the environmental impacts. In contrast, assembling and distribution were the stages with lower contributions to the environmental impacts. Furthermore, it is crucial to emphasize that despite collapsible boxes having an extra step of assembling, this process incurred such minimal energy consumption, that their contribution to the environmental impacts was insignificant, and collapsible boxes continued to be the best option for the environment. With this in mind, it is expected that the box under development will present a better environmental performance.

4. CONCLUSIONS

The insights from this preliminary study comparing the two existing boxes suggest that the new collapsible box developed in the project will be even better. This result proves that using collapsible transportation boxes can significantly reduce environmental impacts associated with transportation in the food value chain.

5. ACKNOWLEDGEMENTS

This article was developed within the scope of the “Agenda/Alianças Verdes para a Inovação Empresarial” by the Consortium “Embalagem do Futuro |+ ECOLÓGICA + DIGITAL + INCLUSIVA” co-financed by NextGenerationEU.

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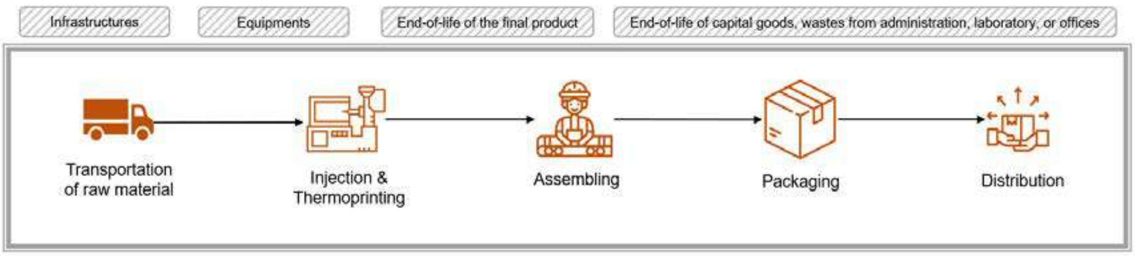

Figure 1. System boundaries for the production and distribution of one transportation box.

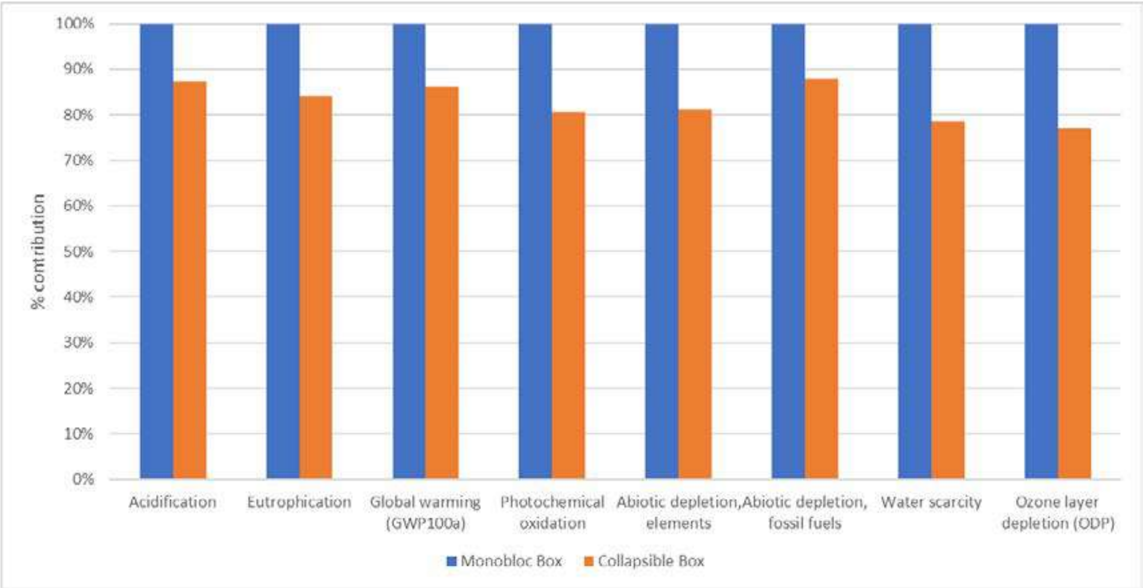

Figure 2. Environmental impacts (%) obtained by impact category for the options under study by FU (production and distribution of one transportation box).

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Life Cycle Assessment comparing conventional and active packaging for fresh-cut salads.

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1. INTRODUCTION

Sustainable packaging emerges as a solution to reduce Food loss and waste (FLW) by up to 14% and retail waste by 17% (Programme, 2021). In LCA on packaging, is examining the manufacturing and end-of-life management, nevertheless, it is important to include the food product itself in the scope (Molina-Besch et al., 2019). The LCA community increasingly emphasizes the application of this methodology during the initial stages of product Research, Development, and Innovation (RDI), known as ex-ante perspective LCA (Sampaio et al., 2023). This work examines the implications of FLW within agri-food systems and end-of-life packaging for fresh-cut salads using ex-ante LCA, comparing conventional packaging (CP) and active packaging (AP) designed to extend product shelf life.

2. METHODS

The packaging examined was used for fresh-cut salad. CP used polypropylene (PP) film, while AP involved a coating of copolymer (EVOH) with oregano essential oil (OEO) on the same PP film. This LCA study, conducted using SimaPro® 9.1.1.1 Ph.D., applied the ReCiPe 2016 Midpoint (H) V1.04 for impact assessment, with impact categories shown in Figure 2. The functional unit (FU) was set as "1 kg of packaging film for salad," with each package containing 250 g. AP extended the shelf life of fresh products from 7 days with CP to 10 days. The system boundaries for the inventory analysis encompassed the production phases of fresh products and the manufacturing of packaging, illustrated in Figure 1. The study quantified food loss reduction by comparing salad packaged over 70 days using CP and AP, which extends shelf life, thereby minimizing waste generation.

3. RESULTS AND DISCUSSION

Evaluation of the indicators shows a notable 40% to 60% reduction in impacts with AP, indicating decreased environmental damage from fewer packaging units and reduced salad production (**Figure 2**). Salad production makes a substantial contribution to impact categories, due to the larger quantities produced and waste generated. The extended shelf life provided by AP signifies a reduction in the volume of product needs and minimizes damage incurred throughout the product's lifecycle processes (Villanova-Estors et al., 2023). A comparative analysis to evaluate the end-of-life for salad (Scenario 1 corresponds to: Landfill disposal 8%, Energy recovery 22%, Composting 70%; the Scenario 2 to 100% Landfill disposal and Scenario 3 to 100% Composting), revealed that across all analyzed scenarios, AP demonstrated superior performance (**Figure 3**), the result evidenced by significantly lower scores of AP in comparison to CP. In each of the categories, the AP had lower values that are associated with the lowest amount to be disposed of in the period analyzed.

4. CONCLUSIONS

Long-term analysis shows that AP reduces adverse effects on human health, ecosystems, and resources. Recycling and composting at end-of-life can improve system performance. AP significantly mitigates food loss, promoting better food production and waste management. Optimizing AP design through material selection, durability, recyclability, energy efficiency, and waste reduction enhance sustainability.

5. ACKNOWLEDGEMENTS

FUSILLI project. European Union's Horizon 2020 No. 101000717. University of Valladolid predoctoral contracts co-financed by Banco Santander.

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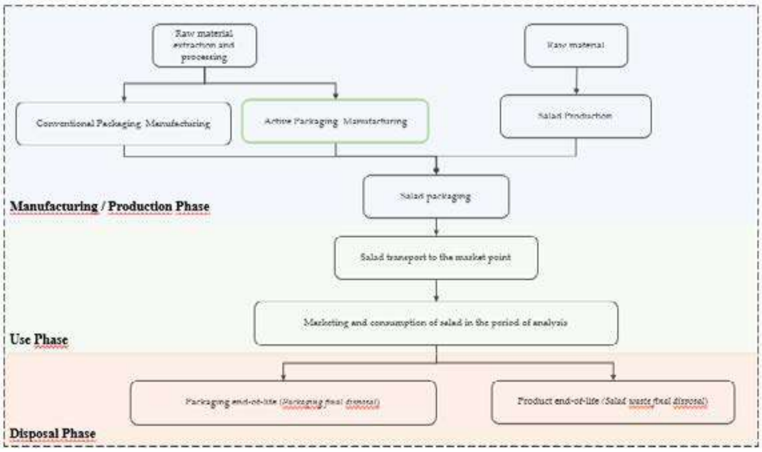

Figure 1. System boundaries of the LCA

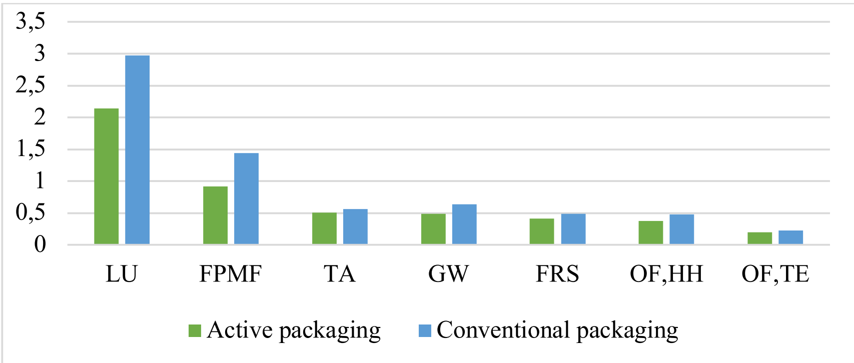

Figure 2. Comparison between the environmental impact of Active Packaging vs Conventional Packaging

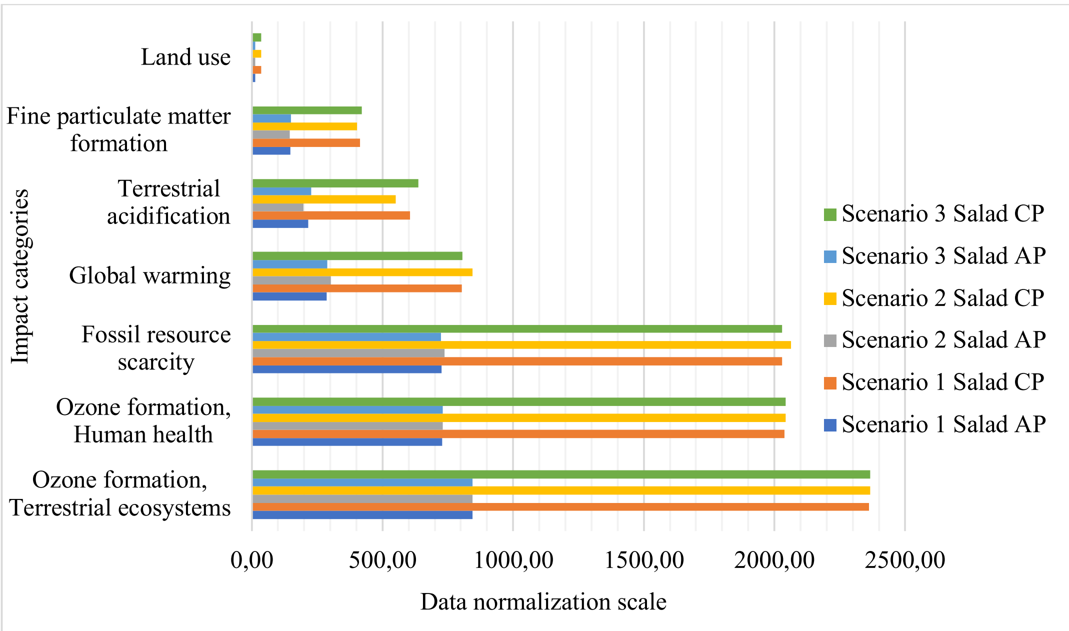

Figure 3. Salad end-of-life analysis

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Integrated Assessment of E-LCA and S-LCA based on a techno economic assessment of side stream valorization in the brewery industry

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1. INTRODUCTION

Today agricultural residues and side streams are often not valorised and still considered as a waste. A high potential to produce high value-added products lies in using residues and side-streams from beer production: in Europe, 34 billion litres of beer were produced in 2021 and each cubic metre of beer produces 0.2 ton of brewer's spent grain and other substances as CO_2, yeast, wastewater etc. Within the Horizon Europe Project "CHEERS", the side streams of beer production are transformed with innovative biorefinery technologies into five bio-based products. One output of this biorefinery involves utilizing brewer's spent grain as feed for mealworms (*Tenebrio molitor larvae*) to produce protein flour. The other four products are created by microbiological processes using carbon dioxide and methane from the anaerobic digestion of wastewater (Figure 1).
This research strives for a comprehensive life cycle sustainability assessment (LCSA) quantifying environmental, social, and economic impacts of the biorefinery established in a Spanish brewery in Europe. By taking a holistic perspective, LCSA aims to identify potential hotspots, trade-offs, and synergies across different life cycle stages and sustainability dimensions.

2. METHODS

The entire production system is examined in a screening based on the techno-economic assessment (TEA) for the environmental life cycle assessment (E-LCA) and the social life cycle assessment (S-LCA). For this purpose, the following methods are used:

An E-LCA covers categories of the environmental footprint impact assessment method, such as greenhouse gas emissions, energy demand, biodiversity, water footprint, and resource depletion. A particular focus is on conducting a life cycle biodiversity impact assessment, which aims to measure the project's impacts on biodiversity in industrial sites and supply chains. The S-LCA evaluates socio-economic benefits following the "Guideline for Social Life Cycle Assessment of Products and Organizations 2020" (UNEP, 2020). It is conducted using the product social impact life cycle assessment (PSILCA) method. This assessment considers the social risks and opportunities and the positive impacts for five stakeholder groups along the entire life cycle of the products.

3. RESULTS AND DISCUSSION

The results demonstrate the integration of the independently conducted TEA, E-LCA, and S-LCA into a comprehensive framework. The combination is carried out using a qualitative approach, such as expert assessment and multi-criteria analysis. This approach still allows to see the strengths of each assessment method considering their individual perspectives, uncertainties, and limitations and showing the relevance of upstream processes like agricultural production, while recognizing the interconnections among the three sustainability dimensions. The other integration options like a) TEA with environmental externalities & social externalities and b) TEA as basis, social impacts based on (minimal) wellbeing, environmental impacts as limitations for the solution space are discussed.

4. CONCLUSIONS

The greatest challenge for the evaluation is the integration of the results from the economic, social, and ecological dimensions, with particular attention to the high dependency of the results on the allocation decisions. The results are significantly influenced by the choice of the allocation method. It is crucial whether the cutoff approach or economic allocation is chosen. This initial assessment serves to identify the most relevant hotspots in the analyzed value chains and to explain the possibilities of extending the conclusions to valorization strategies in other foods productions.

5. ACKNOWLEDGEMENTS

CHEERS

Producing novel non-plant biomass feedstocks and bio-based products through upcycling and the cascading use of brewery side-streams

Funded by the European Union

"This project has received funding from the European Union's Horizon Europe Research and Innovation programme under Grant Agreement No 101060814"

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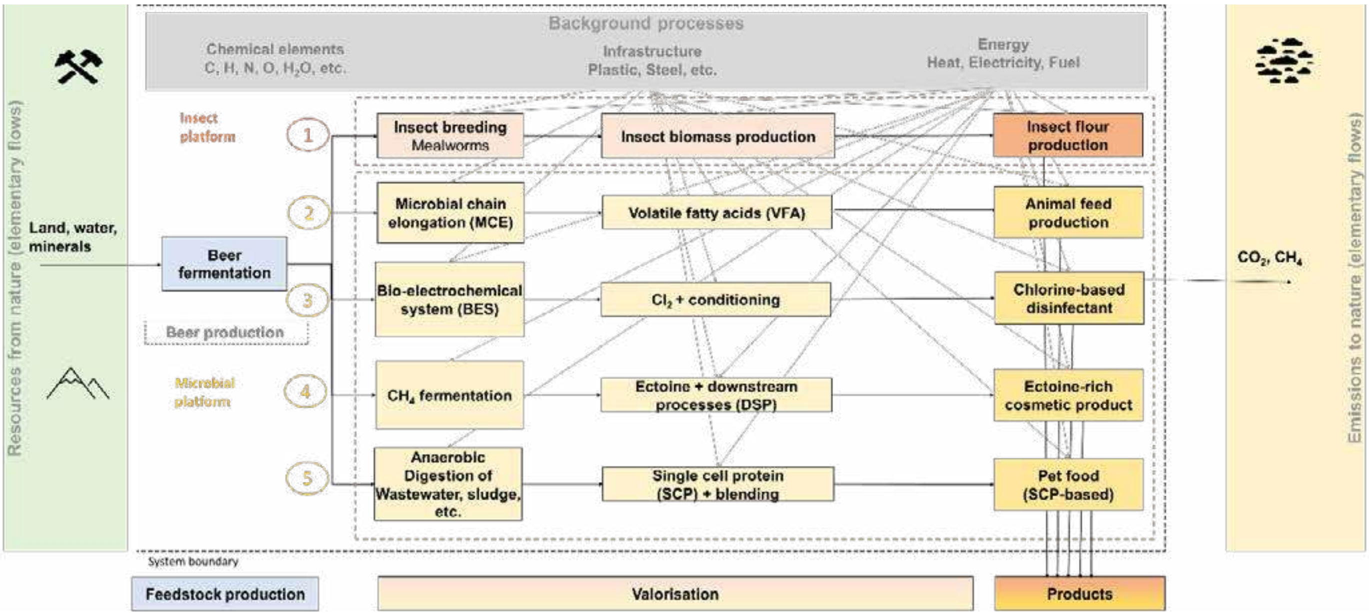

Figure 1. System boundaries of beer production with its valorised side streams.

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Technical and Environmental Assessment of Mushroom Production and its Inputs

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1. INTRODUCTION

There has been a considerable rise in cultivated edible mushroom production worldwide since 1997 (Royse et al., 2017), with mushrooms now a major component of diets worldwide. Button mushroom (*Agaricus bisporus*) production accounts for about 11% of total production worldwide (4.73 million tonnes) with significant production in China, Europe and the USA (Singh et al., 2020). This research conducts an LCA on (i) the production of mushroom substrate, (ii) the production of *A. bisporus* mushrooms and (iii) differing packaging approaches. Substrate ingredients can have an impact on emissions, for example, through the source of ingredients or the storage condition of manure (Dunkley and Dunkley, 2013). While packaging technology has a known impact on shelf life in retail and home settings (Zhang et al., 2018), making it a potentially significant contributor to the environmental impact.

2. METHODS

This LCA uses a combination of primary data collected through growth and packaging trials and data collected directly from producers. The production of substrate, mushrooms, and packaging stages of the mushroom supply chain are included in the system boundary for the functional unit of 1 kg of packaged mushrooms (Figure 1). SimaPro® v.9.5 was used for LCI and LCIA. The impact assessment method selected is ReCiPe midpoint (H). Mushroom growth trials of 6 weeks duration were carried out at Teagasc (Dublin, Ireland) in a small-scale commercial mushroom unit with different packaging types: polypropylene (PP, as industry standard), recycled PET (rPET) or compostable material.

3. RESULTS AND DISCUSSION

A preliminary scenario for mushroom production suggests that the pre-farm stage contributes highly to the impact categories assessed e.g. global warming potential (GWP), terrestrial acidification, freshwater eutrophication, fossil resource scarcity. Mushroom substrate inputs such as wheat straw and supplement are high contributors to pre-farm stage GWP impact (Figure 2). Mushroom substrate production involves composting and pasteurisation which generate gaseous emissions such as nitrous oxide and methane that have a high impact in the GWP category. The mushroom production, i.e. on-farm, and packaging stages mostly had a lower impact (16.9% and 7.7%, respectively). Although, other studies of *A. bisporus* have emphasised the on-farm processes as high contributors to overall GWP (Leiva et al., 2015; Robinson et al., 2019).

4. CONCLUSIONS

This study presents the preliminary work in the generation of a life cycle for *A. bisporus* production including novel packaging types. The scenario indicates that the pre-farm stage accounts for greater GWP than on-farm or post-farm stages. Further work is being undertaken to gather data on substrate production and packaging as part of the mushroom production cycle, in order to reflect current industry practices as accurately as possible and inform the environmental profile of *A. bisporus* production. Further analysis will include a comparison of the different packaging types in terms of their impact at extending the shelf life and the different end-of-life scenarios. The LCA model will be updated accordingly with new data.

5. ACKNOWLEDGEMENTS

We would like to acknowledge Science Foundation Ireland for funding this project (grant number 20/FIP/FD/8934P). We acknowledge the technical assistance of the Horticulture Development Department and the Food Industry Development Department at Teagasc, as well ESHI at TU Dublin for growing, harvesting, packaging and assessment of the mushroom crop.

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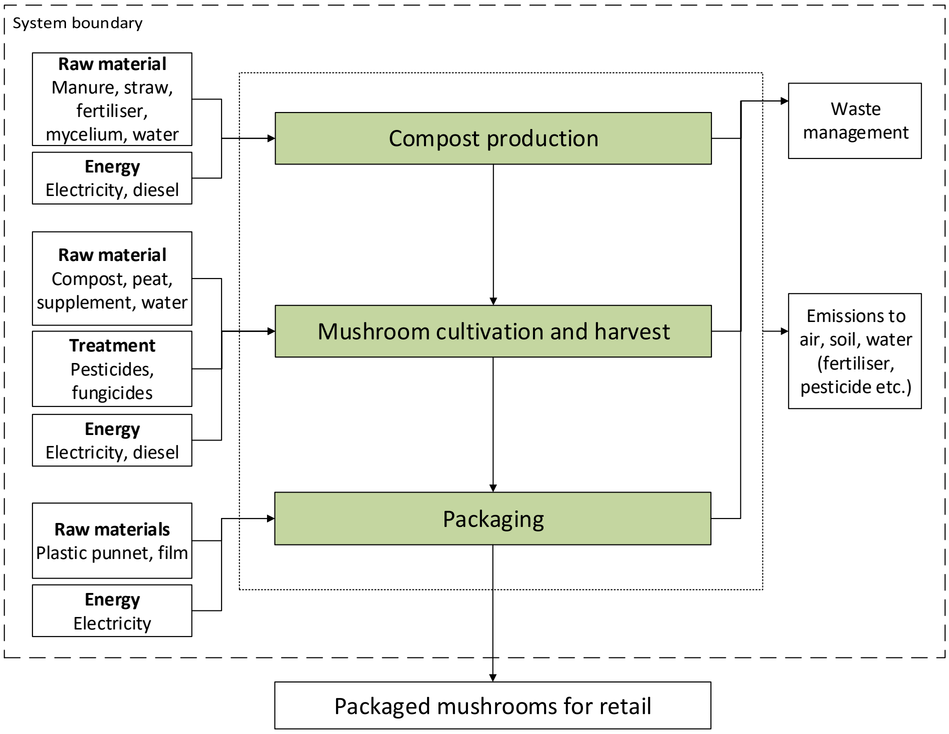

Figure 1. Mushroom cultivation schematic with system boundary for study

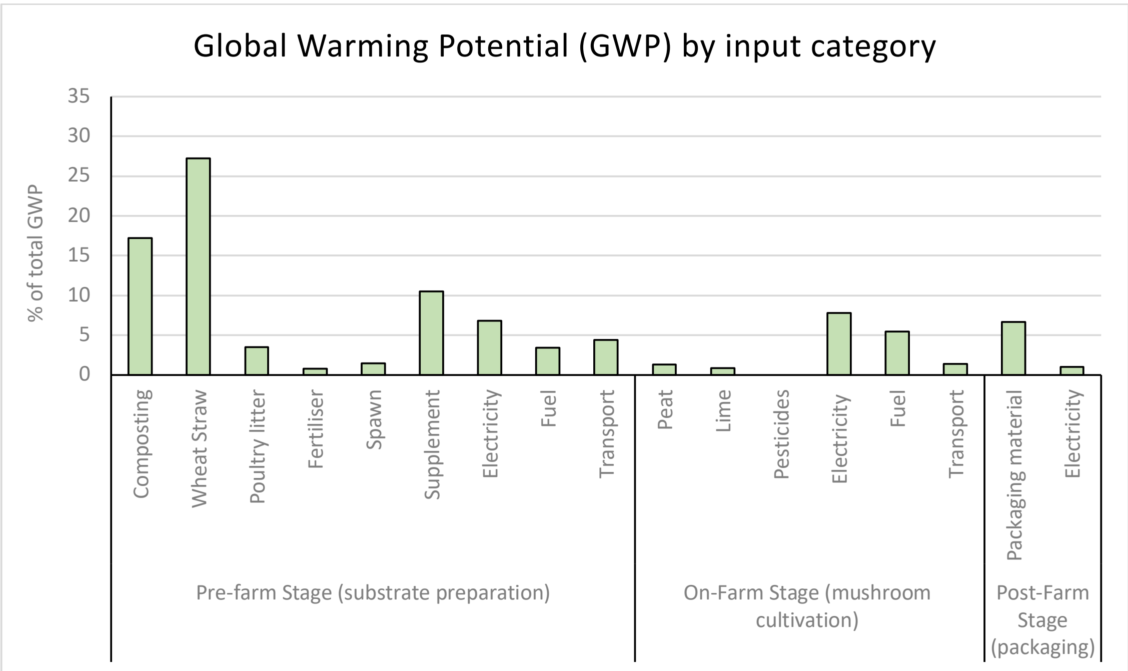

Figure 2. Global Warming Potential (as % of total GWP) of mushroom life cycle by input category

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Life cycle assessment of processed peas, lentils, and beans products in Canada

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1. INTRODUCTION

Pulses, which include lentils, chickpeas, dry peas, and beans, have become increasingly popular due to their nutritional benefits and environmental sustainability attributes. Certain regions of the Canadian prairie (i.e., Alberta, Saskatchewan, Manitoba) provinces are conducive to the production of different pulses (Getty, 2021). Along with whole pulses, different processed products like flour, protein, starch, and fiber are also in demand. With 2.3 million vegetarians and around 850,000 vegan people, the market for pulse-based products is predicted to grow substantially in Canada. These pulse-based products are good alternatives to animal-based products due to their sensory quality attributes, high protein, nutrient, mineral, and vitamin contents and lower environmental impacts (Peoples et al., 2019). Numerous studies support the lower environmental impacts of pulse production and consuming pulses instead of animal-based products. However, it is still unclear whether processing these pulses in the industry to produce flour, protein, starch, and fiber is environmentally sustainable or not. Life cycle assessment (LCA) was hence used to quantify the impacts in numerous environmental categories for the 'cradle-to-processing facility gate' system boundary.

2. METHODS

An ISO 14044 LCA has been undertaken for different pulse products – whole pea flour, split pea flour, split pea grit, pea hull fiber, pea fiber bran (for pets), lentil flour, lentil grit, tempered lentil flour, navy bean flour, navy bean grit, black bean grit, and tempered navy bean flour. Primary data for processing these pulse products were collected from Avena Foods for their Rowatt, Saskatchewan and Portage la Prairie, Manitoba facilities. The LCA study adopted a 'cradle-to-processing facility gate' system boundary (extraction of raw materials, transportation from farm/supplier, and processing in facilities) and functional unit was 1 kilogram of final product. For the background models of pulse production, the high-resolution, regionalized pea, lentil, and bean production models produced at the Food Systems PRISM Lab at the University of British Columbia Okanagan were utilized, which were developed based on the primary data collected from Canadian pulse farmers (Bamber et al., 2022, 2024).

3. RESULTS AND DISCUSSION

The IMPACT World+ method has been used to identify the impacts on 18 impact categories and a mass-based allocation procedure was adopted. For example, the impact assessment results for whole pea flour, lentil flour, and navy bean flour are presented (
Table *1*). Also, the contribution of different unit processes for climate change (long-term) impact category is illustrated (

Table 2). From the analysis, it can be said that the production of pulses is the main contributor unit process, followed by transportation from Saskatchewan to the Manitoba facility, and processing stages (i.e., cleaning, grinding) are not very energy intensive and less impactful unit processes.

4. CONCLUSIONS

Using regionalized high-resolution LCA models for pulse production is one of the main strengths of this study. Another strength is the employment of industry-specific data for the processing stages. This study highlights Avena Foods' sustainable processing techniques.

5. KEYWORDS

Processed pulse products; IMPACT World+; regionalized pulse production models

6. ACKNOWLEDGEMENTS

This work has been funded by Avena Foods.

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Table 1. Impact assessment results of whole pea flour, lentil flour, and whole navy bean flour

Impact Categories	Units	Whole Pea Flour	Lentil Flour	Navy Bean Flour
Climate change (long term)	kg CO_2 eq	1.81E-1	2.14E-1	4.47E-1
Climate change (short term)	kg CO_2 eq	1.86E-1	2.20E-1	4.58E-1
Fossil and nuclear energy use	MJ	2.88	3.28	4.27
Freshwater acidification	kg SO_2 eq	6.58E-15	9.50E-15	1.82E-14
Freshwater ecotoxicity	CTUe	8.48E+2	9.58E+2	1.78E+3
Freshwater eutrophication	kg PO_4 P-lim e	6.72E-5	1.34E-4	7.08E-6
Human toxicity cancer	CTUh	7.29E-9	8.07E-9	1.16E-8
Human toxicity non-cancer	CTUh	3.12E-8	3.91E-8	4.45E-8
Ionizing radiations	Bq C-14 eq	1.26	1.46	2.01
Land occupation	m^2 arable land eq.yr	1.18E-2	1.47E-2	4.74
Land transformation	m^2 arable land eq	6.37E-5	7.01E-5	8.62E-5
Marine eutrophication	kg N N-lim eq	1.51E-5	2.64E-5	1.05E-4
Mineral resources use	kg deprived	3.02E-3	3.60E-3	4.65E-3
Ozone layer depletion	kg CFC-11 eq	3.81E-8	4.62E-8	5.05E-8
Particulate matter formation	kg PM2.5 eq	9.87E-5	1.42E-4	3.51E-4
Photochemical oxidant formation	kg NMVOC eq	7.49E-4	8.67E-4	1.08E-3
Terrestrial acidification	kg SO_2 eq	4.59E-9	7.33E-9	2.10E-8
Water scarcity	m^3 world-eq	3.47E-1	3.95E-1	4.66E-1

Table 2. Contribution of different unit processes (%) for whole pea flour, lentil flour, and whole navy bean flour for Climate Change (long-term) impact category

Unit Processes	Whole Pea Flour	Lentil Flour	Navy Bean Flour
Pulse production	39.5	50.5	69.8
Transportation to SK facility	4.75	2.41	7.69
Cleaning	2.2	1.9	0.9
Transportation to MB facility	44.3	37.5	17.9
Grinding	9.1	7.7	3.7

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Carbon Footprint of Pasteurized Foods: A Case Study on Salmorejo Production

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1. INTRODUCTION

According to FAO, 16.5 billion tonnes of greenhouse gases (GHG) were emitted from agri-food systems in 2019 (United Nations, 2021). Although most of these emissions are produced at the farm, processing is also responsible, as concerns energy-intensive processes such as pasteurisation or drying. Different alternatives are stemming to reduce food production's resources costs, such as pasteurisation with radiofrequency (RF). S*almorejo* is a traditional Spanish food that consists of a soup of tomato, bread, vinegar, olive oil and garlic, whose industrial production is rising and implies pasteurization. In this paper, a carbon footprint (CFP) analysis of *salmorejo,* focused on changes at the processing stage, is performed. To this aim, different technological options that companies could use in their production process are considered. To do so, the likely scenarios are designed.

2. METHODS

Calero et al. (2022) estimated the impacts of RF vs conventional pasteurisation for *salmorejo*. In this study, we extend the analysis to consider different packaging alternatives (liquid packaging board (LPB), PET or recycled PET (rPET)), the use of natural gas vs. solar energy for heat production, and current (Base EoL) and future (Imp EoL) waste treatment, and these imply 24 scenarios (Table 1). The functional unit (FU) is 1 kg *salmorejo*, the system boundaries are set from cradle to grave, and the CFP is calculated using the Recipe 2016 v1.1 Midpoint (H) (Huijbregts et al., 2016). Figure 1 shows the diagram of the process.

3. RESULTS AND DISCUSSION

The CFP of the assessed scenarios range from 0.347 kg CO_2-eq/FU to 0.478 kg CO_2-eq/FU in scenario 6 and 21 respectively (Figure 2). In scenario 6, PET packaging generates 0.149 kg $CO_{2\text{-eq}}$/FU, whereas using LPB and rPET emits 0.101 kg CO_2-eq/FU. However, the end-of-life of PET and rPET decreases the CFP at -0.026 and -0.106 kg $CO_{2\text{-eq}}$/FU (negative for avoided loads) in Base EoL and Imp EoL, respectively. On the one hand, in the RF pasteurisation process, the equivalent emissions are 1.2E-6 kg $CO_{2\text{-eq}}$/FU in solar and non-solar. On the other hand, in conventional pasteurisation are 0.003 and 0.006 kg $CO_{2\text{-eq}}$/FU in solar and non-solar, respectively. Regarding the contribution of the CFP (Table 2), ingredients production dominate in all the scenarios. The packaging represents from 22.1% to 37.7% of the total CFP. It is worth mentioning the end-of-life stage, with a negative contribution (-30.5%) or near 0% due to the avoided loads resulting from the materials' recovery.

4. CONCLUSIONS

This paper assessed the CFP of *salmorejo* with different processing alternatives. RF does not significantly influence the CFP compared to conventional pasteurisation. Regarding the packaging, virgin PET is the most polluting, while rPET proved to be the best option tested. In the case of LPB, GHG equivalent emissions fall between PET and rPET. To support decision-making, the present work should be complemented with an economic analysis.

5. ACKNOWLEDGEMENTS

This study forms part of the PRIMA 2021 programme and was supported by MCIN funding from the European Union Plan de Recuperación Transformación y Resiliencia (PCI2022-132972) and the Spanish Ministry of Science, Innovation and Universities through the project RF-SUSVEG (RTI2018-098052-R-C31)

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Table 1. Combination of the different scenarios in the *salmorejo* production.

		RF pasteurisation			Conventional pasteurisation		
		LPB	PET	rPet	LPB	PET	rPet
Solar	Base EoL	Scenario 1	Scenario 3	Scenario 5	Scenario 13	Scenario 15	Scenario 17
	Imp EoL	Scenario 2	Scenario 4	Scenario 6	Scenario 14	Scenario 16	Scenario 18
Non-Solar	Base EoL	Scenario 7	Scenario 8	Scenario 9	Scenario 19	Scenario 21	Scenario 23
	Imp EoL	Scenario 10	Scenario 11	Scenario 12	Scenario 20	Scenario 22	Scenario 24

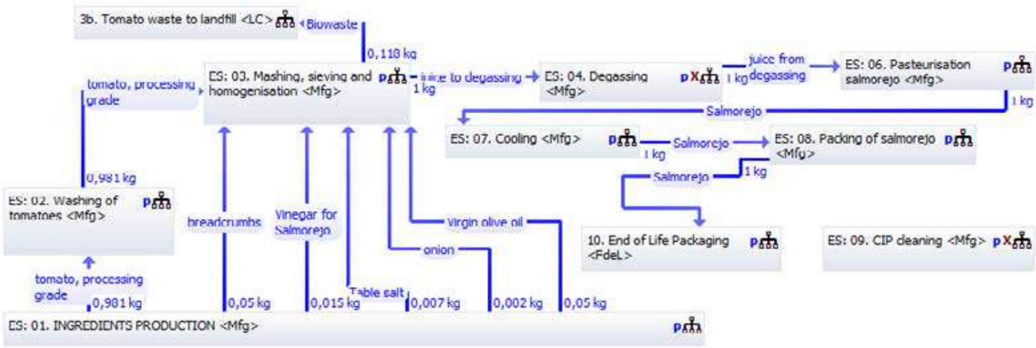

Figure 1. Process scheme.

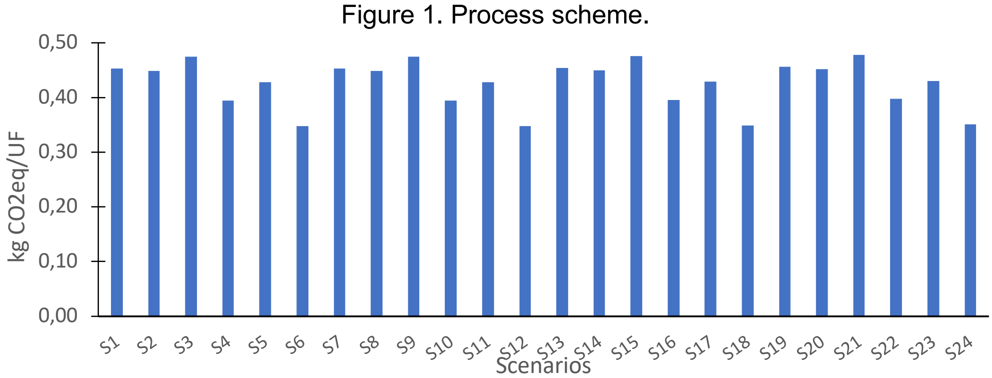

Figure 2. Cradle to grave CFP of *salmorejo* scenarios.

Table 2. Contribution analysis of the stages of *salmorejo* production

Process	Minimum (%)	Maximum (%)	Process	Minimum (%)	Maximum (%)
Ingredients production	52.7	72.5	Pasteurisation *salmorejo*	2.62E-04	0.8
Washing of tomatoes	0.5	0.6	Cooling post-pasteurisation	1.2	1.6
Mashing, sieving and homogenisation	0.6	0.8	Packaging of *salmorejo*	22.1	37.7
Tomato waste to landfill	12.5	17.3	CIP cleaning	0.4	0.6
Degassing	5.8	8.0	End of Life Packaging	-30.5	0.1

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Promoting Food Safety and Sustainability through the revalorization of a winery by-products in fermented Sausages

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1. INTRODUCTION

The revalorization of food processing by-products not only reduces the environmental impact of their disposal, but also generates added economic value. Cava lees are a winery by-product consisting of non-viable cells of *Saccharomyces cerevisiae*, which are rich in fiber and phenolic compounds[1].

Lees are currently the second most important by-product generated by the cava industry, with an estimated production of approximately 200 tons per year[2]. From the circular economy approach, these by-products of the wine industry could be recycled, reused or recovered, thus improving the economic and environmental sustainability of winemaking activities. A new strategy for revaluation of cava lees could consist on its addition in the formulation of certain fermented foods as an ingredient with application in food safety. Their richness in ß-glucans and mannan-oligosaccharides could lead to a better implantation of bacteria responsible for fermentation and a higher and faster reduction in pH, which would ultimately reduce the risk of foodborne pathogens in products such as dry-fermented sausages. In addition, the lees contain bioactive substances present in cava, such as phenolic compounds, which could also exert or enhance this antimicrobial effect.

In this framework, the aim of the present study was to assess the effect of cava lees on the behaviour of technological microbiota (lactic acid bacteria (LAB) used as a starter culture) and the foodborne pathogens *Salmonella* spp. and *Listeria monocytogenes* during the fermentation and ripening of dry fermented sausages using a challenge test. Moreover, it was investigated whether the use of lees can help to control biogenic amine formation in this fermented product.

2. METHODS

Ten batches of fermented sausages were prepared with and without cava lees, and with or without a selected stater culture (*Latilactobacillus sakei* CTC494). Meat batter was inoculated with a mixture of three *L. monocytogenes* and three *Salmonella* strains at a level of ca. 6 log10 CFU/g. All batches were submitted to a process of fermentation (2 days at 23°C) and drying (19 days at 15°C). Along the process, the pH and a_w were monitored; LAB and pathogens were enumerated on MRS and selective chromogenic agar. The biogenic amine content was analyzed by UHPLC-FL[3].

3. RESULTS AND DISCUSSION

Previous in vitro studies showed that the addition of 5% lees produced a growth-promoting effect of on certain *Latilactobacillus* strains, in a dose- and strain-dependent manner. In dry fermented sausages, the addition of 5% lees resulted in greater acidification of the meat batter, and pH remained below the control sausages throughout the fermentation and ripening process (Fig. 1). However, no effect on spontaneous LAB or the starter culture was observed (Fig. 1).

Regarding the antimicrobial effect of lees against foodborne pathogens in dry fermented sausages, this by-product significantly prevented the growth of *Salmonella* and *L.monocytogenes*, with an effectiveness similar to that obtained when the starter *L. sakei* CTC494 was added (p<0.05) (Fig. 2). In addition, the combination of cava lees and the starter culture had a synergistic and bactericidal effect against *Salmonella*. The addition of cava lees to dry fermented sausages significantly reduced the contents of cadaverine and putrescine throughout the ripening process, with reduction percentages in the finished product of over 60% (p<0.05) (Fig. 3).

4. CONCLUSIONS

The revalorisation of cava lees as a natural ingredient to improve the microbiological safety of fermented sausages is a potential strategy that would promote a circular economy.

5. ACKNOWLEDGEMENTS

The authors thank the project AGL2016-78324-R (CICYT) and the INSA Maria de Maeztu Unit of Excellence grant (CEX2021001234-M) funded by MICIN/AEI/FEDER, UE.

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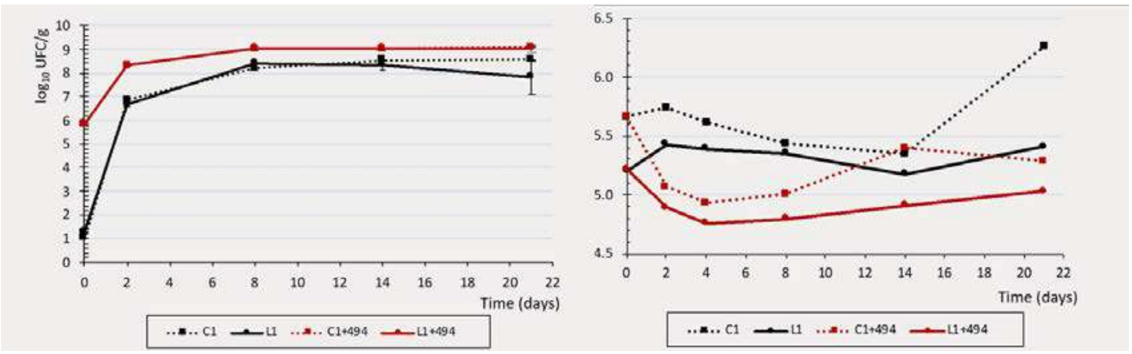

Figure 1. Growth of LAB (left) and pH values (right) in spontaneously fermented sausages with (L1) or without (C1) the addition of 5% of cava lees or fermented with the starter culture *L. sakei* CTC494, with (L1 + CTC494) or without (C1 + CTC494) cava lees.

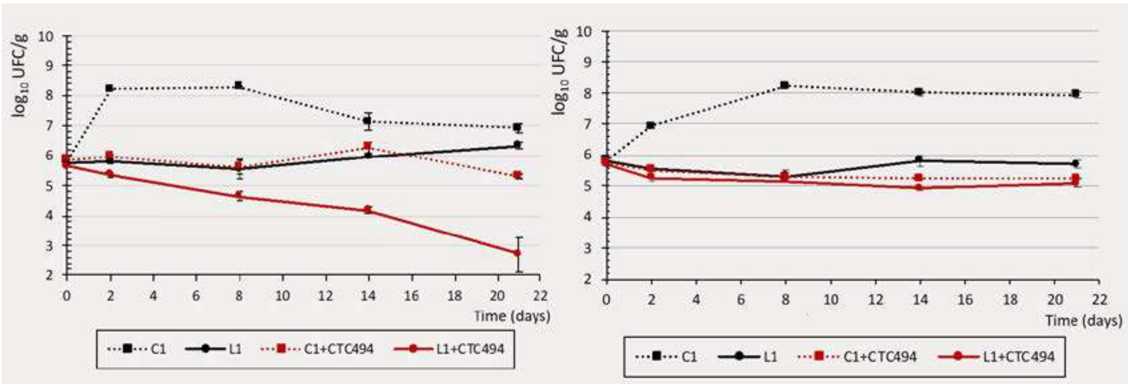

Figure 2. Counts of *Salmonella* (left) and *L. monocytogenes* (right) strains in pork dry fermented sausages spontaneously fermented with (L1) and without (C1) the addition of 5% of cava lees or fermented with the starter culture *L. sakei* CTC494 with (L1+ CTC494) or without (C1+ CTC494) lees.

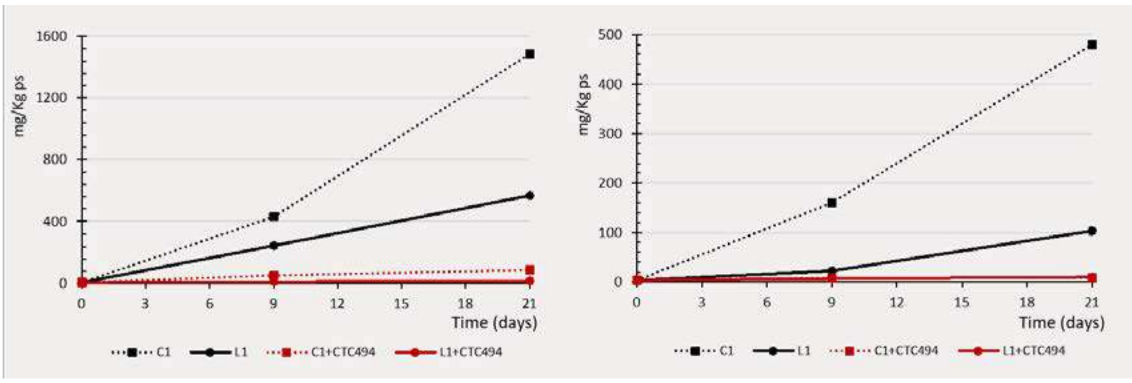

Figure 3. Cadaverine (left) and putrescine (right) contents in spontaneously fermented sausages with (L1) or without (C1) the addition of 5% of cava lees or fermented with the starter culture *L. sakei* CTC494, with (L1 + CTC494) or without (C1 + CTC494) cava lees.

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Environmental assessment of multilayer flexible coffee packaging: Italian case study

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1. INTRODUCTION

The paper explores a LCA study comparing the environmental impact of different flexible packaging for 250g of ground coffee. European Commission aim to limit plastic usage and promote recycling. The solution adopted is a transition from multimaterial to monomaterial multilayer structure. This work, supported by Goglio SpA (https://www.goglio.it), has the ultimate goal of finding a trade-off between barrier properties and environmental impacts.

2. METHODS

The functional unit is "packaging for 250g of ground coffee", thus, the weight of the packaging itself serves as reference flow. The study is an attributional LCA "cradle-to-gate-with-end-of-life", according to PCR for packaging [1]. Three structures are analyzed: **Standard** (PET[2]/Al/PE[3]), **MonoPE** (PE/PE-EVOH[4]), and **MonoPP** (PP/mPP[5]/PP). The system boundaries encompass the entire life cycle, from material extraction to end-of-life, excluding coffee production, and usage phases. Primary data, including raw materials, packaging stratigraphy, and energy demand are provided by Goglio S.p.A. Indeed, secondary data are sourced from the Ecoinvent v3.7.1 database. Furthermore, most of primary data are provided on annual basis, consequently a mass allocation method was employed. The Environmental Footprint Method 3.0 is used for impact assessment with the support of SimaPro software.

2.1 End of Life

The end-of-life phase involves collection, sorting, and disposal, in particular mechanical recycling (with previous delamination in case of Standard), incineration with energy recovery, and landfill options are considered. The information required to construct the model for mechanical recycling and delamination is sourced from [2] and [3], respectively. Credits have been given for recycling. Three end-of-life (EoL) scenarios are formulated, based on PlasticsEurope [4] report and reflecting the objectives of CEAP [5] and PPWR [6]. Scenario 2022 represents the current situation, Scenario 2030 anticipates advancements in infrastructure and technology, while Scenario 2035 aligns with "recyclable at scale"[6] goal for all packaging.

3. RESULTS AND DISCUSSION

In Figure 1, the results of the impact assessments for Scenario 2022 are presented for all impact categories. Monomaterial packaging have lower impacts in 14 out of 16 categories compared to the Standard one; in terms of the carbon footprint, there is about a 40% reduction. The Standard packaging slightly outperforms MonoPE and MonoPP in only "water use" and "land use" impact categories. Figure 2 (left) provides a detailed analysis of the percentage contribution to each impact category for the main stages of the packaging's life cycle. Figure 2 (right) illustrates the percentage reductions across three proposed scenarios for MonoPE, emphasizing the effectiveness of recycling within a circular economy. In Figure 3, a trade-off is presented, the single score in µPt (normalization as defined in the Environmental Footprint 3.0 methodology) versus barrier properties (OTR and WVTR). It highlights the environmental benefits and performance limitations of transitioning from a multimaterial to a monomaterial structure. Low barrier levels reduce shelf life, increasing food losses and environmental impact. This aspect has not been studied yet but will be part of future analysis.

4. CONCLUSIONS

The current use of multimaterial multilayer packaging poses challenges for mechanical recycling. The article emphasizes the growing trend toward monomaterial packaging, which is designed for recycling. The proposed LCA study compares a multimaterial structure (Standard) with two monomaterial structures (MonoPE and MonoPP) to evaluate environmental impacts. The Scenario 2022 results reveal significant environmental benefits, reducing impacts in 14 out of 16 categories compared to the Standard. In the ultimate trade-off between sustainability and packaging performance (Figure 3), the outcome indicates that MonoPP stands out as the optimal choice among the three proposed.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Goglio S.p.A. for the provision of data.

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[2] **PET**=polyethylene terephthalate, Ecoinvent unit process: Polyethylene terephthalate, granulate, amorphous {RER}| production | Cut-off, U

[3] **PE**= polyethylene, Ecoinvent unit process: Polyethylene, low density, granulate {RER}| production | Cut-off, U

[4] **EVOH**=ethylene vinyl alcohol, Ecoinvent unit process: Ethylene vinyl acetate copolymer {RER}| production | Cut-off, U (Proxy)

[5] **PP**=polypropylene, mPP stands for metallized polypropylene, Ecoinvent unit process: Polypropylene, granulate {RER}| production | Cut-off, U

[6] **Recyclable at scale** means that at least 75% of plastic packaging put on the market has to be recycled

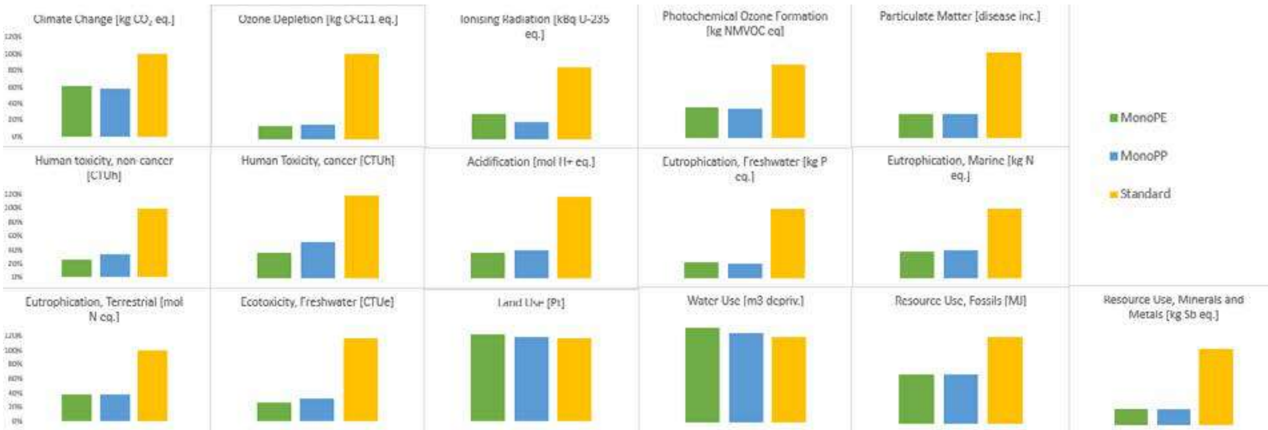

Figure 1. Percentage comparison of the environmental footprint of the 3 structures, in Scenario 2022

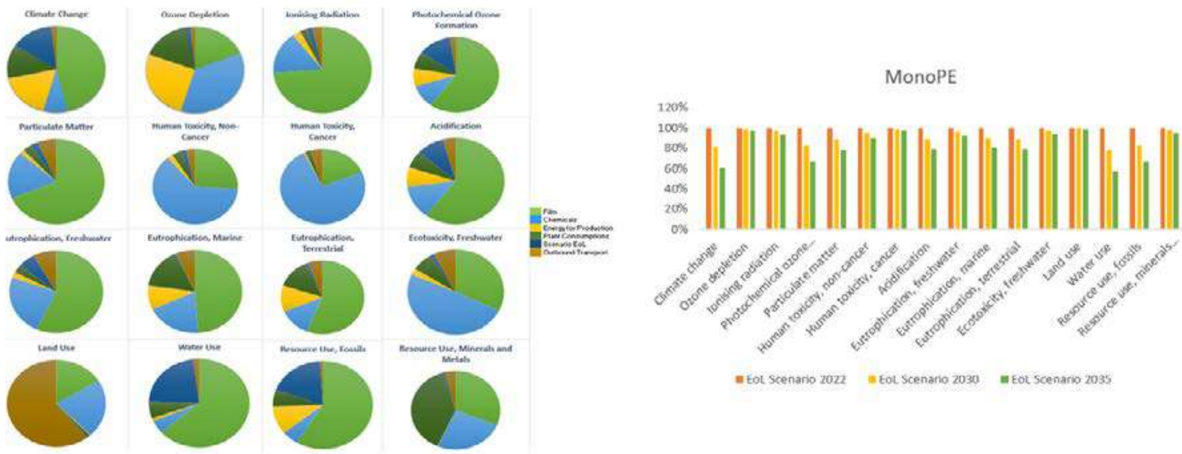

Figure 2.
Percentage contribution of the main stages (left). End-of-life scenario impact (MonoPE) (right)

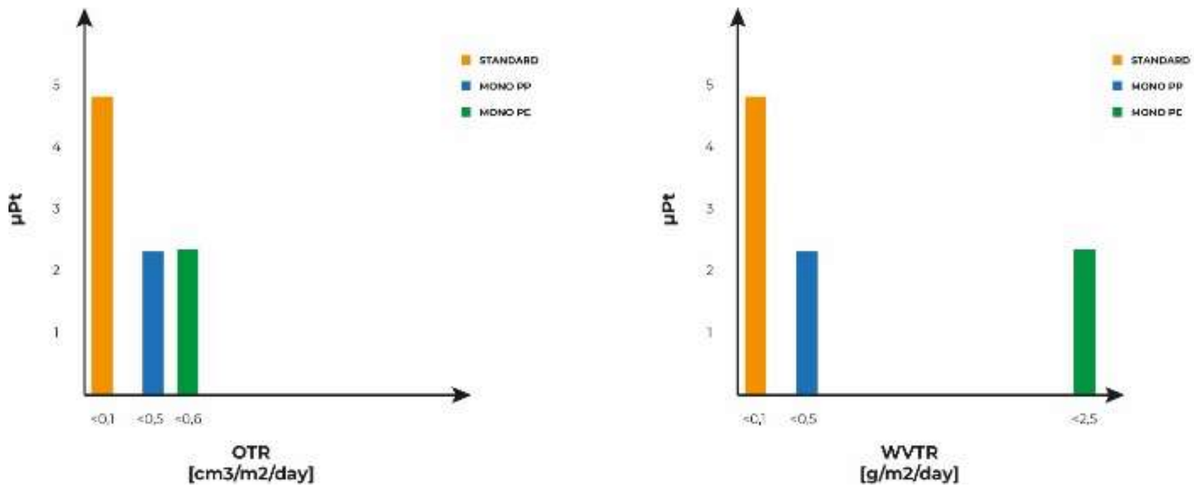

Figure 3. Trade-off between sustainability (in µPt) and barrier performance (Oxygen Transmission Rate (OTR) and Water Vapor Transmission Rate (WVTR)) for all 3 packaging versions

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Design of a sustainable product in gastronomy: integrating LCA and consumer-centered design

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1. INTRODUCTION

Gastronomy is an area of knowledge with the potential to promote the transition towards a more sustainable food system thanks to its ability to influence food production and people's eating habits. In the context of new food product development, consumer-centered design (CCD) is a methodology that places the end consumer at the center of the various stages of the product design and development process to meet their demands and expectations (van Kleef et al., 2005). On the other hand, life cycle assessment (LCA) is a useful tool when designing products from an environmental point of view. Due to the potential of these methodologies to boost product acceptance and sustainable product design, the aim of this project is to propose a methodology that integrates LCA and CCD to optimize the design and development process of new products from an environmental and sensory perspective. The design of a new food product is presented as a case study: a hot sauce based on green chili discards.

2. METHODS

Different qualitative and quantitative research methodologies were used for product conceptualization: (i.) Focus groups and interviews with stakeholders from the food value chain were conducted to identify demands related to local food and potential innovative products of interest from a sustainability perspective. (ii.) Notions of the creative process for the design of three product prototypes to meet previously identified demands. (iii.) Discriminative techniques of sensory analysis to select one of the prototypes. (iv.) LCA was used to design an improved version of the selected prototype. For this purpose, the CML-IA baseline 3.07 midpoint method was applied. The impact categories studied were global warming (GWP100a), ozone layer depletion (OLD), acidification (ACD), eutrophication (EUT), and abiotic depletion (AD). Likewise, the Cumulative Energy Demand (CED) method was used.

3. RESULTS AND DISCUSSION

Food waste and lack of locally sourced products were some of the main problems mentioned by the different actors in the value chain. An agricultural surplus (local green chili) was identified, and three prototypes (hot sauces) that differed in ingredients and/or transformation processes were created. The results of the sensory tests allowed us to discard some of the unit operations for lack of impact on the final product profile. Thus, the product that contained fewer ingredients and did not require a specific transformation process (15 days of fermentation) was selected as a potential for scaling up. The LCA results of the selected prototype determined that secondary ingredients and packaging were the main hotspots, and an alternative improved version was proposed as a final product. The combination of LCA and CCD methodologies enabled the design of a new product with an environmental impact reduced by 57-91% with respect to the baseline (Table 1).

4. CONCLUSIONS

Involving stakeholders in the design process of food products and using LCA can be a useful combination of tools for developing more sustainable foods while meeting consumers' expectations.

5. ACKNOWLEDGEMENTS

This work was supported by EITFOOD Cross-KIC New European Bauhaus and the Department of Economic Development, Sustainability and Environment of the Basque Government. Financial support for BC3 research was provided by the Spanish Government through María de Maeztu excellence accreditation 2023-2026 (Ref. CEX2021-001201-M, funded by MCIN/AEI/10.13039/501100011033); and by the Basque Government through the BERC 2022-2024 program. The authors want to acknowledge the participants in the studies for their helpful collaboration.

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Impact category	Unit	Baseline	Final version	Diff (%)
GWP 100a	kg CO_2 eq.	0.37	0.10	74
OLD	kg CFC-11 eq.	2.28E-06	4.28E-07	81
ACD	kg SO_2 eq.	3.27E-03	6.42E-04	80
EUT	kg $PO4^{3-}$ eq.	2.17E-03	3.06E-04	86
AD	kg Sb eq.	1.14E-05	9.93E-07	91
CED	MJ	4.35	1.87	57

Table 1. Environmental impact per 150 g of packaged sauce: baseline and final prototype version.

LCA as a tool to unravel the challenges of algae biomass production

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1. INTRODUCTION

New sources of proteins have been searched in order to solve the issue of increasing global food demand due to the population growth. Algae arise as an outstanding option due to their fast growth and capacity to produce a variety of valuable components with nutritional and health benefits [1]. *Chlorella* sp. is a green, unicellular, freshwater eukaryotic microalga that can achieve protein contents higher than 50% of its dry weight [2]. Because of its potential, algae production has been supported by European initiatives such as GIANT LEAPS project that aims to accelerate the dietary transition to reduce the environmental impacts of the European food system and improve the health and well-being of the general consumers [3]. However, novel protein sources pose a challenge that needs to be addressed: the possible environmental impacts during their production. New cultivation technologies, such as those used to produce algae, can have higher impacts than the ones used for established crops. Therefore, a Life Cycle Assessment (LCA) is required to quantify and evaluate the environmental impacts of the algae production system, identify its hotspots, and compare it to those of other protein sources.

2. METHODS

Chlorella sp. cultivated under heterotrophic conditions (fermenters) at the Allmicroalgae facility in Pataias, Portugal, was evaluated. LCA was performed following the methodology defined by ISO 14040/44 (2006) and using OpenLCA software with the Ecoinvent database. The LCA followed a cradle-to-gate approach with the functional units of kg of protein, with allocation by mass. The production system was divided into four main stages: cultivation, harvesting, processing, and packaging. The environmental impacts were calculated using the ReCiPe Hierarchist Midpoints impact assessment approach. Five main impact categories were evaluated: agricultural land occupation (ALOP), climate change (GWP100), fossil depletion (FDP), freshwater eutrophication (FEP), and water depletion (WDP).

3. RESULTS AND DISCUSSION

LCA revealed that the operation of the algae facility has a higher impact than its construction (Figure 1.a). This can be explained due to the high productivity of the algae. The cultivation phase has higher impacts than harvesting, processing, and packaging (Figure 1.b); these are mainly associated with the carbon source (glucose), air injection, and electricity (Figure 1.c). Electricity used in the upstream process to maintain agitation and temperature during the fermentation process and in the downstream process to dry the biomass has a significant impact. When electricity is derived from solar panels instead of the grid, the impacts decrease by up to 60%. Comparing the algae to other protein sources, GWP100 is higher than that of traditional crops, but ALOP and WDP, for example, are much lower, which highlights the competitiveness of this new protein source and the importance of not limiting the analysis to climate change, moving beyond the “carbon emissions tunnel vision”.

4. CONCLUSIONS

New protein sources, such as algae, have several challenges and opportunities to improve their impacts, especially during cultivation. Fermented *Chlorella* sp. is still a process under development with a lot of potential, and it is already competitive compared to several alternative protein sources.

5. ACKNOWLEDGEMENTS

The authors would like to thank Allmicroalgae – Natural Products S.A. for allowing access to its facilities and providing the required data for the life cycle inventory. GIANT LEAPS has received funding from the European Union's HORIZON EUROPE research and innovation programme under grant agreement No 101059632.

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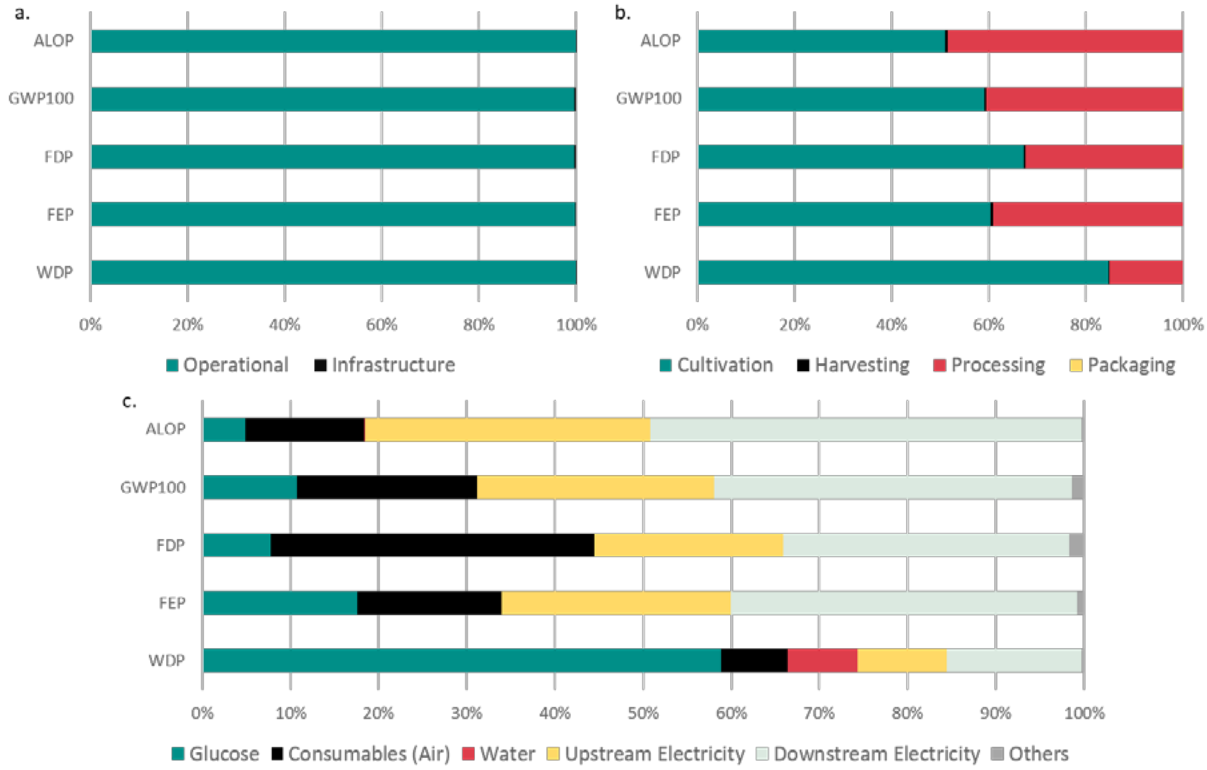

Figure 1. Environmental Impacts of *Chlorella* sp. production separated by operational and infrastructure (a), by production stage (b) and by main contributors (c).

Combined nutritional and environmental assessment of foods and diets

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Are quinoa-based snacks a healthier and more ecofriendly alternative to their traditional counterparts? A comparative study based on nutritional life cycle assessment

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1. INTRODUCTION

The growing trend towards the adoption of healthier habits is leading to a rise in the demand for nutritionally enhanced foods, which in many cases are composed of the so-called 'superfoods' that offer interesting alternatives to traditional products. However, when studying these new products, research is frequently oriented towards assessing the benefits to humans, while the planet health is usually overlooked. Therefore, this work focuses on quinoa (*Chenopodium quinoa* Willd.) and its potential to make healthy snacks by approaching a life cycle thinking, thus analyzing the potential environmental impacts of the crop and its derivatives, and without forgetting the nutritional contribution of the products.

2. METHODS

The system under study consisted of two subsystems: (i) quinoa production and processing, and (ii) traditional snacks formulation and adaptation. The boundaries were defined from cradle to gate and two functional units (FUs) were considered: 1 kg of product, both of quinoa and snack, and sNRF9.2 score, which evaluates the contribution of a product to cover the main nutritional shortfalls of the Spanish population (Fernández-Ríos et al., under review).

Inventory data for quinoa production were obtained from a company located in Spain. Regular snacks formulation (i.e. without quinoa) was performed using information compiled from life cycle assessment (LCA) studies. Afterwards, modification of the recipes was carried out by substitution of the main source of fiber, protein or carbohydrates, with quinoa, and was based on the concentration of available commercial products. The modelling of the systems was conducted in SimaPro, using the Ecoinvent and Agribalyse databases and the Environmental Footprint 3.0 method. Outcomes of the study were subjected to major environmental concerns caused by agriculture and the food industry. In addition, an energy analysis was conducted by the calculation of the EROI (energy return of investment).

3. RESULTS AND DISCUSSION

Results on quinoa production evidenced a major contribution of the cultivation stage to the overall environmental impacts. Fertilizers' production and application together with the watering system were the main carriers of environmental degradation. On the other side, the performance of snacks showed that nutritionally enhanced options with quinoa present slightly higher burdens than the conventional snacks considering a FU of 1 kg of product. Nevertheless, when the nutritional properties were considered, results changed importantly due to trade-offs between the environmental performance and the nutritional quality of snacks. For all indicators tested, quinoa-based products reported much lower impacts than the conventional snacks, reaching regular multicereal biscuits the highest footprints, while salty crackers with 40%, breadstick with 25% and sponge cake with 6% of quinoa generally got the best profiles (Figure 1). Regarding the energy analysis, we discovered that the production of ingredients constituted the most energy intensive stage, where quinoa production contributed between 3% and 32%. EROI values were estimated at a maximum of 4.35%, obtained for regular salty crackers, and a minimum of 1.77%, reported for regular sponge cake, which evidenced the relatively low energy efficiency of the production systems as only a small percentage of the energy invested is returned.

4. CONCLUSIONS

The main findings of the study revolve around the importance of considering nutritional aspects within the environmental evaluation of food products. In particular, quinoa-based snacks appeared to be more environmentally sustainable than their regular counterparts, which can be deduced from the application of the sNRF9.2 index as functional unit.

5. ACKNOWLEDGEMENTS

This work was supported by the Spanish Ministry of Science and Innovation through the KAIROS-BIOCIR project (PID2019-104925RB) (AEO/FEDER, UE). Ana Fernández-Ríos thanks the Ministry of Economy and Competitiveness of Spanish Government for their financial support via the research fellowship RE2020-094029. The authors thank the company manager for the provision of the data.

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Figure 1: Radar charts comparing the environmental impacts of the regular (green) and quinoa-based (purple) snacks, considering a FU of 1 kg of snack (dashed line) and of 1000sNRF9.3 (colored area). Results are scaled to the highest value of each indicator.

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NOT PRESENTED

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Perceptions of food and food sustainability among college students in the field of food science

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1. INTRODUCTION

Food systems have been increasingly associated with environmental, economic, and social impacts that directly affect human conditions and the planet [1]. In this context, food sustainability has become a key concept in all spheres of social, cultural, economic, and political life. However, it is a broad, multidimensional, and complex notion that is difficult to define [2]. Although there are official definitions regarding sustainability [3], individuals perceive this concept in multiple ways [4,5]. Food professionals, such as dietitians and food scientists and technologists, are in a unique position to influence sustainability at different stages of the food chain, but little research has addressed this issue among these professionals [6]. The aim of this study was to analyze the perceptions related to food and food sustainability among college students of Human Nutrition and Dietetics (HND) and Food Science and Technology (FST) at the University of Barcelona (UB) (Spain).

2. METHODS

An exploratory and descriptive cross-sectional study, using both qualitative and quantitative methodology, was carried by an interdisciplinary team. The study was conducted with a convenience sample of male and female college students enrolled in any of the four years of the Bachelor's degrees in HND and FST at the UB. Two focus groups and an online questionnaire were conducted (300 participants completed the survey).

3. RESULTS AND DISCUSSION

Although students expressed concern about issues related to sustainability, their eating practices were primarily associated with or influenced by taste/pleasure, health, and nutrition. Gender differences were identified, supporting that the topic of food sustainability seems more internalized by women than by men. A generalized conception of the notion of sustainable nutrition was verified, regardless of the Bachelor's degree or gender. Sustainability was mainly associated with environmental aspects (not wasting food, consuming Km0 or local products, and consuming fresh food and seasonal products), largely ignoring the socioeconomic dimensions. Furthermore, awareness on the issue of food sustainability was not significantly higher among students at the end of the degree compared to those in the first year, indicating that their perceptions did not change considerably along the academic training.

4. CONCLUSIONS

There is a need to promote the concept of sustainability in all its complexity and multidimensionality among Nutrition and Food Science students and food sustainability should be discussed during their training in a more holistic, transdisciplinary, and intersectoral way.

5. ACKNOWLEDGEMENTS

We acknowledge support of Generalitat de Catalunya (2021-SGR-00861), INSA·UB Maria de Maeztu Unit of Excellence (Grant CEX2021-001234-M) funded by MICIN/AEI/FEDER, UE and Càtedra d'Alimentació Saludable i Sostenible UB-Danone.

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Table 1. Perceptions of what constitutes a sustainable diet among college students studying Bachelor's degrees in Human Nutrition and Dietetics (HND) and Food Science and Technology (FST) according to gender and showing the distribution (%) of responses.

Aspects that constitute a sustainable diet	TOTAL (%)	Bachelor's degree				Gender			
		HND (%)	FST (%)	χ2	p value	Female (%)	Male (%)	χ2	p value
Consuming Km0 or proximity products	18.9	20.1	17.7	1.60	.205	19.2	17.8	.341	.559
Consuming organic products	4.3	3.1	5.4	3.17	.075	4.0	5.2	.512	.474
Not wasting food	22.5	22.5	22.4	.006	.936	21.7	25.3	2.44	.119
Following a Mediterranean Diet	1.45	1.1	1.8	.766	.381	1.0	2.9	3.97	.046*
Using biodegradable or compostable materials	9.0	7.3	10.7	4.08	.043*	8.9	9.8	.180	.672
Following a vegetarian diet and/or reducing consumption of animal products	10.0	11.3	8.7	2.06	.151	1.1	5.7	5.66	.017*
Consuming fair trade products	2.4	2.2	2.5	.067	.796	2.6	1.1	1.41	.235
Reducing the consumption of industrial products	5.0	5.1	4.9	.013	.910	5.0	5.2	.012	.912
Being part of a consumer group/consumer cooperative	0.2	0.4	0	1.99	.159	0.3	0	.485	.486
Shopping in the neighborhood market or stores	6.1	5.7	6.5	.525	.615	5.7	8.0	1.58	.209
Growing/producing your own food	1.8	1.5	2.0	.293	.588	2.1	0.6	1.87	.172
Buying products directly from the producer	1.7	1.8	1.6	.057	.812	1.7	1.7	.004	.952
Consuming fresh and seasonal products	16.9	17.9	15.9	1.08	.299	16.9	16.7	.007	.932

Knowledge and perceptions of food sustainability in a Spanish university population

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1. INTRODUCTION

The modern food system faces an unprecedented challenge: on the one hand, to manage the environmental and socioeconomic consequences of the industrial production model, and on the other, to produce affordable and nutritious food in adequate quantities in a context of population growth in a sustainable and resilient manner, reducing environmental impacts and the overexploitation of natural resources (1,2). In this scenario, sustainability has become a key concept of new strategies promoting a global transformation of the current food system (3). Universities have a great potential as catalyzers for sustainability, being both formal learning institutions and places where informal, mutual influences and lay/expert knowledge meet (4). However, studies addressing the perceptions of sustainability in large university communities are still lacking. The aim of this study was to analyze the level of knowledge and perceptions of food sustainability in a university community from Spain.

2. METHODS

A descriptive cross-sectional study, based on an online questionnaire, was carried out between July and November 2021 with convenience sampling. The survey included 28 items and was distributed among students, teachers, researchers and administrative staff from the University of Barcelona. A total of 1,220 participants completed the survey.

3. RESULTS AND DISCUSSION

70.4% of the respondents heard about the environmental impact of food and more than 50% were aware of the Sustainable Development Goals. Participants tended to be more familiar with more general and less technical concepts, such as “local products/Km0 and “food waste/food lost”. The different aspects related to diet that concerned them the most were food waste, plastic usage, and environmental impact. They stated that a sustainable diet should be mainly based on local and seasonal products and with a low environmental impact, as well as no or the minimum food waste. When asked if they were following a sustainable diet, 77% answered affirmatively. Moreover, the food groups more associated with a sustainable diet were vegetables and fruits, olive oil, legumes, and whole grains. Regarding food waste, 60% of the surveyed population claimed to generate it at home, with the use of leftovers and planning shopping and meals being some of the most important domestic act ions to avoid it.

4. CONCLUSIONS

The results indicate that a greater effort is needed to enhance knowledge of food sustainability and to improve the importance given to this dimension in food choice in the university community. Moreover, the findings highlight that future strategies should be designed taking into account the differences among the different population groups analyzed.

5. ACKNOWLEDGEMENTS

We acknowledge support of Generalitat de Catalunya (2021-SGR-00861) and INSA·UB Maria de Maeztu Unit of Excellence (Grant CEX2021-001234-M) funded by MICIN/AEI/FEDER, UE.

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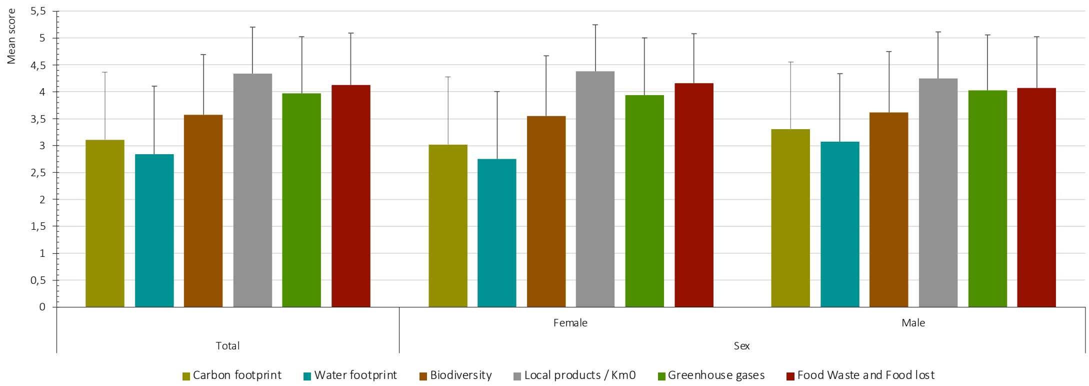

Figure 1. Level of knowledge of concepts related to sustainability.

Table 1. Distribution (%) of answers about the most important aspects of a sustainable diet.

	Total		Sex (%)		p-value	Collective (%)			p-value
	n	%	Male	Female		Adm. Staff	Teach. Staff	Students	
Rich in plant-based foods	106	8.8	10.8	7.9	.105	8.2	12.4	1.8	<.001
With no or the minimum amount of food waste	450	37.7	39.2	36.8	.413	38.4	37.9	33.6	.463
With biodegradable, compostable packaging	372	31.0	28.2	32.4	.144	31.9	25.6	46.1	<.001
With locally produced, seasonal products	863	71.8	74.5	70.8	.190	67.1	71.5	81.6	.001
Respectful of ecosystem biodiversity and with a low environmental impact	822	68.6	69.2	68.3	.740	69.8	69.1	65.0	.434
With products from companies that respect workers' social rights	165	13.8	25.5	15.0	.064	14.7	13.8	12.9	.807
Affordable	250	20.9	21.8	20.4	.565	20.0	18.8	28.1	.014
Organic / ecological	186	15.5	12.6	16.8	.060	16.7	16.6	9.2	.022
Simple, without additives, based on foods with few ingredients and little processed	339	28.3	30.0	27.5	.366	28.0	31.7	18.0	.001
Culturally acceptable	43	3.6	2.6	4.0	.226	4.8	2.5	3.7	.153

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Sustainability on the plate- Footprint Reduction and Nutritional Improvement through Meal Optimization in University Canteens

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1. INTRODUCTION

In Europe, food is available around the clock. The global food system enables us - regardless of season and distance – to eat what we like. This carefree way of eating today is contrasted by an enormous consumption of resources: The global food-system is responsible for 26% of anthropogenic greenhouse gas (GHG) emissions[1]. Also, our health is influenced to a considerable extent by our diet. Diet-related diseases and the costs they cause are steadily increasing.

“Farm to table” is a project that focussed on healthy and sustainable nutrition with the goal to analyse possible optimizations in both environmental impact and healthy nutrition by a change in the meal offering.

2. METHODS

Within the “Farm to table” project, the meals at Zurich University of the Arts canteen were assessed with Menu Sustainability Index (MSI)[2], an instrument that quantifies life cycle greenhouse gas emissions and the nutritional-physiological balance of meals based on qualifying and disqualifying nutrients. The results were then used to optimise recipes from an environmental and health perspective and raise awareness among guests. The optimisation included replacements of components, quantities, or entire meals, which then were offered over a period of 4 weeks. The nutritional-physiological balance of meals is indicated in nutritional balance points (NBP), using the method of Müller & Berger (2018)[2], GHG emissions are indicated in CO_2-eq, according to IPCC (2021) [3]. As reference, the standard offering from a Swiss University was taken.

3. RESULTS AND DISCUSSION

Within a 4 weeks test phase, 10’800 meals were sold with total CO_2-eq emissions of 10 tons. Compared to the reference, this corresponds to savings of 6 tons CO_2-eq. Extrapolated to one year, this savings is equivalent to 78 tons CO_2-eq.

Compared to the reference, the average GHG emissions per meal were reduced by 38% (

Figure 1). The greatest leverage was achieved by swapping GHG-intense meat-based meals (e.g. veal cutlet with fries and carrots) with vegetarian/vegan meals (e.g. planted chicken with pasta and vegetables). Meals containing meat proportionally contributed more than meatless meals: Although just 17% of all sold meals contained meat, they contributed 33% of all CO_2-eq.

Figure 2 shows that the average meatless meal has significantly lower GHG emissions (-60%) but only slightly higher Nutritional Balance points than the average meal. Still, the optimization resulted in an 89% increase in meals labelled as “balanced”. The share of nutritionally unbalanced meals decreased by 14%.

4. CONCLUSIONS

Meals containing meat and dairy products have the highest climate impact. A replacement of these components can reduce the environmental impact of meals substantially. The project proves that it is possible to optimise both the environmental friendliness and health aspects of meals at the same time. Replacing meals with high GHG emissions and high negative nutritional balance points could further improve the sustainability of the meal offering. To take both aspects into account, kitchen managers should focus on menus in the green coloured box of

Figure 2.

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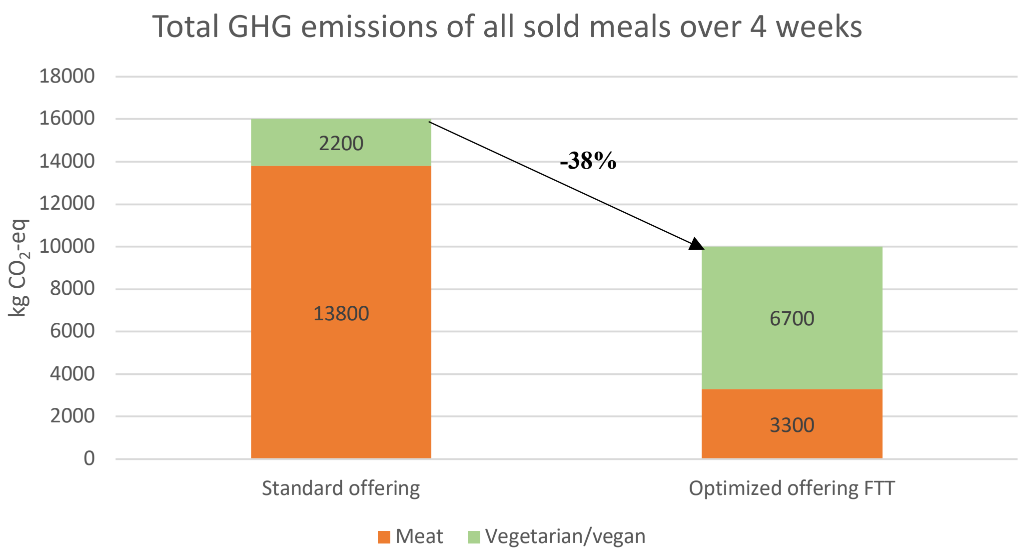

Figure 1 Total GHG savings of all sold meals (N=10'782), compared to the reference scenario (meal offering of a Swiss University).

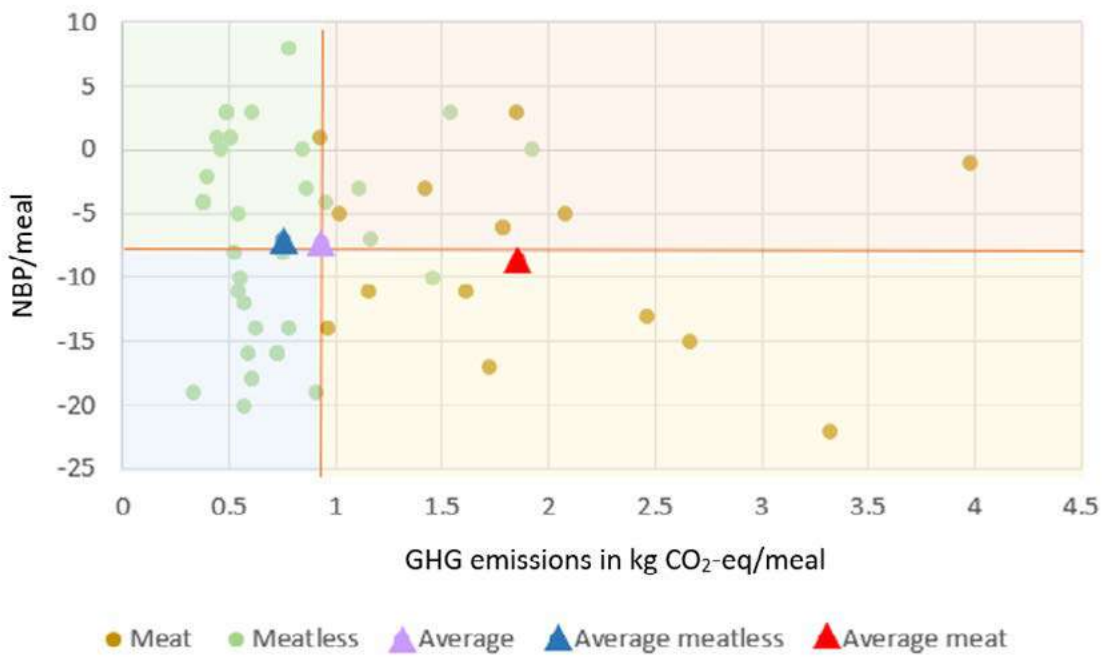

Figure 2 Comparison of nutritional-physiological balance points (NBP), according to Müller & Berger (2018) and life cycle greenhouse gas emissions (IPCC 2021).

NOT PRESENTED

Eating habits and sustainability: environmental impacts of the consumption of fruit and vegetables

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1. INTRODUCTION

Human food systems are a key contributor to climate change and other environmental concerns and combining growing consumer demands, oriented towards the consumption of a variety of fresh foods, with environmental sustainability is becoming an important challenge (Bai et al., 2021). Approximately 24% of global CO_2 emissions come from agriculture, forestry and other land uses (Câmara-Salim et al., 2021) and a change towards maintaining quality and sustainable consumption patterns is necessary. This research aims to analyze the environmental impacts associated with consumers' habits of fruit and vegetables and contributing to new insights regarding consumers' choices towards environmental sustainability.

2. METHODS

A systematic literature review was conducted to explore the environmental impacts associated with the consumption of fruit and vegetables through the application of the life cycle assessment methodology. The database used was ISI Web of Knowledge, using the following keywords: "lca AND diet* AND consumer* AND (agri* OR fruit* OR vegetable*)". The study presents a review based on 27 scientific papers published between 2008 and 2023 (Table 1), which allowed evaluating the influence of eating habits on environmental sustainability.

3. RESULTS AND DISCUSSION

The dietary patterns can influence food production in terms of cultivation mode, processing and transportation (Nemecek et al., 2016; Vinci et al., 2023). From the literature analysis, it emerges that domestic behaviours have an important influence on the total GHG emissions of the diet, despite the higher impact is associated with the production and agricultural phases. In fact, the cooking phase and foodwaste generation, are responsable for approximately 15% and 12%, respectively, of the total emissions (Corrado et al., 2019). Heller and Keoleian (2015) refer that food losses contribute 1.4 kilograms of CO_2-eq capita−1day−1 (28%) to the overall carbon footprint. A transition to vegan or vegetarian diets would reduce the environmental impact associated with food consumption. In fact, the substitution of 20% of the per-capita ruminant meat consumption globally by 2050 would offset future increases regarding the land use, deforestation and related CO_2 and CH_4 emissions (Humpenöder et al., 2022; Corrado et al., 2019; Treu, et al., 2017). Furthermore, adopting diets based on a consumption of local products, organic food, fresh and seasonal products, low-processed foods or home cooked meals would also contribute to reducing emissions (Hospido et al., 2009). From a nutritional point of view, a healthy diet consisting of a low intake of sodium, added sugars and saturated fats can also favour environmental sustainability (Esteve-Llorens et al., 2019).

4. CONCLUSIONS

Dietary behavioural choices have a significant effect on the environmental impact of the food system. More research should be conducted on human diets, to establish the healthiest form of nutrition and improve the sustainability of agri-food supply chains. A universal sustainability label or simple guidelines may enable consumers to make more environmentally friendly food choices. This article highlights the central role of consumers in the agri-food sector, while also demonstrating the relevance of using life cycle thinking to understand and optimize the environmental profile of agricultural systems.

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Table 1. Studies included in the literature review

Reference	First authors affiliation	Journal	Product/Object of study	DOI
Bai et al., 2021	China	Resources, Conservation & Recycling	Edible vegetable oil	10.1016/j.resconrec.2021.105606
Câmara-Salim et al., 2021	Spain	Journal of Environmental Management	Potato	10.1016/j.jenvman.2021.112351
Cancino-Espinoza et al., 2018	Perù	Science of the Total Environment	Organic Quinoa	10.1016/j.scitotenv.2018.05.029
Corrado et al., 2019	Italy	Science of the Total Environment	Dietary patterns	10.1016/j.scitotenv.2018.12.267
Davis and Sonesson, 2008	Sweden	International Journal of Life Cycle Assessment	Chicken meals	10.1007/s11367-008-0031-y
Esteve-Llorens et al., 2019	Spain	Science of the Total Environment	Atlantic dietary	10.1016/j.scitotenv.2018.07.264
Esteve-Llorens et al., 2019 b	Spain	Science of the Total Environment	Atlantic and Galician diet	10.1016/j.scitotenv.2019.05.200
Heller and Keoleian, 2015	USA	Journal of Industrial Ecology	US dietary	10.1111/jiec.12174
Heller et al., 2018	USA	Environmental Research Letters	US dietary	10.1088/1748-9326/aab0ac
Hospido et al., 2009	UK	International Journal of Life Cycle Assessment	Lettuce	10.1007/s11367-009-0091-7
Humpenöder et al., 2022	Germany	Nature	Beef and mircobial protein	10.5281/zenodo.4730378
Lazzarini et al., 2018	Switzerland	Journal of Cleaner Production	General	10.1016/j.jclepro.2018.07.033
Martin and Brandao., 2017	Sweden	Sustainability	Swedish diet	10.3390/su9122227
McAuliffe et al., 2020	UK	International Journal Life Cycle Assessment	General	10.1007/s11367-019-01679-7
McAuliffe et al., 2023	UK	International Journal Life Cycle Assessment	General	10.1007/s11367-022-02123-z
Nemececk et al., 2016	Switzerland	International Journal Life Cycle Assessment	General	10.1007/s11367-016-1071-3
Poor and Nemecek, 2018	UK	Sustainability	General	10.1126/science.aaq0216
Potter et al., 2021	Sweden	Journal of Cleaner Production	Plant based food	10.1016/j.jclepro.2020.124721
Saarinen et al., 2017	Finland	Journal of Cleaner Production	General	10.1016/j.jclepro.2017.02.062
Saget et al., 2020	Ireland	Sustainable Production and Consumption	Pasta	10.1016/j.spc.2020.06.012
Scherer and Pfister, 2016	Switzerland	Environmental Science and Technology	Swiss dietary	10.1021/acs.est.6b00740
Sonesson et al., 2019	Sweden	Journal of Cleaner Production	General	10.1016/j.jclepro.2018.11.171
Svanes and Johnsen, 2019	Norway	Journal of Cleaner Production	Apples, sweet cherries and plums	10.1016/j.jclepro.2019.117773
Treu et al., 2017	Germany	Journal of Cleaner Production	Organic diets	10.1016/j.jclepro.2017.05.041
Ulaszewska et al., 2017	Italy	Science of the Total Environment	Mediterranean and Nordic diets	10.1016/j.scitotenv.2016.09.039
Vinci et al., 2023	Italy	Science of the Total Environment	Mushrooms	10.1016/j.scitotenv.2023.166044
Yue et al., 2022	China	Sustainable Production and Consumption	General	10.1016/j.spc.2022.04.030

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Assessing the climate impacts of different protein sources: an nLCA approach based on system expansion

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1. INTRODUCTION

Nutritional aspects of food have been recently addressed under a concept called a nutritional LCA, or nLCA (e.g. McLaren et al 2021, McAuliffe et al. 2023), based on specific nutritional indices. Despite the methodological development in this area, the problem of comparability still remains. Even if the function of certain food items is seemingly similar (e.g. provision of high-quality protein), each item may have some additional functions, the most important of which is usually the provision of energy. It is very difficult to capture all these functions in nutritional indices in a comparable way. In this study, an LCA approach based on system expansion was developed for quantifying the Global Warming Potential of different protein sources. The method focused on the functionality of protein in diet, i.e. the provision of balanced amino acids for human nutrition. In addition to provision of amino acids, also a "by-product" of the protein sources, namely the provision of energy for metabolic functions, was taken into account with system expansion.

2. METHODS

The Global Warming Potential (GWP) of different protein sources was determined by applying the Life Cycle Assessment (LCA) methodology as specified in the ISO 14040 standard. The functional unit of the assessment was selected to be the daily requirement of a 75 kg adult for all essential amino acids, and the reference flow was the amount of a food product that would fulfill this required function. In addition to the main function (delivery of essential amino acids), an additional function was also considered, namely the delivery of energy for human metabolic functions. To allow the comparison between all food items included in the study, fat, or more specifically vegetable oil, was selected as an additional food item to be included in the assessment based on system expansion. As a result, ten combinations of food items (protein source + fat) were formulated, each fulfilling the daily requirement of essential amino acids, and also providing equal amount of food energy.

3. RESULTS AND DISCUSSION

The required amounts of different protein sources to fulfil the daily requirement for essential amino acids varied strongly, depending on their protein concentrations and amino acid profiles (Fig. 1). This variation, together with the differences in their energy contents, had a strong effect on the climate impact of these different food items (Fig 2). Amongst the protein sources included in the comparison, the highest greenhouse gas emissions were found in two of the meat products included in the study, namely beef and high-fat pork, and in milk products. Amongst the plant-based protein sources, nuts had the lowest emissions. The emissions of chicken meat, eggs and peas were slightly higher and of a similar magnitude with each other. Soybeans had higher emissions than some animal-based products, due to land use changes associated with production of soya.

4. CONCLUSIONS

This study has provided a potential solution for some inconsistencies that currently still exist in the nutritional nLCA framework. Although nutritional indices can capture multiple functions of food items, the comparability of different items has remained a challenge. The system expansion approach can help resolve the issues related to comparability.

5. ACKNOWLEDGEMENTS

This study was funded by Aviagen.

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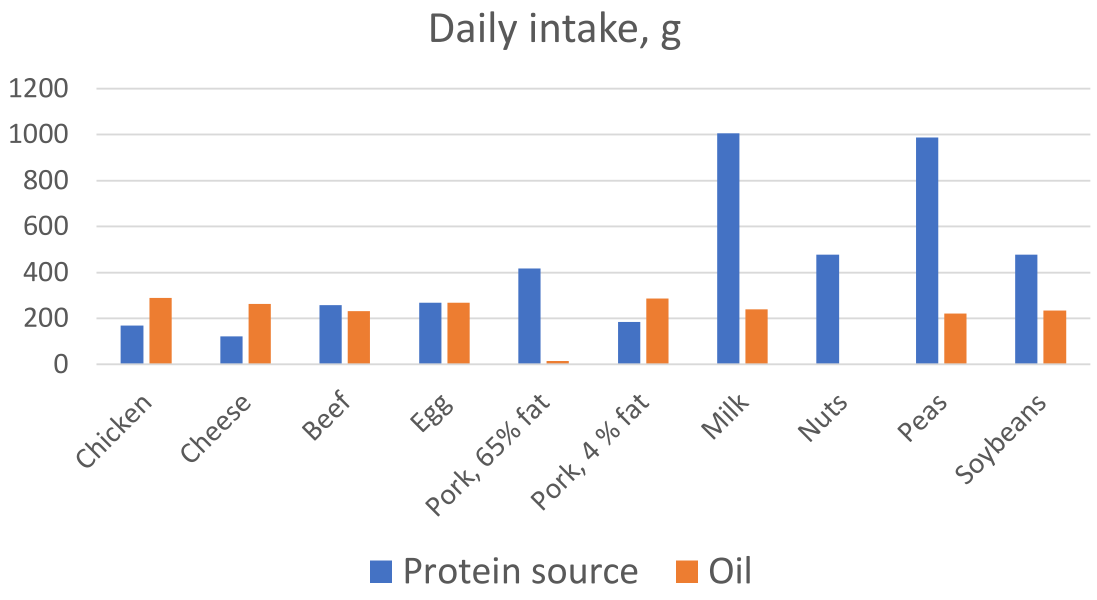

Figure 1. The intake of the total amount of each protein source as needed to fulfil the daily requirements for all essential amino acids. The additional intake of vegetable oil is also shown that would be needed to keep the energy content of each of the intake options at the same level.

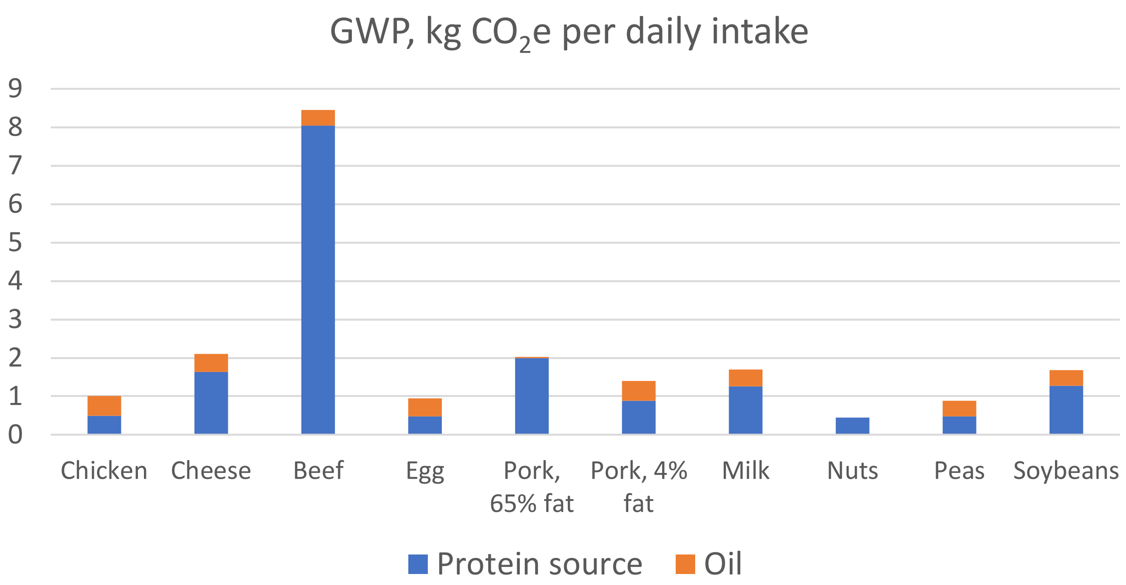

Figure 2. Global warming potential of the combinations of protein source + vegetable oil that would fulfil the daily requirement for all essential amino acids and contain equal amount of metabolizable energy.

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Climate and nutrition benefits of diets compatible with 1.5°C lifestyles

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1. INTRODUCTION

Meeting the 1.5°C climate target aspired to in the Paris Agreement requires substantial greenhouse gas emission reductions. Technological changes alone are insufficient and must be complemented by lifestyle changes (Cap et al. 2024). Food systems play a central role in climate change mitigation. Recognizing this, almost 160 countries have signed a food and agriculture declaration at COP28 (United Nations Climate Change 2023). Here, we focus on food-related lifestyle options and assess their carbon footprint reduction potentials, contribution to 1.5°C lifestyles, and co-benefits for human health across five EU countries.

2. METHODS

The carbon footprint reduction potentials of lifestyle options were calculated using environmentally extended multi-regional input-output (MRIO) analysis. MRIO analysis, like life cycle assessment, allows for quantifying environmental impacts across supply chains. We used MRIO tables from EXIOBASE (Stadler et al. 2018), projected to the year 2030 following Shared Socioeconomic Pathway 1 and Representative Concentration Pathway 1.9 but without lifestyle changes (Cap et al. 2024). The lifestyle options were implemented in the MRIO model, following the framework of Wood et al. (2018). Various lifestyle options (food and non-food) were combined proportionally to derive the share of each lifestyle option that would need to be implemented so that the average overall lifestyle footprint of a country is compatible with the 1.5°C target in 2030.

The health impacts of diets compatible with such 1.5°C lifestyles were assessed through average dietary risk factors (DRFs) that translate the consumption of dietary risk components (nutrients or food groups) to health impacts expressed in disability-adjusted life years (DALYs; Scherer et al. 2024). Such DRFs were first developed for the US (Stylianou et al. 2021) and then updated and extended to further countries across the world in the Global Life Cycle Impact Assessment Method (GLAM) project of the Life Cycle Initiative hosted by UN Environment (Verly Junior, personal communication).

3. RESULTS AND DISCUSSION

Among the 11 examined food-related lifestyle options, switching to a vegan diet has the greatest potential to reduce greenhouse gas emissions and eating only seasonal vegetables and fruits the least (Figure 1). As a part of 1.5°C lifestyles in 2030, such food-related options contribute 4.8-10.3% of the necessary carbon footprint reductions across the five EU countries. Six of these options yield co-benefits for health through changes in the dietary composition, as, for example, the consumption of red meat reduces and the consumption of fibers increases (Figure 2).

4. CONCLUSIONS

Dietary choices can make considerable contributions to climate change mitigation while benefiting human health through improved nutrition.

5. ACKNOWLEDGEMENTS

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 101003880. The sole responsibility for the content of this paper lies with the authors.

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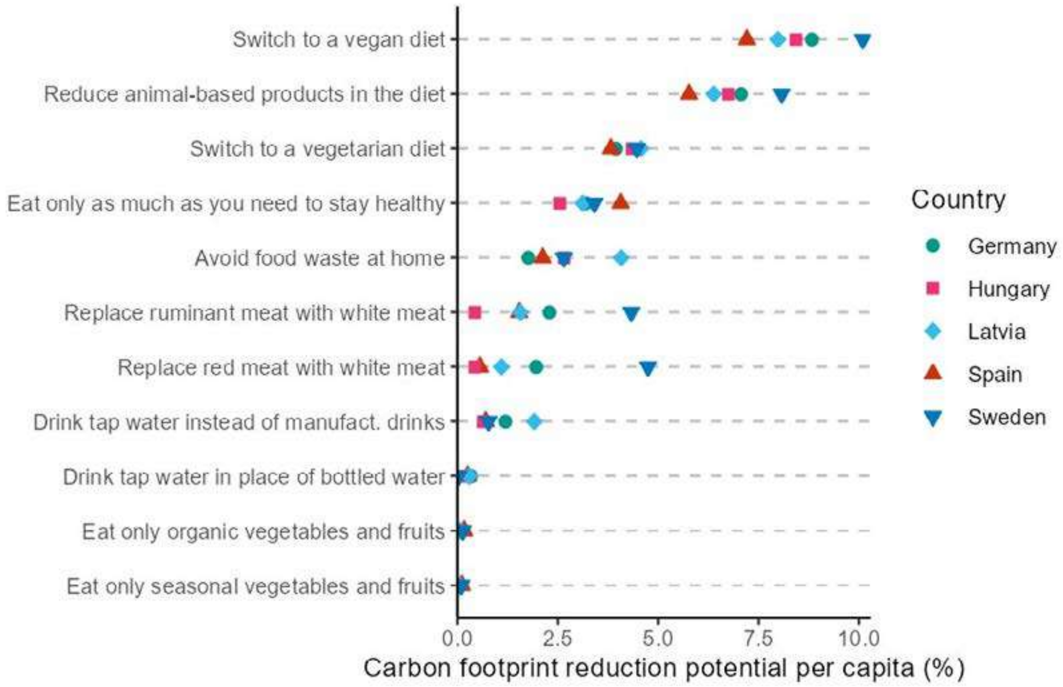

Figure 1. Carbon footprint reduction potentials per capita of food-related lifestyle options in 2030 across five EU countries.

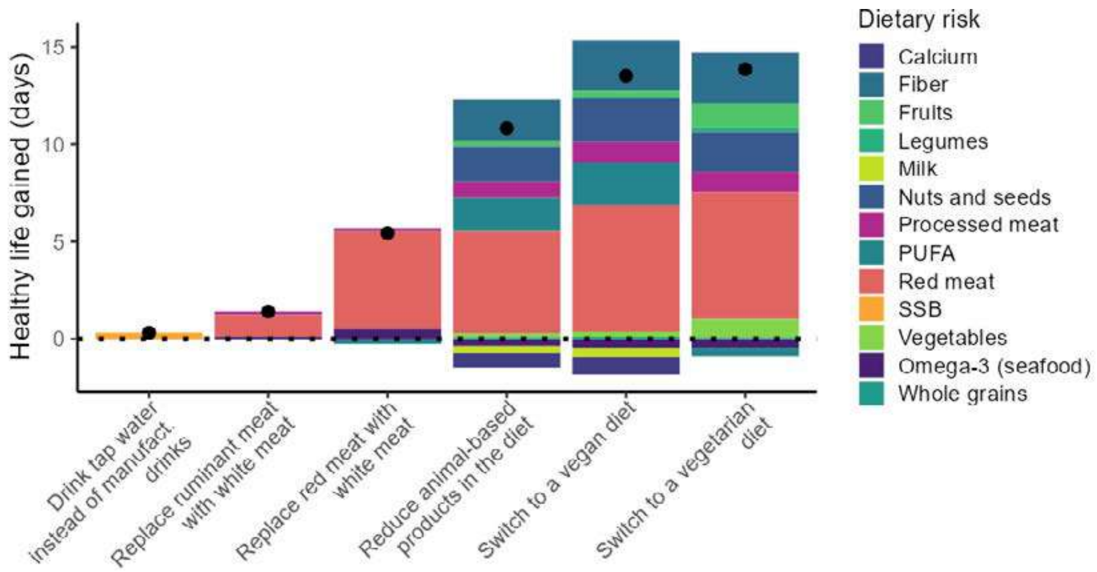

Figure 2. Nutritional health gains per capita of relevant food-related lifestyle options in 2030. Average of the five EU countries. PUFA: Polyunsaturated fatty acids; SBB: Sugar-sweetened beverages.

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Assessing the Nutritional Attributes of Plant-Based Meat Analogues and conventional Meat Products: A Comparative Study

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1. INTRODUCTION

The production of food of animal origin, particularly meat, carries a significant environmental footprint and entails a higher consumption of water resources compared to vegetal foods. This fact has fostered, in part, a growing awareness within the food industry about the need to offer more sustainable alternatives. Thus, this concerns for planetary health alongside factors such as increasing vegetarian/vegan population in Western societies and ethical considerations related to animal welfare, have led to a striking emergence of plant-based meat analogues in the market. However, little has been published on their nutritional composition in comparison with conventional meat products. The aim of this work was to perform a comparative assessment of the nutritional profile of plant-based meat analogues available in Spain in comparison with the equivalent meat products.

2. METHODS

A total of 148 products retailed in supermarkets and small shops in Barcelona (Spain) were evaluated: 100 plant-based meat analogues and 48 meat equivalents, grouped into four categories: burgers (25 plant-based and 25 animal-based), meatballs (25 plant-based and 9 animal-based), sausages (25 plant-based and 8 animal-based) and nuggets (25 plant-based and 7 animal-based). We reviewed the information on product labels about ingredients, nutritional composition and allergens. The nutrient composition per 100 g of plant-based and animal-based products of the same category was compared using the Mann–Whitney U test. The analysis of variance among products of the same category was performed using the Kruskal–Wallis test (IBM SPSS Statistics 27.0 statistical software package).

3. RESULTS AND DISCUSSION

A high number of ingredients listed on the labels of the four categories of plant-based and animal-based products was observed, together with a high variability even within the same category. For example, it can be found plant-based burgers formulated from nine ingredients to others made with 22 ingredients. Almost half of plant-based meat analogues were just made with legumes as the main ingredient, with soy being the most frequent (used in the form of soy, tofu, texturized soybean protein, or soybean flour). In addition to soybeans, some meat analogues used other legumes, such as pea protein (18%) and chickpea protein (9%). Only 8% of all plant-based products were made with cereals as the main ingredient, mainly oats, wheat, and rice; and 22% of meat analogues contained a mixture of legumes and cereals.

The energy and nutrient content of plant-based meat analogues was found to vary considerably, even among products of the same category, with a coefficient of variation that in several cases approached or exceeded 100% (Figure 1). This variability can be explained by the wide range of ingredients and formulations used in their preparation. Similar differences were also observed in the products of animal origin, partly due to the different proportion of meat used in their formulation (ranging from 33% to 100%).

Many plant-based analogues were a good source of proteins, but not all of them. The protein complementation of cereals and legumes identified in some products, could contribute to their nutritional quality. Additionally, certain technological treatments applied to plant proteins could also enhance their digestibility. Compared to the meat products, the plant-based meat analogues contained in general lower levels of total fat as well as saturated fat; in contrast, they contained higher amounts of fiber and complex carbohydrates. The salt content, while also highly variable, was generally lower in the plant-based products, although none could be labelled as low in salt.

4. CONCLUSIONS

The great variability of formulations used in the preparation of plant-based meat analogues do not allow them to be considered, globally, as nutritionally similar to conventional meat products. Therefore, there are notable challenges to be addressed. Careful ingredient selection and appropriate formulation are key elements for enhancing the nutritional profile of these plant-based meat products, while also addressing sustainability issues.

5. ACKNOWLEDGEMENTS

The authors thank INSA Maria de Maeztu Unit of Excellence grant (CEX2021001234-M) funded by MICIN/AEI/FEDER, UE, and the ACSA, Reference project FBG311509

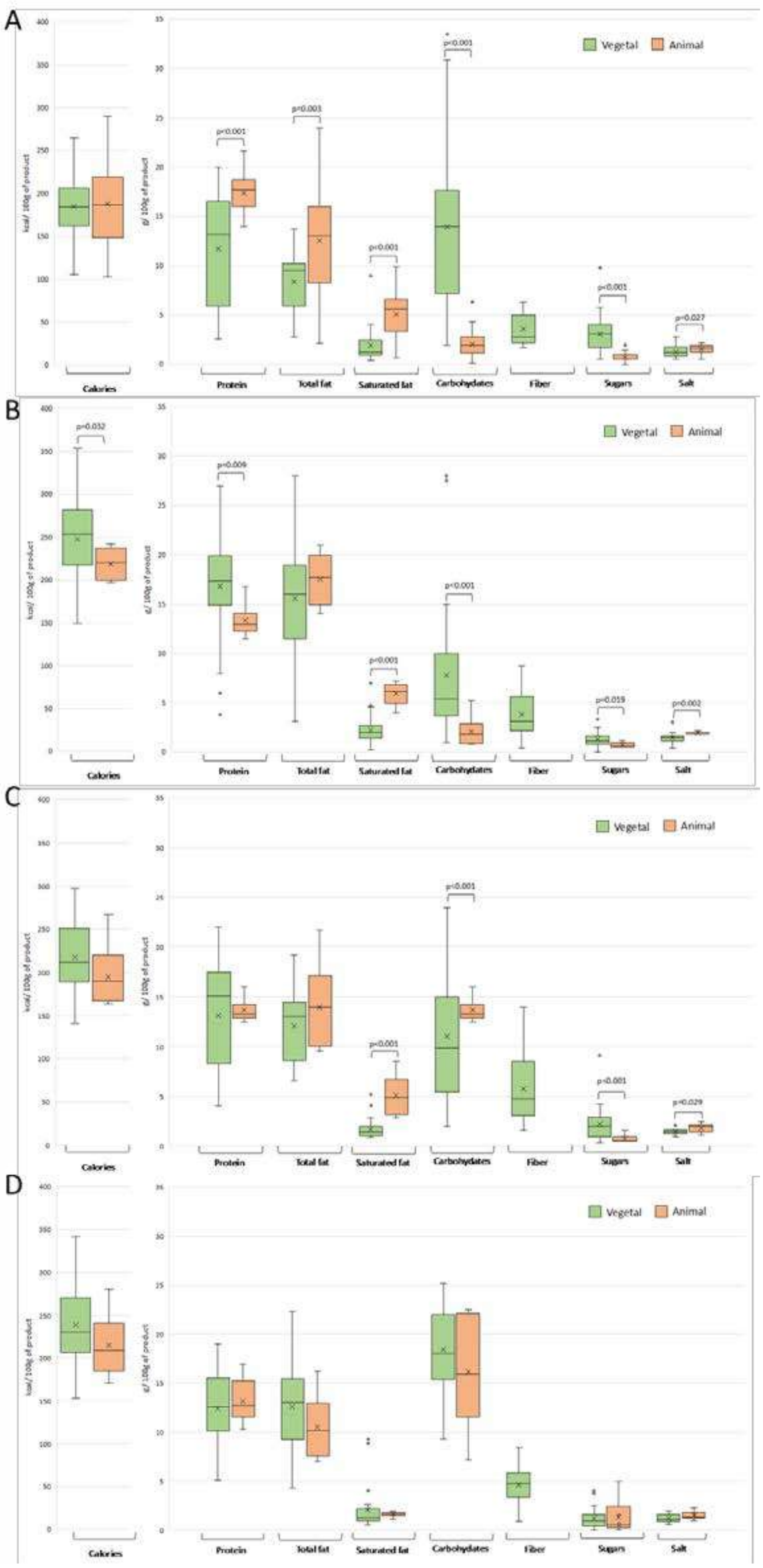

Figure 1. Energy value and nutrient content in plant- and animal-based burgers (A), sausages (B), meatballs (C) and nuggets (D). Outliers are plotted as circles and the "x" represents the mean. Significant differences between the two types of products for the different nutritional parameters are shown.

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Increasing healthier and more sustainable food consumption at daycare centres

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1. INTRODUCTION

Food served and food education provided in early childhood education and care can support children's healthy and sustainable diets, and help children adopt sustainable consumption habits which continue into adulthood. Thus, changes in day-care centres can have a significant role in achieving the shift to healthy and sustainable diets. The food served in the day-care is particularly critical in the Finnish context as almost 80% of children participate in early childhood education mainly at daycare centers, where they receive three meals a day, primarily funded by tax revenues. The meals are recommended to cover up to 2/3 of the daily intake of energy and nutrients. The FoodStep project[1] promotes healthy and sustainable diets for children in Finland. It studies the impact of menu changes and food education on children's food consumption, nutrient intake, and climate impact in 17 daycare centres in two regions through intervention.

2. METHODS

The FoodStep intervention included menu changes and food education in the participating day-care centres, including nine day-care centres in the intervention group and eight in the control group. The menus of the day-care centres included a breakfast, a lunch, and a snack served in the afternoon, and the menu changes of the intervention aimed at increasing consumption of fruits and vegetables, legumes/pulses, sustainable fish, and decreased intake of red meat, processed meat products, and milk and dairy products. The impacts of the intervention on food consumption were evaluated based on measurement periods before the and after the intervention. The measurement periods covered a one full menu cycle of a daycare centre.. The climate impacts were assessed from cradle to plate, also considering the food waste. Data on the amount of food served and food waste was obtained by measuring prepared and discarded food with an online application.

3. RESULTS AND DISCUSSION

The average amount of main meat dishes served per menu cycle decreased about a quarter per client per day, while the amount of main vegetarian dishes and vegetarian soups roughly doubled. There was no change in the amount of fish dishes served during the intervention. The menu changes decreased the climate impacts of the children's food consumption in the daycare centres. In intervention daycare centres global warming potential was about 10 – 20 % lower than in control daycare centres depending on the time span.

4. CONCLUSIONS

The Foodstep intervention successfully improved the sustainability of food consumption in daycare centres by increasing the serving of fruits, vegetables, and vegetarian dishes while reducing main meat dishes. This led to reductions in the global warming potential of menus, particularly in the longer run. These findings suggest that sustainable dietary practices can be effectively integrated into early childhood education settings, offering a model for similar programs to enhance both nutritional and environmental outcomes.

5. ACKNOWLEDGEMENTS

This work was supported by Grant Number 340306, 340407, 340408, and 340494 from the Academy of Finland (Special funding for system-level research into climate change mitigation and adaptation).

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Product grouping and nutrient selection for nutritional functional units in the product-group specific approach to nutritional Life Cycle Assessment

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1. INTRODUCTION

Nutritional quality is one of the main functions of food and therefore it is justified to be used as a basis for functional unit in food LCA. Nutrient indices composed of multiple nutrients have been employed as nutritional FUs (nFU), because the nutritional quality of a product cannot be derived from any single nutrient. However, since nutrient indices are traditionally designed for nutrition education to promote healthy diets, they may not be the most suitable nFUs for direct comparisons of individual products in the context of LCA. This raises key questions: Should different product groups be addressed more specifically? What product categorization would be appropriate? And how should the nutrients of each nutrient index be selected? In this study, we tested and validated the feasibility of the product grouping and the effectiveness of the nutrient selection strategy in capturing the nutritional functionality of product groups.

2. METHODS

To establish nutritional functional units (nFUs) for various product groups, we adopted a product group-specific approach based on the "plate model", designed to guide consumers in creating healthy meals and promote the healthy diet. According to the plate model, we identified four product groups: a protein-rich foods, a carbohydrate sources, a group consisting of vegetables, fruits or berries, and meal drinks. Grouping products according to their intended use and function in a meal allows for comparing products used similarly, aiding consumers in making consumption choices. To capture the nutritional function of each group in the context of diet, we selected nutrients for the nFU indices based on the population's current food consumption, identifying key nutrient sources within each product group. Following these principles, we developed nFUs for protein sources, carbohydrate sources, vegetables, fruits and berries group, fats, and milk as a meal drink. Most developments were made first in a Finnish context[1,2] and replicated the index formation protocol in a Spanish context (Toran-Pereg et al. unpublished). Developed nFUs were tested through assessments of typical foods in the regions. For the Finnish case, the product grouping, and the ability of the nutrient selection strategy to capture the nutritional functionality of the different product groups were then examined in a validation study using principal component analysis (PCA)[3].

3. RESULTS AND DISCUSSION

The case study findings revealed the usability and value of the product group-specific approach and nFUs based on the product group-specific nutrient indices in guiding product selection towards sustainability considering both nutrition and environmental aspects. The food grouping and the choice of nutrients resulting from the principles followed in the development work in the Finnish context were largely supported by the validation study, although some changes in the nutrient selection could be suggested. The product group-specific nFUs based on nutrient indices, adapted to Finland and Spain, led to differences in the sets of nutrients included in the indices. This highlights the differences in food cultures, which should be considered in the assessment when producing information to support changing food consumption.

4. CONCLUSIONS

The results demonstrated that the product-group-specific approach can be systematically applied to formulate nFU indices and that it can consistently represent the nutritional function of different product groups.

5. ACKNOWLEDGEMENTS

We acknowledge the funding received from the Ministry of Agriculture and Forestry and the stakeholder companies.

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Prediction of oil losses with a filter (winter) cake during the sunflower oil winterization

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1. INTRODUCTION

Filter (winter) cake is obtained as a waste by-product of winterization, the oil refining step. Approximately 4 kg of filter cake is generated per ton of refined oil, which makes a significant amount of waste, since filter cake has not usage already. The winterization process is carried out for several reasons: removal of waxes and other non-triacylglycerol components, natural high-melting triacylglycerols etc. Waxes are being removed by the oil filtration assisted by filtration aids (Nedić Grujin et al., 2023). The filter cake is formed on the filter leaves and consists of a filtration aid containing absorbed oil and waxes on its surface. As part of the oil is lost with the filter cake during the waxes removal, it is necessary to determine their quantities and other parameters affecting the process (Casas et al., 2015). In this regard, the aim of this work is to determine the oil losses with the waste filter cake after oil winterization. Oil content in filter cake indicates direct oil losses during oil refining, but also influences the potential application of filter cake. Also, by applying MLR, a model was obtained for prediction of oil losses based on the waxes content in oil before the filtration, the amount of filtration aid and the concentration of suspension of filtration aid and oil. Obtained results can be used as a valuable data in the potential valorization of the filter cake and thus waste reduction.

2. METHODS

Oil samples with different wax contents were used for the investigation. Samples were taken during the industrial refining of sunflower oil (Figure 1), i.e. in the step of wax removal (winterization). In addition to oil, filter cake samples were also examined. Filter cake samples were taken at the end of each filtration cycle (22 in total) after drying the filter with compressed air. The following cellulose-based filtration aids were used: ECO950, EFC1350 and EFC950. Filter aid quantity used for application and dosing (Q) was between 250 - 455 kg, while the concentration of the filter aid and oil suspension (CS) was 0.10 - 0.31%. Total wax content (W_in) was investigated in oils before filtration using gravimetric method, described by Nedić Grujin et al. (2023). The oil losses (OL) with a filter cake are calculated based on the total extracted substances and based on the filtration aid quantity.

3. RESULTS AND DISCUSSION

Based on the experimentally obtained data by examining the composition of the filter cake and oil losses, the multiple linear regression was applied and obtained a model for the prediction of oil losses with the filter cake in one filtration cycle (Table 1). The oil losses (OL) prediction model used wax contents in the oil before the filter (W_in) (values between 281 - 549 mg/kg), filter aid quantity used for application and dosing (Q) and the concentration of the filter aid and oil suspension (CS) as independent variables. Based on the Pearson correlation coefficient value (0.7760) and other validation parameters shown in Table 2 it can be concluded that the obtained model does not have high quality, but still can serve to predict oil losses with the filter cake at the end of each filtration cycle.

4. CONCLUSIONS

The oil loss is a very important economic and ecological parameter of the oil refining process, therefore its prediction is also very important. In this paper, a model for prediction of oil losses with waste filter cake based on the wax contents in the oil, quantity of filter aid and the concentration of the filter aid and oil suspension was obtained. The resulting model can be used to predict oil losses, however, it could be improved by selecting other independent variables, which will be part of future research.

5. ACKNOWLEDGEMENTS

This research was supported by the Science Fund of the Republic of Serbia, #Grant No 7752847, *Value-Added Products from Maize, Wheat and Sunflower Waste as Raw Materials for Pharmaceutical and Food Industry - PhAgroWaste*.

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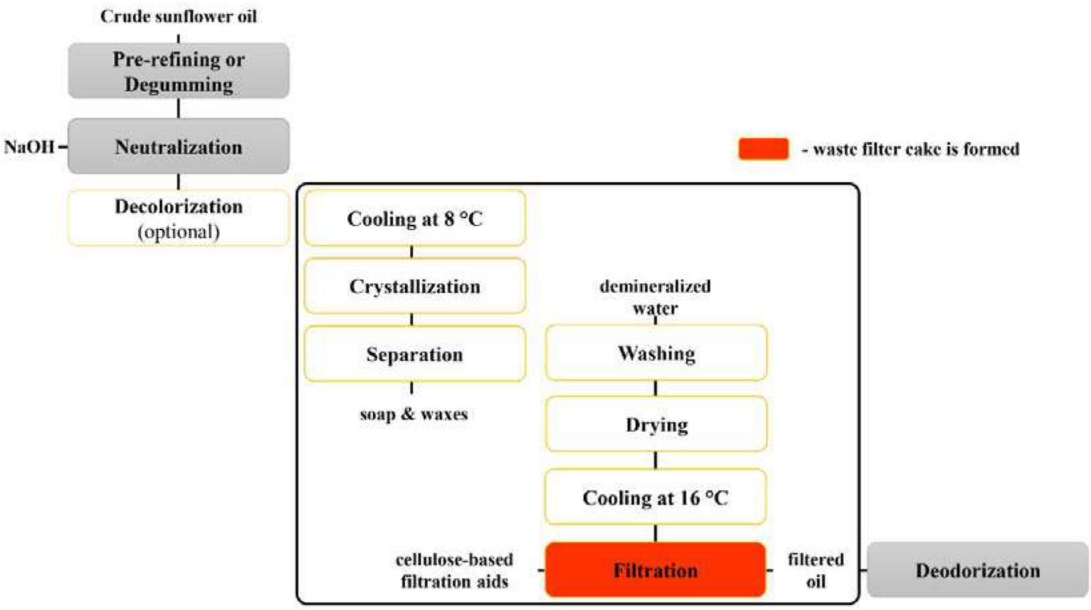

Figure 1. Industrial refining of sunflower oil emphasizing winterization facilitated by the cellulose-based filtration aids

The equation of the MLR model
$OL = 0.001\ (\pm 40.376 \cdot 10^{-5})\ W\_in - 0.001\ (\pm 0.000)\ Q + 0.684\ (\pm 0.493)\ CS - 0.356\ (\pm 0.222)$

OL - oil losses; W_in - wax contents in the oil before the filter; Q - filter aid quantity used for application and dosing; CS - concentration of the filter aid and oil suspension.

Table 1. MLR model for prediction of oil losses with waste filter cake

Statistical validation parameters		Value
R	Pearson's correlation coefficient	0.7760
R^2	Coefficient of determination	0.6021
F	Fisher's value	9.078
R^2_{adj}	Adjusted coefficient of determination	0.5357
R^2_{cv}	Cross validation coefficient of determination	0.3741
RMSE	Root mean square error	0.2623
PRESS	Predicted residual sum of squares	0.1774
TSS	Total sum of squares	0.2834
PRESS/TSS	Predicted residual sum of squares / Total sum of squares	0.6259
SD	Standard deviation	0.0792
VIF1	Variance inflation factor	4.6798
VIF2	Variance inflation factor	1.7613
VIF3	Variance inflation factor	3.3857

Table 2. Statistical validation parameters of the obtained MLR model

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Investigation of wax content in sunflower winter cake

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1. INTRODUCTION

Waxes are esters of low molecular weight monohydroxyl alcohols and long chain fatty acids. Waxes origin is from the non-glyceride components of some vegetable oils. Pure sunflower waxes are white crystals, with specific gravity 0.97 g/cm^3, melting point 76 - 77°C, acid value 0.1 - 0.3 mgKOH/g, saponification value 85 - 88 mgKOH/g and iodine value 10 - 12 g/100 g. Although their content is very low (0.05 - 0.15%), waxes cause a distinct turbidity of the oil, so their separation is necessary during refining in order to obtain a clear edible oil (Kochhar et al., 2020).

Waxes are removed from the oil in the winterization stage and remain in the winter (filter) cake. Winter cake is a by-product of sunflower oil rafination that is usually treated as waste. According to the Statistical Office of the Republic of Serbia data, in Serbia is produces an average of 160000 to 180000 tons of refined sunflower oil annually, resulting in approximately 40000 to 45000 tons of filter cake, which practically represents waste. This represents an additional environmental and economic problem of sunflower oil refining. Valorization of filter cake is possible through selective extraction of sunflower waxes. In this regard, the aim of this work is to examine the chemical composition of the filter cake obtained by winterizing sunflower oil and to determine the waxes content.

2. METHODS

Filter cake samples obtained at the end of filtration cycle in the sunflower oil winterization step were used for the investigation (Figure 1).

Moisture content in the filter cake was determined according to ISO 665:2000. The total hexane-extracted substances were determined according to ISO 659:2009. Total wax content was investigated using gravimetric method, described by Nedić Grujin et al. (2023).

3. RESULTS AND DISCUSSION

Winter cake remains on a filter leaves after the oil winterization (Figure 2). Sunflower oil filtration is facilitated by the cellulose-based filtration aid, therefore, obtained filter cake, in addition to waxes and residual oil, also contains filtration aid.

In the investigated winter cake, the moisture content amounted 4.91 ± 0.07%. The total hexane-extracted substances content found in the cake was 75.10 ± 1.10%, thus, filtration aid content was about 25%. The total hexane-extracted substances mainly contain oil and waxes. Total waxes content found in the cake sample were 39.21 ± 1.10%. Compared to other sources of sunflower waxes, winter cake is by far the richest in waxes. Unrefined sunflower oils contain 0.05 - 0.40%, while sunflower seed hull contains below 3% of waxes.

4. CONCLUSIONS

Investigated winter cake contains high wax content (39.21 ± 1.10%), thus cake present source of waxes potentially used in other industries (cosmetics, pharmaceutical etc.). Further research in this area will be directed to sunflower waxes isolation from winter cake in higher amount and its application in cosmetics and pharmaceutical industry products.

This will significantly contribute to this by-product of sunflower oil refining becoming a "higher value" product. Due to the reduction of oil losses and the reduction of the amount of unused by-products, the refining process would become an economically and environmentally acceptable process.

5. ACKNOWLEDGEMENTS

This research was supported by the Science Fund of the Republic of Serbia, #Grant No 7752847, *Value-Added Products from Maize, Wheat and Sunflower Waste as Raw Materials for Pharmaceutical and Food Industry - PhAgroWaste*.

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Figure 1. Waste winter cake obtained after sunflower oil winterization process

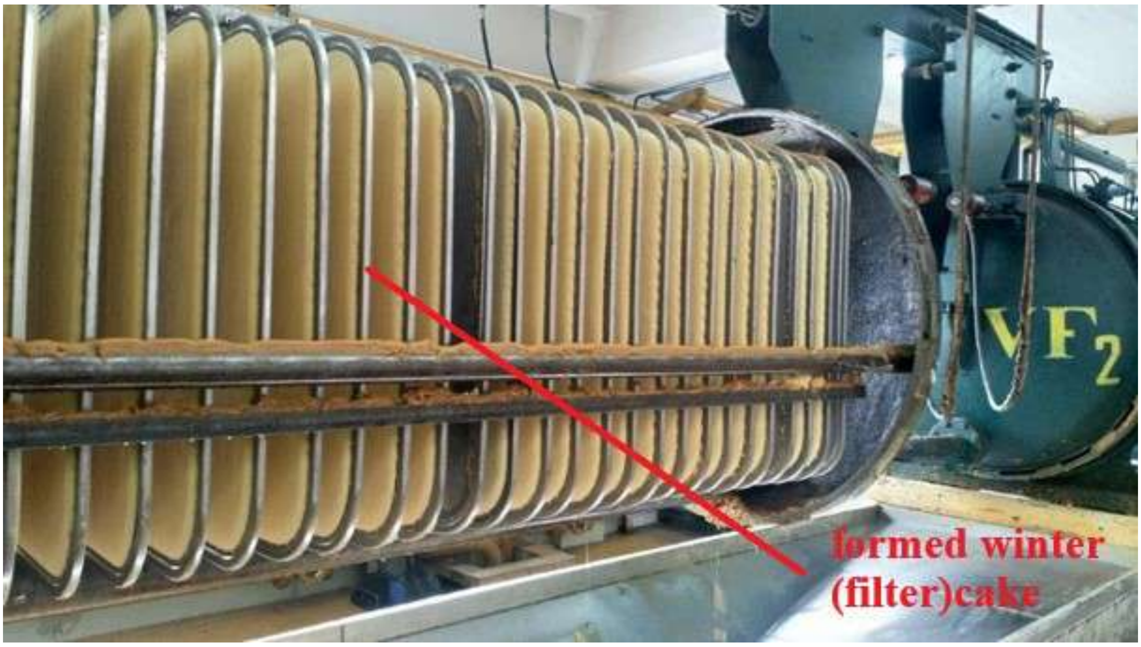

Figure 2. Filtration after wintarization of sunflower oil on a horizontal pressure leaf filter

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Novel Sustainable Food Profiling Model to evaluate the absolute environmental sustainability of foods while considering nutritional quality

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1. INTRODUCTION

Numerous studies show that shifting towards low-emission diets can reduce the environmental impact of food systems while ensuring adequate nutrition, and the issue of keeping global food consumption within the safe operating space (SOS) (i.e., planetary boundaries)[1] has been addressed in the EAT-Lancet Commission's framework for a planetary healthy diet.[2] However, nutritionally adequate and environmentally sustainable food consumption and production can include a wide selection of foods, which requires detailed information on individual food products. Also, from industry and consumer perspectives, product-specific information is often more useful than diet-level results. To evaluate product-level information, we introduce Nutrient Index-based Sustainable Food Profiling Model (NI-SFPM), a novel approach that combines environmental and nutritional aspects to evaluate the sustainability of food products and profile them as sustainable or unsustainable against the assigned share of SOS (SoSOS).

2. METHODS

The NI-SFPM combines the methodological approaches of nutritional life cycle assessment (nLCA)[3] and planetary boundary-based life cycle assessment (PB-LCA)[4] (Figure 1). The model compares the nutrient composition of food products against the daily recommended intakes and the environmental impacts against the SoSOS (share of planetary boundaries assigned for food system). To showcase the NI-SFPM's applicability, an assessment of 559 food products across various categories was conducted by applying product-group specific NR-FI nutritional functional units[5] and evaluating the SoSOS offood systems[2] based on the nutritional functional units. The food product selection and nutrient composition were derived from the Food Composition Database Fineli®[6], and environmental impacts from the Agribalyse[7] database using the ReCiPe 2016 endpoint (H) LCIA-method[8].

3. RESULTS AND DISCUSSION

The results demonstrate the model's effectiveness in differentiating food products and food categories based on their environmental and nutritional sustainability performance. The model promotes for example many vegetables, whole grain foods, legumes, and some fish, as sustainable food products, which aligns with recommendations given in several diet-level studies (Kyttä et al., unpublished).

4. CONCLUSIONS

By evaluating the sustainability of food products, the NI-SFPM enables informed decision-making for consumers, policymakers, and food industry stakeholders. Moreover, the NI-SFPM identifies areas for improvement in both environmental and nutritional aspects, thereby assisting in optimising production processes, sourcing sustainable ingredients, and enhancing product formulations.

5. ACKNOWLEDGEMENTS

We acknowledge the funding received from the Ministry of Agriculture and Forestry.

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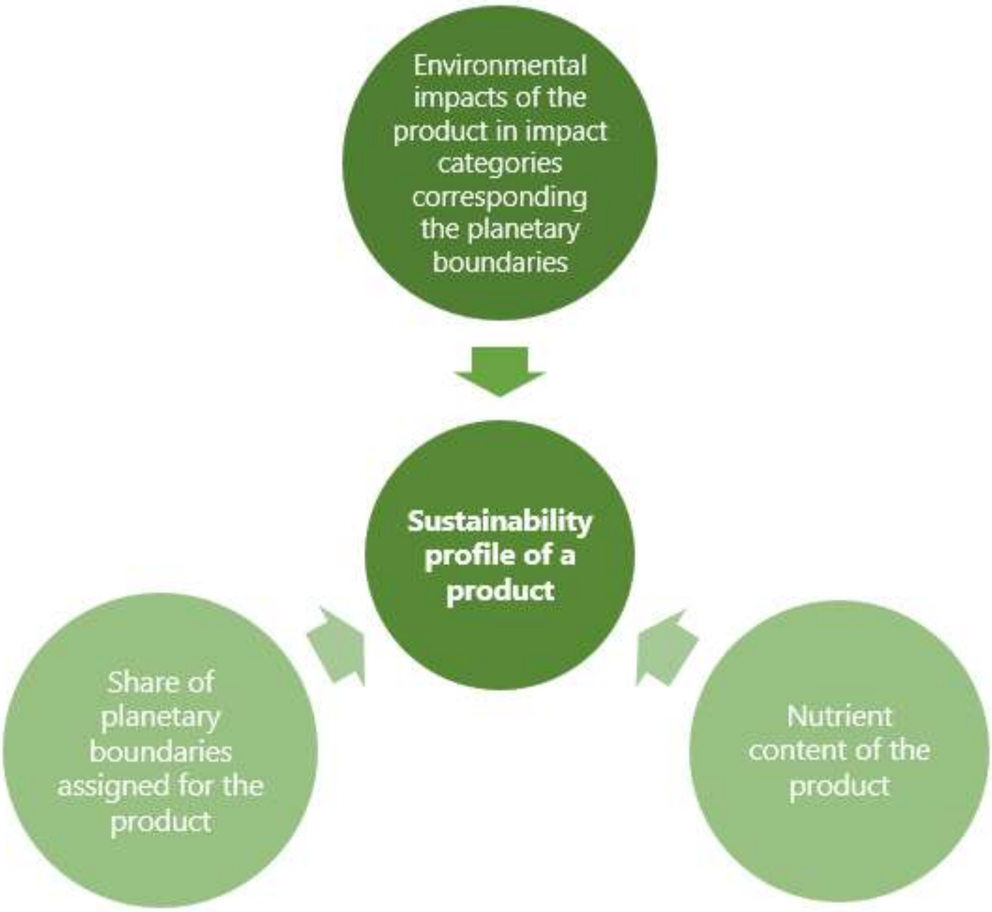

Figure 1. The starting points of the NI-SFPM.

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Eating Within Planetary Limits- Life Cycle Assessment of Food Waste Prevention and Dietary Shifts in Danish Universities

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1. INTRODUCTION

Climate change is a significant threat for the health of human-being and society from various perspectives. In 2022, 735 million people lived in hunger, and over 3 billion people are unable to afford a healthy diet, which undoubtedly exacerbates the threat to global security (United Nation, 2023). While social stability is threatened, the environmental safety of the Earth faces significant challenges. The concept of planetary boundaries (PB) was established in 2009, which aims to define the environmental limit for human safety operation, and in the 2015 update, four of nine PB have been transgressed (Steffen et al., 2015). The food system has long been recognized as one of the driving forces behind environmental change. Under dual pressures, it becomes crucial to focus on how the food system can better nourish humanity while reducing environmental impact.

2. METHODS

Life cycle assessment (LCA) is a method to evaluate the EI of a product through the life cycle from the origin of raw material, processing, manufacturing, distribution, consumption, and waste management (Ilgin & Gupta, 2010).We focus on four key impact categories from the ReCiPe2016 life cycle impact assessment (LCIA) method, chosen for their relevance to the studied systems and their importance in both local and global socio-geographical contexts. These include global warming, marine eutrophication, mineral resource scarcity, and water consumption. Additionally, we consider the blue water footprint due to the water-scarce nature.

3. RESULTS AND DISCUSSION

Over the two-year observation period, significant changes were observed in the sales of plant-based foods in two out of the three cafeterias participating in the experiment. Trends suggest a growing acceptance of plant-based foods in Danish cafeterias year by year.

Based on the weight of a single food portion, the average environmental impact of plant-based choices was found to be lower than that of animal-based foods. However, plant-based foods also exhibited lower protein content and energy compared to animal-based foods. This reveals potential challenges associated with plant-based foods and provides direction for future research: How can we ensure a low environmental impact while also ensuring consumers' nutritional intake is adequate?

We found that in a university canteen setting, replacing animal-based foods with plant-based alternatives can reduce environmental impact across observed metrics. However, regarding the sales of individual menu items, it was observed that the waste proportion of plant-based foods was higher than that of animal-based foods. Nevertheless, due to the lower environmental impact of plant-based foods, the observed environmental impact still remained lower than that of wasting animal-based foods.

4. CONCLUSIONS

In conclusion, this study analyzed the nutritional composition and environmental impacts of plant-based and animal-based foods across different scales, revealing the promising potential of plant-based foods in cafeteria environments. Future research directions could explore strategies to enhance the acceptance of plant-based foods, reduce waste associated with plant-based options, and ensure nutritional content while maximizing their potential for low environmental impact.

5. ACKNOWLEDGEMENTS

This research was performed in the scope of the FOODRUS project that has received funding from the European Union's Horizon 2020 research and innovation program (grant agreement no. 101000617).

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Supplementary materials

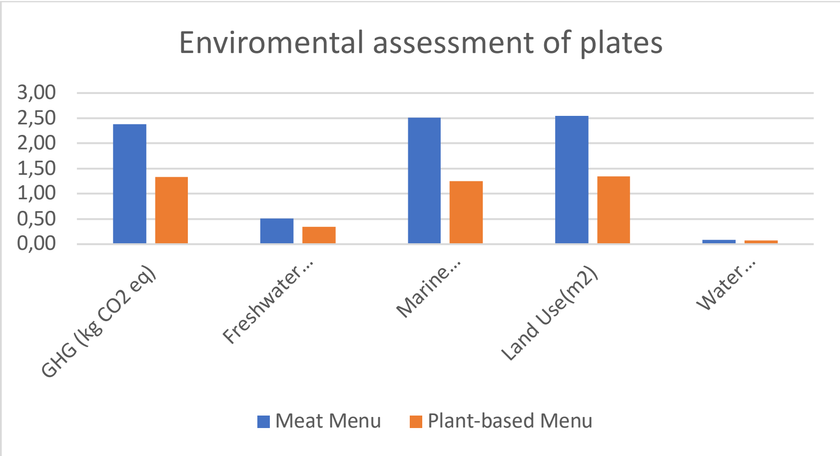

Figure 1. Environmental assessment of plates

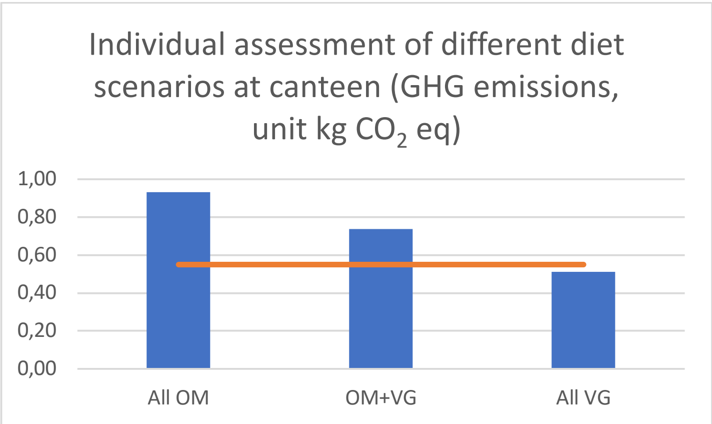

Figure 2. Individual assessment of different diet scenarios at canteen

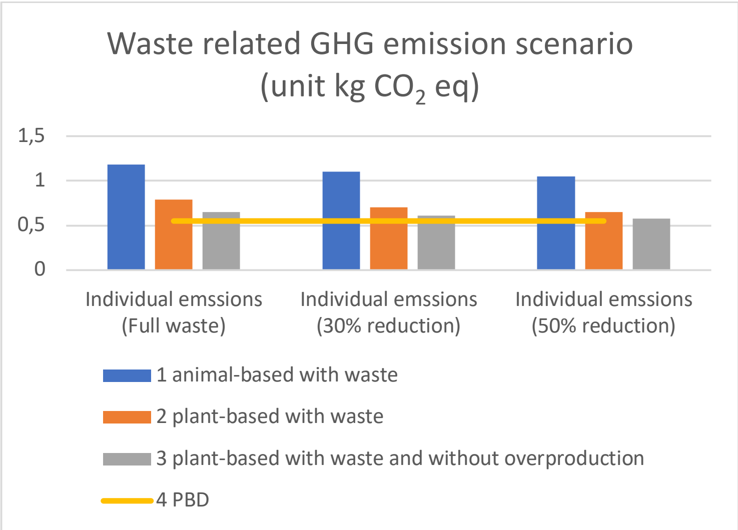

Figure 3. Waste related GHG emission scenario

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The Potential of National Dietary Guidelines to Meet Planetary Boundaries: A Life Cycle Assessment of Canada's Food Guide

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1. INTRODUCTION

The Canada Food Guide (CFG) has been used to inform Canadians on nutrition since 1942, evolving to reflect updated science on nutrition and public health goals. However, the growing concern for environmental issues calls for a diet that not only meets nutritional needs but also has a reduced environmental impact, considering the significant contributions of food systems, particularly animal production(1). While there is a growing body of knowledge on sustainable diets research, there is still little known about the environmental impacts of national dietary guidelines. Although the recent version of CFG released in 2019 mentions some general guidance around reducing impacts of food consumption (eat more plant-based protein, reduce food waste), there have been calls to evaluate the environmental impacts of following the CFG(2). The objective of this study is to quantify the impacts of the average dietary pattern for a person living in Ontario, Canada, and to formulate an average dietary pattern that adheres to the 2019 CFG, aiming to maximize nutrition while minimizing life cycle environmental impacts.

2. METHODS

This study applies LCA and linear optimization with SciPy HiGHS Linear Programming Optimizer(3,4), with specific constraints to design different dietary patterns (omnivore, vegetarian, pescatarian, and no red meat) that maximize nutrition and minimize impacts. The average diet for Ontario was based on the food items reported from the 2015 Canadian Community Health Survey (CCHS) (6). The optimized diets were determined using volumetric ratios given in the 2019 CFG converted to mass using food density data. Snacks, sweets, alcohol, sweet beverages, and saturated fats are removed in the linear optimization model, but all other food types are kept to allow for current food preferences. For LCA, the functional unit is 2000 kcal based on the recommended daily average intake for adults and youth in Canada as well as the Nutrient Rich Factor (NRF version 9.3) score. A Canadianized life cycle inventory (LCI) developed within openLCA was used to assess the cradle-to-cooking gate environmental impacts of the optimized diets. TRACI 2.1 and Water Scarcity were used to assess impacts.

3. RESULTS AND DISCUSSION

This study presents the findings for four optimized dietary scenarios: omnivore, vegetarian, pescatarian, and no red meat compared to the Ontario average diet. Figure 1 illustrates significant shifts in food consumption required to meet the 2019 CFG. Notable changes include a substantial increase in plant-based protein intake (345.7g, +1095%) and a reduction in animal-based proteins (227.7g, -51.9%). The optimized omnivore diet has a GWP of 4.4 kg CO_2 eq (-17.0%), 3.6 kg CO_2 eq (-32.1%) for no red meat, 3.4 kg CO_2 eq (-35.8%) for pescatarian, and 3.2 kg CO_2 eq (-39.6%) for vegetarian, compared to 5.3 kg CO_2 eq for the average Ontario consumption. Even after optimization, the GWPs still exceed the climate boundary of 1.1 kg CO_2 eq per 2000 kcal. Animal protein consumption remains the hotspot, but its impact is much smaller in the optimized diets. The contribution to GWP from increased plant protein consumption in the optimized diet only increases slightly. Figure 2 and Figure 3 show similar trends for GWP and eutrophication per 2000kcal and per NRF9.3. Data for other impact categories will be presented in greater detail.

4. CONCLUSIONS

The study demonstrates the potential of using linear optimization with Canada's Food Guide to create nutritionally balanced diets that significantly reduce environmental impacts. Further research is needed to refine these dietary patterns.

5. ACKNOWLEDGEMENTS

The authors want to acknowledge the Social Sciences and Humanities Research Council and the Natural Sciences and Engineering Research Council of Canada for funding this research.

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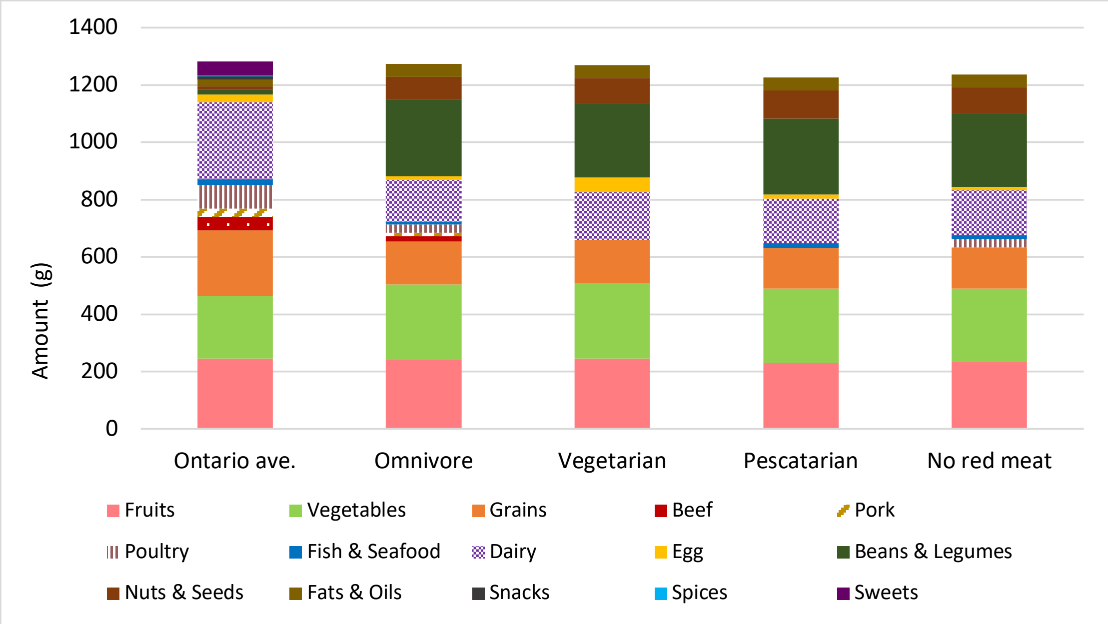

Figure 1. Food Amounts for Ontario Average Diet vs. Optimized Diet in four scenarios

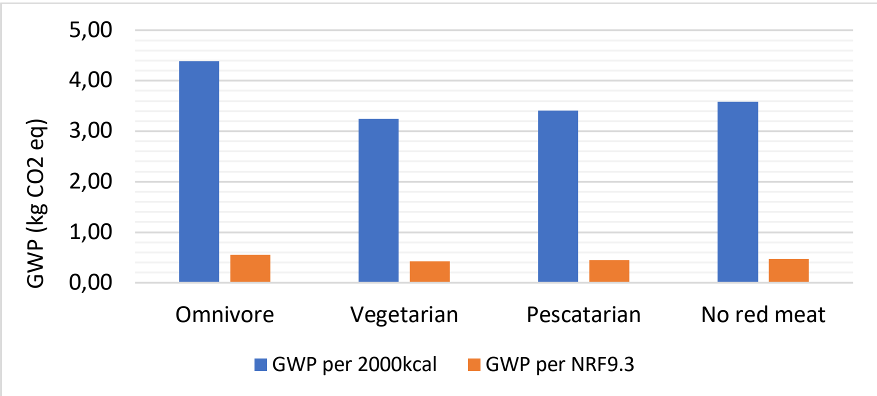

Figure 2. GWP per 2000kcal vs. GWP per NRF9.3 for Optimized Diet in four scenarios

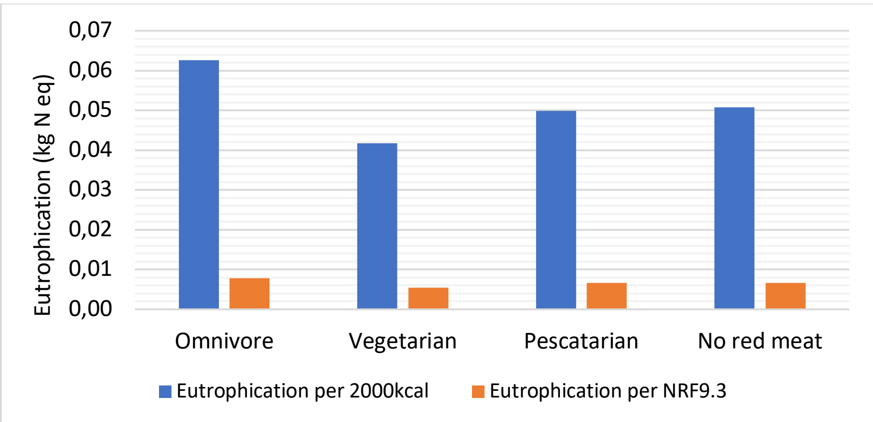

Figure 3. Eutrophication per 2000kcal vs. Eutrophication per NRF9.3 for Optimized Diet in four scenarios

Life Cycle Assessment of Plant-Forward Meals at Canadian University Campuses

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1. INTRODUCTION

Campus food significantly influences university students' well-being through nutritional intake, overall health, academic performance, and dietary behaviours (Caruso et al., 2023; Payne-Sturges et al., 2018). As the sustainability of food systems becomes increasingly critical in the face of climate change, campus food must not only prioritize health and nutrition but also incorporate sustainability into practices. As such, universities across Canada are implementing climate mitigation and sustainability goals within their mission, and reporting on progress. Given the significant environmental impacts of the food system from farm-to-fork, some chefs and sustainability managers are beginning to address sustainability issues within food services by reducing meat in their menus or replacing it with substitutes, increasingly known as 'plant-forward' eating. However, there is limited information on the environmental impacts of these meals. Understanding these impacts is essential for developing strategies to promote sustainable food choices and for informing young adults who are in a transition period of forming new eating habits. This research quantifies the nutrition and life cycle environmental impacts of plant-forward meals created for several university campuses across Canada and compares them to conventional meat-based meals.

2. METHODS

We used Life Cycle Assessment (LCA) to quantify the cradle-to-cooking gate environmental impacts for the recipes provided by partner universities across Canada. We used two functional units: 1000 calories and the Nutrient Rich Factor (NRF version 9.3), which was also a measure of the nutrition of each recipe. The NRF for each ingredient in the recipe was calculated using the Canadian Nutrient File (CNF) database. Material and energy flows were based on the recipes provided by partner universities. We used a Canadianized life cycle inventory (LCI) developed within openLCA and using the ecoinvent© LCI database. We applied TRACI 2.1 as well as Water Scarcity impact assessment methods.

3. RESULTS AND DISCUSSION

We present results for nine pairs of recipes and 19 single recipes. Among the nine pairs, six pairs are meat-based with a complete substitution of meat versions, while the other three pairs are meat-based with their respective partial meat substitution version. Figure 1 shows a clear trend towards lower GWP for plant-forward meals. For example, the Montreal Smoked Meat Hash has a GWP of 6.2 kg CO_2 eq/1000 kcal, whereas its plant-forward counterpart, the Beyond Skillet, had a much lower GWP of 1.7 kg CO_2 eq/1000 kcal, which is a 73.3% reduction. The same pattern is also observed for eutrophication (Figure 2).

A comparison of the environmental impacts using caloric and nutritional functional units shows that the animal-protein dishes still have higher impacts than plant-forward dishes (Figure 3), with the exception of fish tacos which has a lower impact (1.0 kg CO_2eq/NRF) than jackfruit tacos (1.4 kg CO_2eq/NRF). Jackfruit is used to mimic the texture of meat and fish, but has little nutritional value.

Data for other recipes including other impact categories will be presented in greater detail.

4. CONCLUSIONS

Results suggest that climate change impacts and mitigation potential between animal-based protein dishes and plant-forward dishes will depend on which meat is being used. A major challenge in doing LCA of alternative proteins is having representative data for new crops and ingredients which have not been well characterized.

5. ACKNOWLEDGEMENTS

We acknowledge the funding from the Guelph Institute of Environmental Research as well as from the Social Science & Humanities Research Council's Partnership Engagement Grant.

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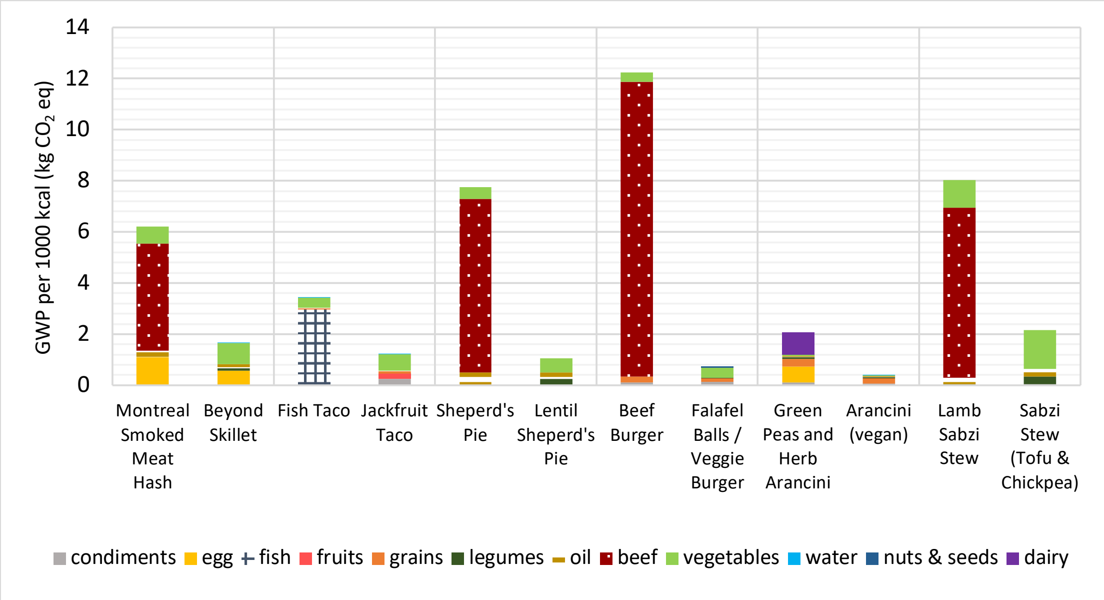


Figure 1. GWP results for 1000kcal of recipes - complete substitution pairs

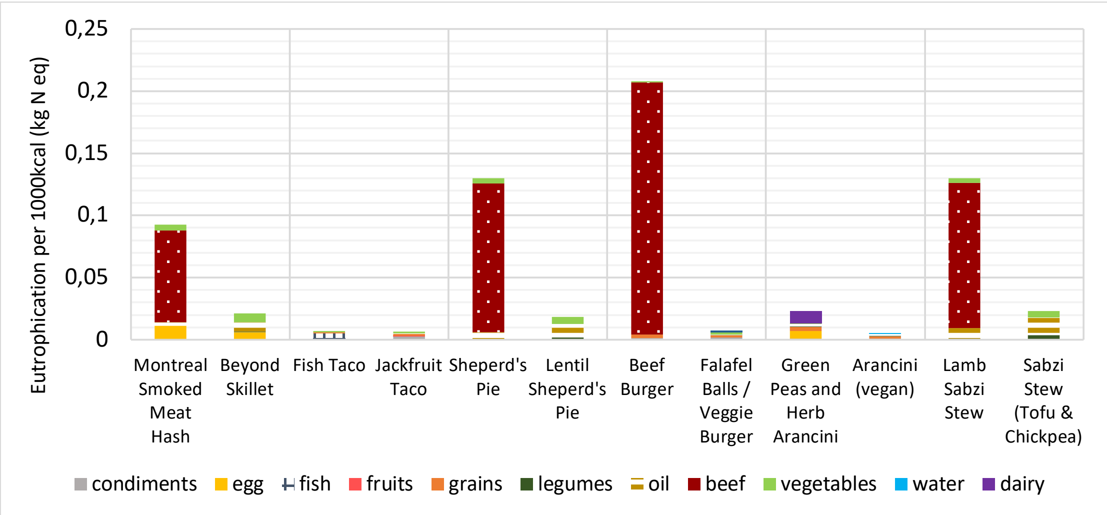
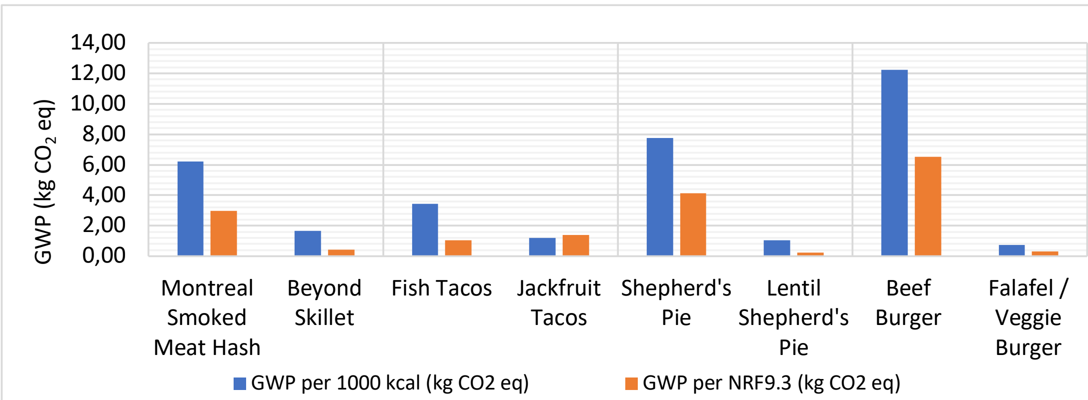


Figure 2. Eutrophication results for 1000kcal of recipes - complete substitution pairs

Figure



3. GWP per 1000kcal vs. GWP per NRF9.3 score for complete substitution pairs

Greenhouse gas accounting and reporting

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Potential Climate Change impact associated with the milk production chain. Is it possible to make a complete assessment?

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1. INTRODUCTION

The climate changes (CC) announced, predicted, and forecasted more than 30 years ago by the IPCC (Intergovernmental Panel on Climate Change) are now felt around the world and their multiple effects on all living species are becoming evident. Scientifically proven to be the result of increased greenhouse gas emissions, they are now the target of numerous projects to reduce their effects due to the climate emergency. In this sense, LCA plays a fundamental role in understanding its main emitters, but it also faces a huge challenge in accounting for this complex carbon balance. This difficulty was observed during the carbon balance calculation of a LCA study carried out for milk production from 14 family farms in São Paulo state (Silva et al., 2023). The objective of this present abstract is to highlight the main points of these calculations.

2. METHODS

The data used in the study in question were collected through local visits. The main agricultural inputs (fertilizers, agrochemicals, soil correctives) for the production of each of the items that make up all the food offered to animals from birth to milk production till the slaughter were included, including the food produced inside and outside the farms. All emissions resulting from transport and the use of agricultural machinery were considered. No changes in land use over the past 20 years were associated with farms located in the sampled area. Methane emissions were estimated based on the composition of the rations offered to cows. In addition to these items normally considered in the LCA calculations, this study incorporated the calculation of carbon absorbed during the photosynthesis process (showed separately) that occurs in the animal feed production stages. Climate Change impact was calculated using the midpoint Recipe 2016 method.

3. RESULTS AND DISCUSSION

The carbon footprint calculated as a simple average across properties for milk was 2189 kg CO_2 eq. per 1000 kg FPCM and for cattle slaughtered subsequently was 15117 kg CO_2 eq. per 1000 kg of live weight of animals. However, when calculating the amount of carbon stored during the agricultural stages of food production, it was found that they represent 76% (milk) and 99% (cattle) of the carbon footprints, a fact that leads us to question whether the current approaches to the calculating of this impact, in which the carbon absorbed in photosynthesis is not accounted for, adequately represent the systems studied. The carbon balances of each production unit show a huge difference in the profile of the farms, which in some cases could even be considered carbon stores. In these calculations, however, the amounts of carbon that are returned to nature, whether in the form of meat, bones and animal excretions, are not considered. On the other hand, there are studies that demonstrate that the use of mulching in agricultural crops can increase carbon retention by the soil.

4. CONCLUSIONS

The results obtained in the published work (Silva et al., 2023) highlight that the amount of carbon absorbed during photosynthesis can significantly alter the results of the carbon balance and it would be important to account for it. On the other hand, it is also important to understand that the carbon balances normally published are incomplete and can hardly represent the complexity of the processes that occur in nature. The balances do not consider the amounts of carbon fixed in other parts of the plants, in the roots and even in the soil. The carbon excreted by animals is also not considered. These items are not easily estimated due to variability in climate and management conditions. All these facts lead to the conclusion that the carbon footprint calculations usually carried out are not complete due to the complexity of the processes involved.

5. ACKNOWLEDGEMENTS

The authors are grateful for the financial support received from the São Paulo State Research Support Foundation (Processes Fapesp 2018/10896-5 and 2018/24730) and Fundepag - Agribusiness Research Development Foundation (Process No. 000153-000197 / 2018), and the support of the owners of the collaborating data farms.

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Radiative forcing climate footprints in China's agri-food systems

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1. INTRODUCTION

Agri-food systems are important emissions sources of non-CO_2 greenhouse gases (GHGs), including the relatively short-lived GHG methane (e.g., in paddy and livestock systems) (https:www.fao.org/3/cc2468en/cc2468en.pdf). A s a country with large population, China's GHG emissions from agri-food systems have received wide attention. Liu et al. (2021) assessed the GHG emissions of China's staple crops, and found that CH_4 emissions from rice paddies accounting for 99% of the total GHG emissions from the source of crop planting. Thus, a research highlight from the journal of Nature claimed that if China's dinners sacrifice some of their rice consumption could slash GHG emissions (https://www.nature.com/articles/d41586-021-02230-1). However, such study which based on the global warming potential (GWP 100) indicator, summing up the climate impact of short- and long-lived GHGs, creates challenges for decision-making (Ridoutt and Huang, 2019). Here we applied a newly developed radiative forcing-based climate footprint (RFCF) indicator to assess the climatic impact of non-CO_2 GHG emissions from China's agri-food systems. The RFCF results were compared with the GWP results. Our purpose was to clarify the differences between these indicators, with the aim to inform actions to stabilize the climate so that they can reliably address policy objectives.

2. METHODS

The RFCF indicator describes the contribution to global radiative forcing (RF), quantifying the contribution to RF associated with current and historical emissions without equivalency factors (Ridoutt and Huang, 2019). We have updated the RFCF method by applying the newly reported parameters (such as atmospheric lifetime and radiative efficiency) from IPCC 6th Assessment Report (Luo et al., 2023). The inventory of non-CO_2 GHG emissions (including CH_4 and N_2O) for China's agri-food systems, covering the period 1961 to 2021, was obtained from FAOSTAT (https://www.fao.org/faostat/en/#home). In this study, we compared the historical non-CO_2 GHG emissions of China's agri-food systems reported using GWP100 and the profile of RFCF over time (Luo et al., 2023).

3. RESULTS AND DISCUSSION

The amount of CH_4 emissions from China's agri-food systems is about 10 to 40 times higher than N_2O (Figure 1). The total GHG emissions based on GWP100 have experienced an overall increasing trend, but decreased recently caused by the decrease of N_2O with a high equivalency factor (GWP100=273) (Figure 2). The key point is that GHG emissions based on GWP100 and the RFCF are trending in opposite directions recently (Figure 3). It shows that the contribution to RFCF from CH_4 emissions is keeping steady since 2005. This is due to agricultural CH_4 emissions being in steady decline since 2005, combined with the relatively short lifetime in the atmosphere of historical emissions. In contrast, N_2O form an increasingly important proportion of total RFCF over time. This is explained by an overall increase in the emissions since 1961, as well as the much longer lifetimes of N_2O. The RFCF indicator presents the profile of RF including current and historical contribution, informing about whether progress is being made toward RF stabilization, which is a requirement for climate stabilization. The indicator can inform RF management actions.

4. CONCLUSIONS

This study demonstrates that CH_4 emissions with short atmospheric lifetime, showing a steady impact over time can be consistent with climate stabilization. The RFCF indicator rather than GWP100 has more relevance in aligning food systems with the aspirations of the Paris Agreement, which indicates that RF needs to be managed downwards from current 2.3 to around 1.9 W m^{-2}. The profile of RFCF over time informs about whether progress is being made toward RF stabilization, and can inform RF mitigations.

5. ACKNOWLEDGEMENTS

This work was funded by the National Key R&D Program of China (2022YFD2300600).

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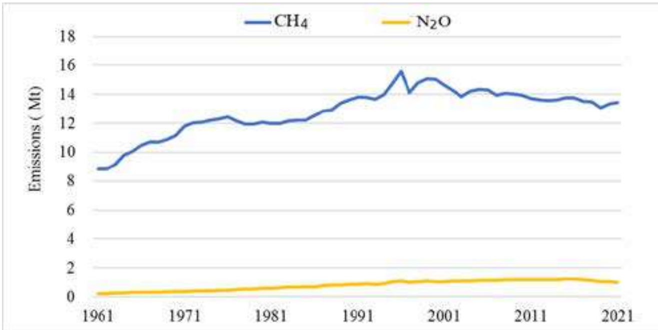

Figure 1. Inventory of CH_4 and N_2O emissions from China's agri-food systems

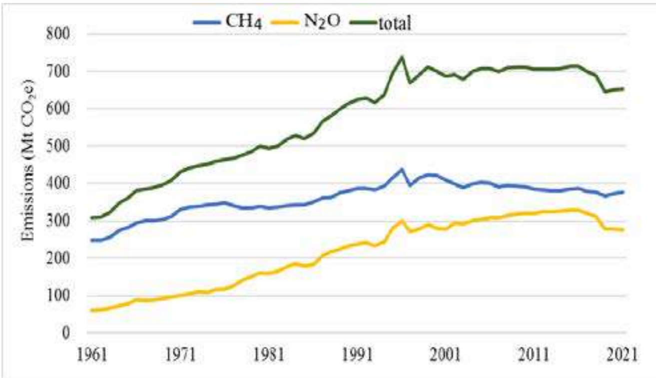

Figure 2. GWP100-based GHG emissions from China's agri-food systems

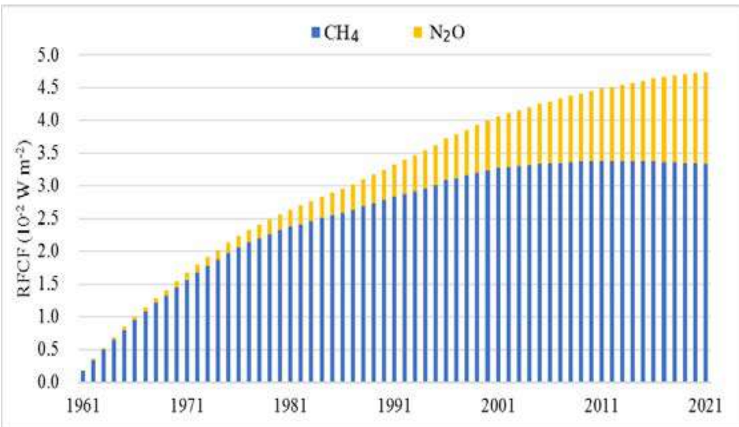

Figure 3. Radiative forcing-based climate footprint from China's agri-food systems

Determination of N_2O emission factor in hydroponic cultivation with alternative nitrogen fertilization sources: the case of Struvite and human urine

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1. INTRODUCTION

In recent years the use of wastewater precipitate struvite (NH4MgPO4·6H2O) as slow-release fertilizer in soil-based agriculture has gained a lot of interest, recycling P and reducing losses into the environment (Ahmed et al., 2018). Recent work has revealed the great potential of struvite in hydroponic agriculture as well as the reduction of P emissions into leachate water (Arcas Pilz et al., 2022). Similarly, urine diversion systems have been deemed a potential solution to the reduction of nitrogen concentration in wastewater, which opens a new possibility to be used as fertilizer (Pimentel-Rodrigues y SivaAfonso, 2019).
While both alternative fertilization sources can pose new paradigms in urban and peri urban agriculture and reduce the reliance on mineral and synthetic fertilizers (Arcas Pilz et al., 2021) their indirect emissions in the form of N_2O have not been defined in emerging hydroponic systems. N_2O is an important and persistent greenhouse gas (GHG) with high global warming potential.
Nitrogen in struvite is found in the form of ammonium, which, when released, can undergo processes of nitrification or dissociation which could lead to the emission of this GHG. Also, in the form of, nitrate, through processes of denitrification, can cause these emissions. At the same time the treatment of concentrated urine through a moving bed biofilm reactor cannot ensure a total nitrification of the effluent which can be then given in the form of ammonium. The present work aims to determine the N_2O emission factor of struvite and treated urine in hydroponic production compared to synthetic NO_3 fertilizer.

2. METHODS

The experimental determination of N_2O is made in the agricultural laboratory in the integrated rooftop greenhouse of the ICTA-UAB building. The production system is hydroponic with an additional installation of four chambers which provide separate spaces for 10 1L plant pots each. Each chamber has a total volume of 0,462m3 respectively and is equipped with sensors for temperature, radiation, and humidity as well as an inlet for a vacuum sampler. The defined experimental crop is lettuce (*Lactuca sativa*) with a defined cropping cycle of 30 days, planted in the commercial substrate perlite. Two consecutive experiments are defined for the comparison of one alternative fertilization method (struvite; urine effluent) to a control treatment, each treatment consisting of two chambers with 10 plants each. The sampling methodology consists of a closed chamber with defined closing periods for pre and post air sampling into airtight 1-L bags. Samples were analysed through gas chromatography with a HP-PLOT-Q column with a makeup gas of 95% Ar / 5% CH4 and an ECD detector, injected manually with an airtight Pressure-Lok Syringe.

3. RESULTS AND DISCUSSION

Preliminary results have shown lower emissions of N_2O in hydroponic production systems compared to soil-based agriculture. Although close to atmospheric concentrations early measurements in the crop cycle have shown greater N_2O emissions through struvite fertilization, which are reduced in later plant stages. Although only preliminary experimental campaigns have been made, a greater emphasis has to be made on the sampling periods and the relationship to irrigation/ fertilization patterns, temperature and humidity during day and nighttime.

4. CONCLUSIONS

Preliminary conclusions of this experimental work are the necessary adjustment of sampling periods during the crop cycle as well as during the daily climatic and radiation patterns.

5. ACKNOWLEDGEMENTS

This study was funded by the Catalan Agència de Gestió d'Ajuts Universitaris i de Recerca (AGAUR) under the g rant 2021SGR00734 Sostenipra, and WEF4Build 2023 CLIMA 00041. BINAFET Project: TED2021-130047B-C2 1, funded by MCIN/AEI/10.13039/501100011033 and the European Union “NextGenerationEU”/PRTR.

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Figure 1. Closed chamber with lettuce (*Lactuca sativa*) and N fluxes.

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Carbon footprints for food systems: A readiness assessment

1. INTRODUCTION

This paper asks what it would take to achieve a system of widespread and reliable carbon footprint information flowing through global food supply chains. Until recently, this idea would have seemed like science fiction. However, the last few years have seen the "fast and furious" rise of environmental impact reporting in food systems, including for carbon footprints (Deconinck, Jansen and Barisone, 2023). The aim of this paper is to identify the necessary building blocks for widespread and reliable carbon footprints, assess to what extent these are in place, and identify priority actions for policy makers, stakeholders, and the research community.

2. METHODS

The analysis in this paper is based on desk research and on expert interviews with a broad range of stakeholders, researchers, standard setters, and policy analysts working on various aspects of the issue. The work benefits from discussions with an expert network assembled by the OECD, as well as discussions with policy makers in OECD member states.

3. RESULTS AND DISCUSSION

This paper identifies seven main “building blocks” for widespread and reliable carbon footprints in food systems. Many elements are indeed already in place, although progress is uneven:

a) Reporting standards and guidelines are quite well developed in general, although there is a need to develop further product category rules and to ensure alignment between standards and guidelines developed by different actors.
b) Farm-level calculation tools exist, but further efforts are needed to ensure these tools’ alignment with reporting standards and guidelines. Tools also need to provide greater transparency. Benchmarking exercises may be needed to compare different tools.
c) Databases with secondary data. It is not always clear to what extent existing databases are consistent with the latest reporting standards and guidelines. Databases should also be refined to provide greater granularity (e.g. moving beyond average values for a country). The proprietary nature and relatively high cost of existing databases may also pose a problem.
d) A way of communicating carbon footprint data along the supply chain, so that detailed calculations by producers at one stage of the supply chain can be used as input at the next stage. This requires interoperability of data formats and software solutions. Major progress has been made in this area through the work of the Partnership for Carbon Transparency (PACT). Moreover, several pilot projects are underway.
e) A way to ensure the integrity and quality of the data, e.g. through third-party verification. The final carbon footprint of a product will consist of emissions from multiple actors in multiple countries. Ensuring the integrity and quality of the data would then probably require traceability and mutual recognition of assurance statements.
f) A way to scale up carbon footprint calculations while keeping administrative costs low. Scaling up carbon footprints in food systems will require finding ways to make the collection of primary data at farm level as easy as possible. Several options exist, for example using existing sources of data to “pre-populate” farm-level calculations; working with agricultural extension services, cooperatives, and farmer associations to help farmers with data entry; etc.
g) A way to update these elements as new scientific insights become available. Reporting standards, calculation tools and databases need to reflect the latest scientific insights. A process is also needed to evaluate new mitigation technologies and update calculation tools to reflect these new options. At the moment, most initiatives do not have a process for reviews and updates, with the exception of ISO standards. Actors should align on realistic timelines for such review processes to ensure continuous improvement of the overall system.

4. CONCLUSIONS

The analysis in this paper shows the availability of many of the building blocks for widespread and reliable carbon footprints in food supply chains. However, not all of these are equally well developed, and some existing initiatives need to be made interoperable. The analysis in this paper can help policy makers, researchers, and stakeholders identify key priorities for future investments.

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Footprint Pro Carbono: a robust tool for carbon accounting of agricultural products

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1. INTRODUCTION

The pressing urgency of global climate change demands immediate action. In Brazil, the agricultural sector stands out as a significant contributor to greenhouse gas (GHG) emissions, representing 33.2% of the nation's total emissions (Brazil, 2021). Effective mitigation and management of GHG emissions in agriculture require robust methodologies, tools, and targeted policies. One such essential tool is Footprint Pro Carbono (FPC), designed to assess the carbon footprint of agricultural products within cropping systems, including key crops like soybeans and corn. This study presents the core features of FPC and insights from a case study involving soybean farmers in Mato Grosso, Brazil's leading soybean-producing state, responsible for a substantial production volume of 38 million tons in 2022.

2. METHODS

The FPC tool, aligning with ISO 14067 and GHG Protocol standards, evaluates GHG emissions' environmental impact in agriculture, aiming to identify intervention opportunities. It calculates the carbon footprint of agricultural products (in kg CO2eq/ton of DM) using a metric ton of product as a reference unit. Spatial coverage includes plot and farm levels, with temporal coverage spanning agricultural harvest or cropping systems. The tool's technology is current, with system boundaries covering processes from cradle to trader’s entrance gate. Background data is from ecoinvent v3.9, while foreground data can be primary or "penalized data" (which corresponds to the highest amounts consumed of each agricultural input observed in Brazilian soybean production). The function of the “penalized data” is to allow a farmer who does not yet have a complete set of primary data to enter the program, but with conservative data. Allocation procedures distribute shared resources and their environmental loads among agricultural products based on resource effect duration and the number of commercial crops grown. Environmental impact assessment uses Climate Change and Global Warming Potential based on IPCC (2021). Uncertainties are addressed via parameter distributions and a Monte Carlo simulation. Farmers input data via an information system, providing details on productive areas, yields, inputs, energy use, and post-harvest processes. Land Use Change emissions use BRLUC v2.0 (Garofalo et al. 2022), and agricultural phase GHG emissions follow IPCC (2019), Tier 1 guidelines.

3. RESULTS AND DISCUSSION

The carbon footprint of agricultural products is visualized by farmers through an integrated information system (Figure 1). GHG emissions are systematically categorized by source (e.g., land-use change, limestone application, nitrogen fertilizers, etc.) and by their biogenic and non-biogenic nature, along with their respective uncertainties. Furthermore, a comprehensive technical report is generated to provide in-depth analysis. Figure 2 illustrates the average carbon footprint of soybeans produced by ten farmers during the 2022-2023 harvest, juxtaposed with both the typical and penalized typical profiles, offering valuable insights into emission variations.

4. CONCLUSIONS

FPC has demonstrated its user-friendly nature, providing accurate reports on the carbon footprint of soybeans with minimal data input. Its intuitive interface facilitates informed decision-making, guiding management strategies to effectively reduce GHG emissions.

5. ACKNOWLEDGEMENTS

The authors would like to thank Débora Camilo, for technical support.

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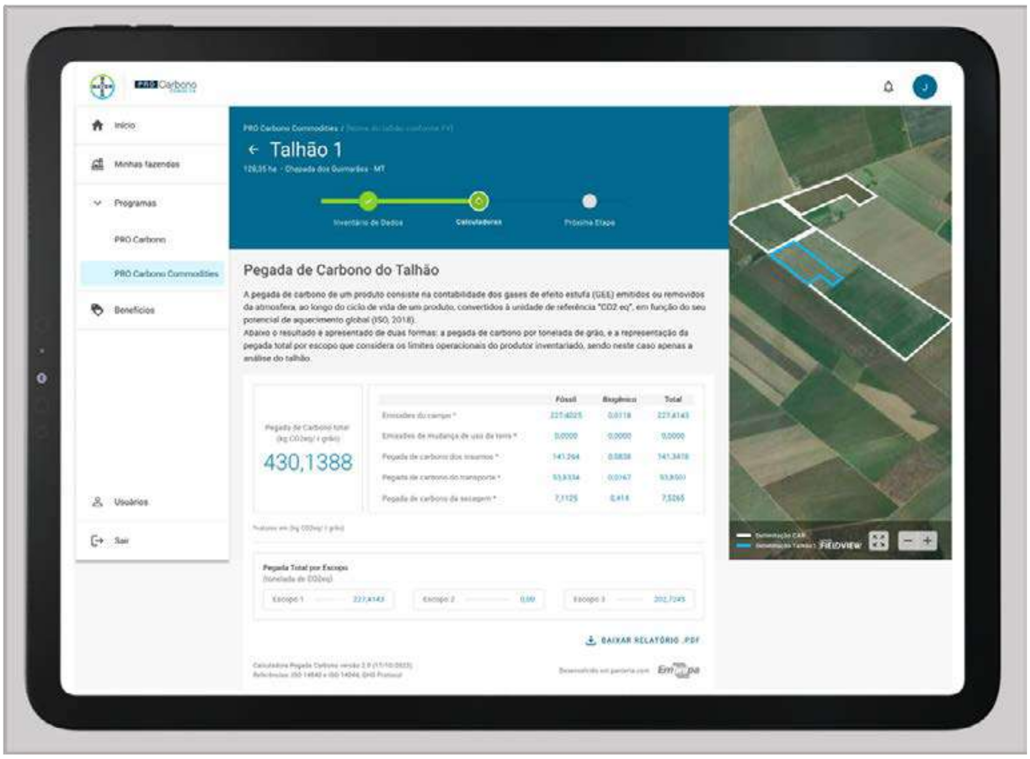

Figure 1. Illustration of the results presented in the Footprint Pro Carbono information system.

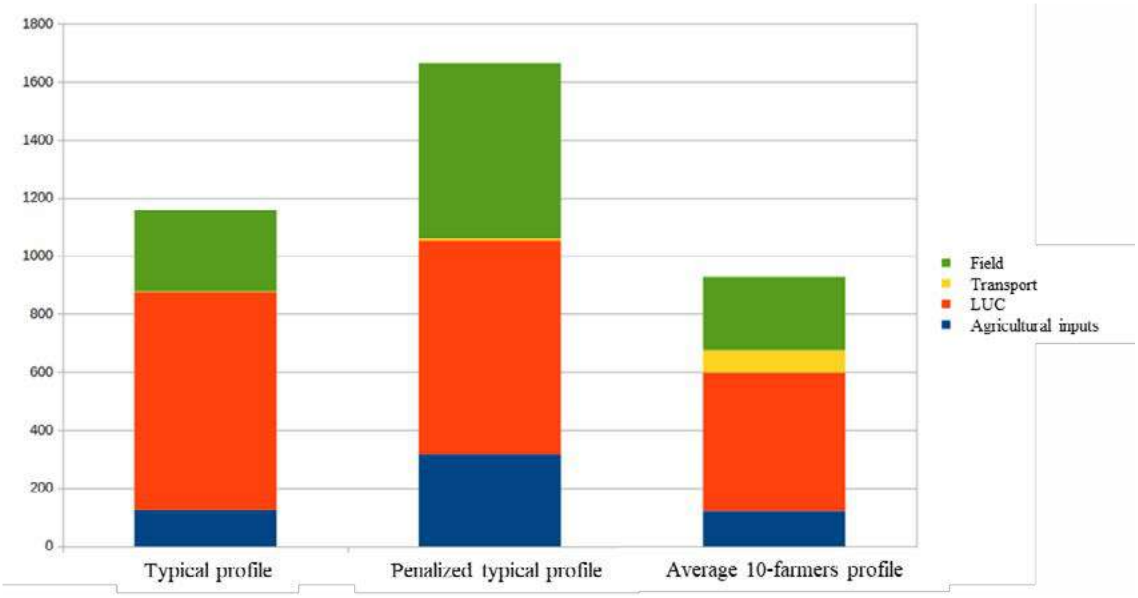

Figure 2. Soybean carbon footprint: 10 farmers from Mato Grosso, season 2022-2023; the typical Brazilian profile and the penalized typical Brazilian profile.

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Evaluating methods to estimate carbon sequestered in biomass and its climate change effects

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1. INTRODUCTION

By 2040, the global average temperature is expected to surpass the critical threshold of 1.5 degrees Celsius above the pre-industrial level. (Stein, 2022). The need for swift, consistent, and substantial carbon dioxide (CO_2) removal from the atmosphere is crucial in order to avert the consequences of climate change. The potential for carbon (C) storage in tree-based systems is promising. However, there is no agreement on how to account for tree biomass C storage in LCA to assess the climate change effects. This study examines various methods for quantifying biomass C storage by trees and explores the climate change effects through a case study on agroforestry in Denmark.

2. METHODS

This research work evaluated and compared four distinct strategies to measure biomass C sequestration: C-budget models, allometric models, parametric models, and process-based growth models. In addition, it summarized and compared several impact assessment methods, including Moura-Costa, Clift & Brandao, Lashof, ILCD, Clift and Brandao, C-seq, dynamic LCA, Müller-Wenk and Brandão, the PAS 2050, and GWP_{bio}.

3. RESULTS AND DISCUSSION

LCA practitioners commonly apply four different methods to estimate biomass C sequestration: process-based growth models, general and specific allometric models, C-budget models, and parametric models. Different approaches to estimating biomass C storage can vary significantly and result in more variations over longer time periods. General models may not very well represent the specific plant species or site climate and soil characteristics. More sophisticated models that consider all such factors typically estimate lower levels of biomass C accumulation. Incorporating tree biomass into a LCA by estimating its climate change effect is challenging and the different approaches yielded varying results due to differences in accounting for time dynamics, reference states etc. Thus, the methods used to account for temporary C sequestration in LCA can influence the outcomes and are sensitive to time perspectives (Brandão et al., 2019).

4. CONCLUSIONS

This paper examines nine methods to evaluate the influence of C sequestration in tree biomass on climate change. Our research suggests that the results of these methods can change depending on the assessment time length and approach selected. It is essential to examine various aspects of impact assessment techniques when interpreting findings. A comprehensive approach is necessary to accurately estimate C storage and its climate effect. This approach should consider the temporal factors, the complexity of the system, the reference state, and the uncertainties associated with the methods. Enhancing the LCA tool with updated methodologies to estimate and characterize biogenic C sequestration can improve accuracy in the future.

5. ACKNOWLEDGMENTS

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An analysis of the mathematical logic on IPCCTier 1 and Tier 2 methods in soil organic carbon storage estimation

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1. INTRODUCTION

It is essential to include soil organic carbon (SOC) balance into life cycle assessment (LCA) for the evaluation of agricultural sustainability (Goglio et al., 2015). To many areas where process-based models cannot be applied, Tier 1 & Tier 2 methods from *IPCC Guidelines for National Greenhouse Gas Inventories* provide a simple calculation for the SOC balance (IPCC, 2019). Here, we explore the implications of applying the IPCC's Tier 1 & 2 to quantify the SOC storage.

2. METHODS

We compared the mathematical logic of Tier 1 & Tier 2 methods ($C_T = C_O \times K$, $0<K$) (IPCC, 2019), and a conceptual model where old SOC decomposition and new SOC formation from plant residues (SOC_{NEW}) are considered ($C_T = C_O \times K' + SOC_{NEW}$; $0<K'<1$, $0<SOC_{NEW}$) (Hu et al., 2022). Where C_O is the SOC storage at present, C_T is the SOC storage after 20 years, K is the coefficient calculated by the land use, field management practices and carbon input at a location, and K' indicates the proportion of C_O remaining in the soil. We assume that the C_O at the location is tested at the beginning.

3. RESULTS AND DISCUSSION

Results showed that if the land use, field management practices and carbon input continued at a location, in terms of the conceptual model (Fig .1), there was a steady SOC storage (C_S), above which the C_T would decrease, while below which the C_T would increase. For the Tier 1 & Tier 2 methods, if 1<K, there was a special C_O lower than C_S, marked as C_A, at which the calculated C_T would be equal to the result from the conceptual model; if K'<K<1, there was a special C_O larger than C_S, marked as C_B, at which the Tier 1 & Tier 2 methods and the conceptual model led to the same C_T.

When 1<K, if C_O<C_A: Underestimations from the Tier 1 & Tier 2 methods would happen in most of the 20 years; if C_A<C_O: The Tier 1 & Tier 2 methods would overestimate the SOC storage for most of the period. The bias grew with the distance between C_O and C_A. Under these two situations, the Tier 1 & Tier 2 methods would suggest cultivating in a land with high SOC storage, which was likely newly converted from a grasslands or forests, being widely known for losing SOC (Kopittke et al., 2017).

When K'<K<1, if C_O<C_B: During the 20 years, the Tier 1 & Tier 2 methods would lead to an underestimation of the SOC storage in the majority of the period; if C_B<C_O: During the same period, the Tier 1 & Tier 2 methods would give an overestimation in most of the years. The bias increased with the gap between C_O and C_B. When K<K', the Tier 1 & Tier 2 methods would underestimate the SOC storage, where the bias increased with C_O. Under these three conditions, the Tier 1 & Tier 2 methods would suggest cultivating in a cropland with lower SOC storage, which tended to be cultivated for long periods, requiring more fertilizers to guarantee the crop yield (Ma et al., 2023).

4. CONCLUSIONS

Soil organic carbon storage is the balance between the new SOC formation and the old SOC decomposition. The results from Tier 1 and Tier 2 methods can be highly variable for fields under different original SOC storage, because the impacts of land use, field management practices and carbon input are finally packed as a coefficient of the SOC storage. The implications of the different SOC methods on the carbon footprint of wheat production will be presented in the full paper and the conference presentation.

5. ACKNOWLEDGEMENTS

This research is sponsored by Academy of Finland: Targeted Academy Project: Digi4CSA: Digital solutions to foster climate-smart agricultural transition.

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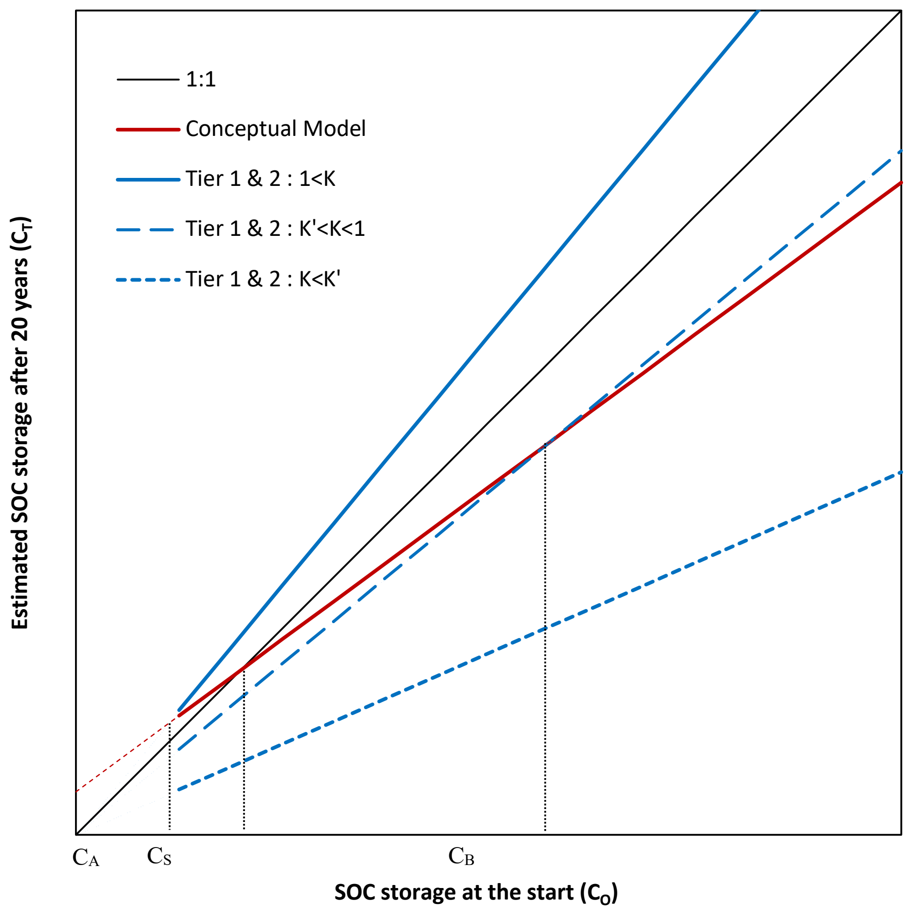

Figure 1. The conceptual figure of the estimated soil organic carbon storage after 20 years (C_T) in terms of the present SOC storage (C_O). The red line means the conceptual model where old SOC decomposition and new SOC formation from plant residues (SOC_{NEW}) are considered ($C_T = C_O \times K' + SOC_{NEW}$; $0<K'<1$, $0<SOC_{NEW}$; where the slope K' indicates the proportion of C_O remaining in the soil). The blue lines are the calculation of IPCC Tier 1 and Tier 2 methods ($C_T = C_O \times K$; $0<K$; where the slope K is the coefficianet calculated in terms of land use, field management practices and carbon input at a location). C_S is the steady SOC storage, while C_A and C_B are the C_O lead to the same results from the two types of calculations with the K value above and below 1 separeately.

Life cycle sustainability assessment of food systems

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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A study of environmental, social and economic sustainability in vegetable and fruit production in Norway

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1. INTRODUCTION

Focus has been on environmental and economic aspects of agricultural sustainability for decades now, while the social aspects have largely been neglected. However, analyses of social sustainability have been facilitated through the development of S-LCA guidelines (UNEP, 2020). Furthermore, there is a tendency to increasingly include social sustainability of in sustainability assessments of agricultural production systems to give a more comprehensive picture of sustainability. Several guidelines have been developed for sustainability assessment on farm level covering all three sustainability dimensions. e.g. Initiative for Sustainable Productive Agriculture (INSPIA; Trivino-Tarradas et al., 2019) and SAFA guidelines (FAO,2013), but these are resource-intensive to use. This study aimed to test a condensed set of indicators for social, economic and environmental sustainability on a group of Norwegian apple and carrot farmers. The aim of the study was to determine whether the indicators could be used to differentiate the level of sustainability between Norwegian vegetable and fruit farmers.

2. METHODS

An indicator set to assess environmental, economic and social sustainability at farm level has been developed together with expert opinion groups and vegetable and a fruit wholesaler (De Sadeleer et al., *submitted*) based on the SAFA- and UNEP setac S-LCA guidelines. The aim was to find a way to assess sustainability that would be less resource-intensive than the above-mentioned frameworks, address all sustainability dimensions, and be targeted towards fruit and vegetable producers (De Sadeleer et al., 2024). The indicator set was tried out by carrot suppliers to the wholesale company and deemed sufficient to meet the sustainability assessment needs of the wholesale company. The indicator set was then tested for 5 and 10 Norwegian carrot and apple producers respectively.

3. RESULTS AND DISCUSSION

The results show that all farmers score high in social and economic sustainability with little spread in indicator scores. The answers indicate that the producers have a strong focus on social sustainability, for example in the form of HSE work, employees` working conditions, rights, wages and living conditions. At the same time, peaks in workload must often be handled by the farmer him/herself, due to strict rules on maximum working hours for employees. The most important negative factor for social and economic sustainability is low income in combination with long working days. This has several consequences, for example, difficulty to recruit the next generation into the profession. Overall, however, most of our informants were very satisfied with their everyday working life. The spread in environmental impact results between producers was higher than for the social and economic sustainability results, see Figure 1 (only results for carrot farms shown).

4. CONCLUSIONS

The study indicates that the social sustainability of Norwegian fruit and vegetable production (F&V) is in general high, with a few exceptions. In addition, the study found higher variability in environmental impacts. The indicator set has not been tested in other countries, but for production in Norway, we can conclude that more work is needed to identify important social sustainability topics in fruit and vegetable production. It will be important to focus more on the farmers themselves and their families.

5. ACKNOWLEDGEMENTS

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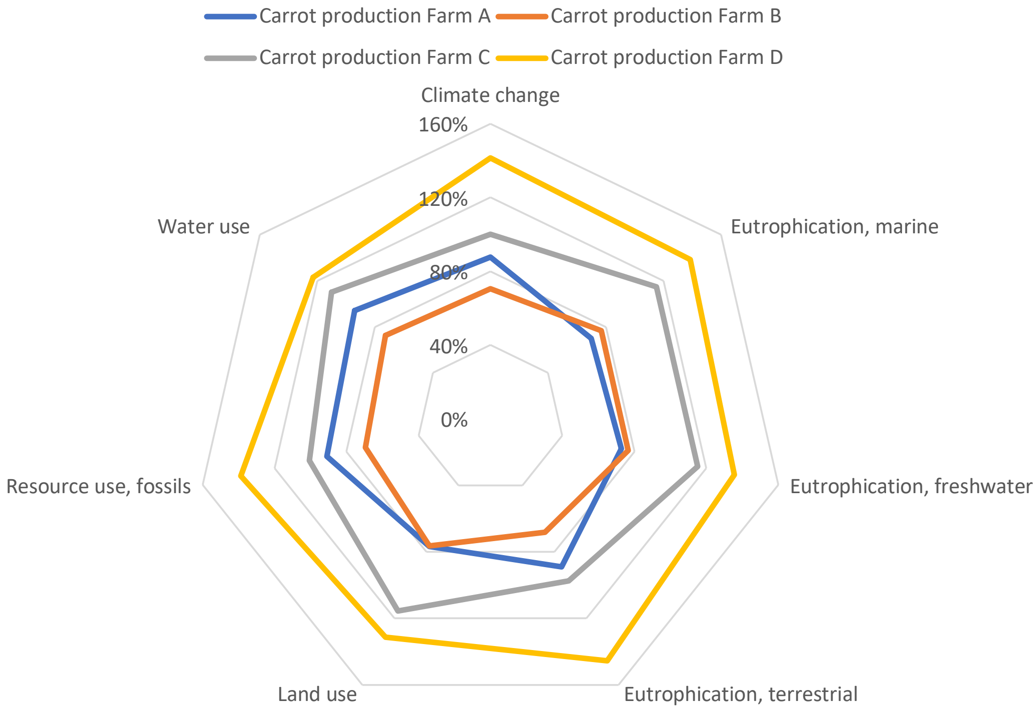

Figure 1.Relative environmental impact of 5 carrot farms compared to the average environmental impact of the 5 farms, for climate change, freshwater eutrophication, terrestrial eutrophication, land use, fossil resource use and water use.

Environmental, economic and social impact of contemporary dairy industry

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1. INTRODUCTION

This is a preliminary study conducted as a foundation for further exploration and project development aimed at creating a sustainable dairy sector. The dairy industry bears a significant responsibility for environmental degradation, primarily due to its extensive use of water and energy, as well as the production of wastewater. Understanding these factors, which contribute to an unsustainable industry, is crucial in ensuring the safety of dairy products for consumers. The purpose of this analysis was to investigate the environmental, economic, and social impact of a dairy industry. This industry comprises both the processing line and the wastewater treatment plant.

2. METHODS

The study was conducted using Life Cycle Sustainability Assessment (LCSA), which encompasses Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Social Life Cycle Assessment (SLCA). To implement this, openLCA was employed to identify the key contributors to environmental pollution. The database used was soca v2, which combines PSILCA v.3 and ecoinvent v.3.7.1. Initially, data collection was conducted through questionnaires distributed to the value chain stakeholders. Subsequently, openLCA was utilized to calculate indicators related to the environmental, economic, and social impacts of the dairy industry.

3. RESULTS AND DISCUSSION

The indicators revealed that the greatest impact arises from the processing line, primarily due to the substantial consumption of energy and water. However, the wastewater treatment plant has the potential to generate energy, conserve water, and reduce wastewater. The analysis, therefore, facilitates informed decisions about necessary changes in the industry to enhance sustainability. In the future, innovative processes will be implemented to clarify the water from the wastewater treatment plant using ultrafiltration membranes with UV disinfection. Additionally, acid whey, the main by-product of the production process, will be valorized through ultrafiltration membranes, spray drying, and anaerobic digestion. These interventions could not only reduce the environmental impact but also improve the economic and social aspects of the dairy industry. The industry's sustainability hinges on balancing economic viability, social responsibility, and environmental responsibility.

4. CONCLUSIONS

Hence, there is a pressing need for interventions to optimize the dairy industry, with a primary focus on the wastewater treatment plant and the valorization of by-products such as the acid whey. These interventions will contribute significantly to addressing all the impacts studied, not only reducing environmental harm but also enhancing the industry's economic viability and social responsibility. The findings from this study provide valuable insights for stakeholders in the dairy sector, offering a pathway towards a more sustainable and responsible future for the industry.

5. ACKNOWLEDGEMENTS

This research is funded by the project AccelWater, which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958266.

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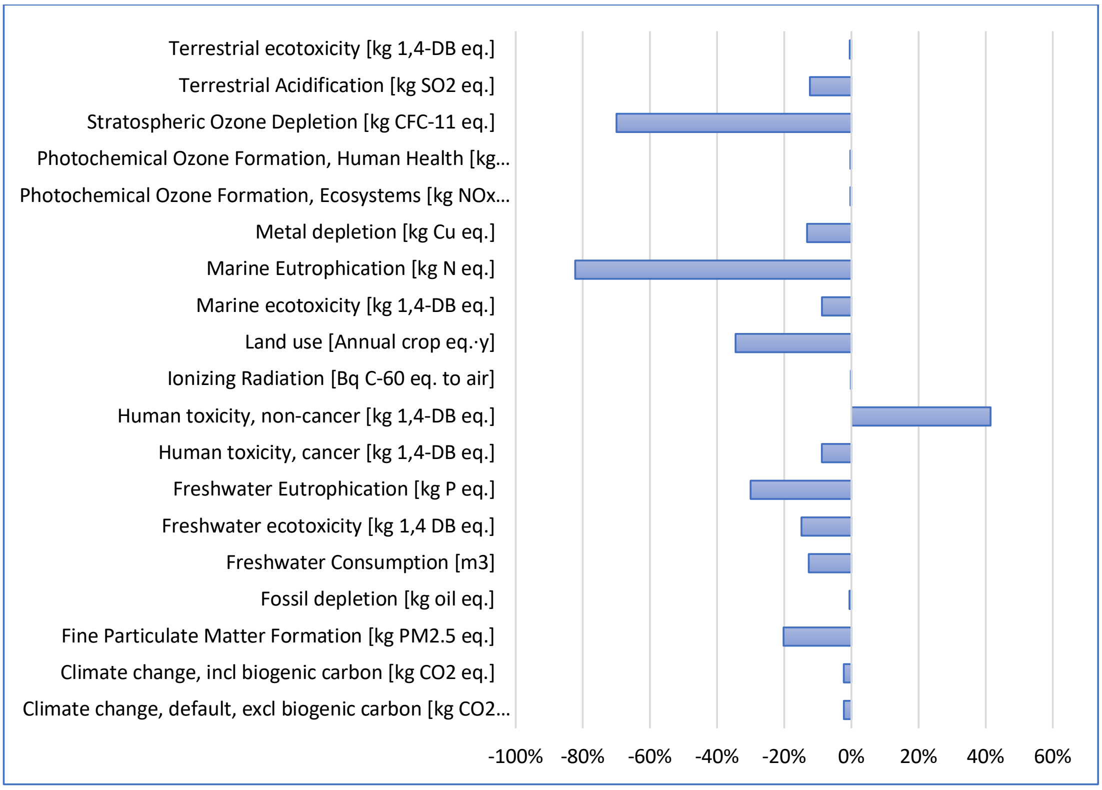

Figure 1. Change in mid-point level indicators from the current to the future situation

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Life cycle sustainability assessment (LCSA) of goat meat in Western Nepal

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1. INTRODUCTION

Food production systems in rural areas of developing countries are in flux not only due to climate change and environmental deterioration, but also due to urbanization, globally integrated supply chains, changes in the consumption patterns and implementation of new agricultural practices, as well as a need to meet the nutritional needs of an increasing population (e.g., Anderson 2015). Livestock can be a source of food and income for rural households and provide insurance and economic buffering (Abu Hatab et al. 2019). Goat is one of the most common ruminants and the second most consumed meat in Nepal with continuously increasing production rate (Neeraj et al. 2022). Goats are produced in household and semi-commercial farms (up to 10 goats) and in commercial farms with more than 30 goats. We conducted a life cycle sustainability assessment (LCSA) of an agricultural product (goat meat) in Nepal for the first time to understand the sustainability impacts of the system and to improve and develop the applicability of LCSA method in the context of agricultural production for further use.

2. METHODS

Carbon footprint, life cycle costing analyses and social impacts were covered in this LCSA study. The life cycle from cradle to the meat sold at butchery for consumers or slaughtered and chopped meat at household was included. Goat meat production in three different geographical regions of Western Nepal were covered: Kailali, Surkhet and Dailekh district (Dullu). Kailali district and Surkhet district systems represented systems with feed imports. The meat was consumed locally but transported to local cities as well as to Kathmandu and Pokhara, the major cities of Nepal. The Dailekh district system represented a remote and local, self-sufficient goat production system. As hardly any LCA data was available in Nepal, quantitative primary data was collected interviewing farmers, middlemen, butcheries, and feed producers. Supporting information was collected from local agrovets, independent local veterinarians. Social impacts data was collected through in-depth interviews.

3. RESULTS AND DISCUSSION

The results give an insight to the overall environmental performance of the three selected systems. The cost structure linked to mass balances along the goat chains and carbon footprint shows the targets/hotspots for future development within the chain. Stakeholder interviews provide better understanding on the social hotspots and underlying reasonings.

4. CONCLUSIONS

First, improving the knowledge of goat farmers on sufficient goat feeding, selection of suitable breeds, and maintaining good animal health, would support them to avoid animal health and reproduction related losses in all systems studied. Cultivation practices and feed crop production could be improved as well by education. Second, improving the transportation practices especially in longer transportations to further cities would decrease both animal mortality and weight loss. Thirdly, developing the live animal market and applying cold storages in butcheries would also improve the overall efficiency. However, the strength of the goat production was that practically all edible parts of the animals were consumed by humans, which improved the efficiency. Especially in the local system of Dullu, animals were slaughtered only on demand, to avoid any food waste.

LCSA is an applicable method in Nepalese context especially in agricultural and livestock production systems. LCSA can be a promising support in the improvement and transformation of the local food system towards more efficient and sustainable direction if integrated already especially in the decision-making levels. However, more experience and improvement of data access and sources is required for better future studies.

ACKNOWLEDGEMENTS

We warmly thank everybody who shared their data, knowledge and time for this study.

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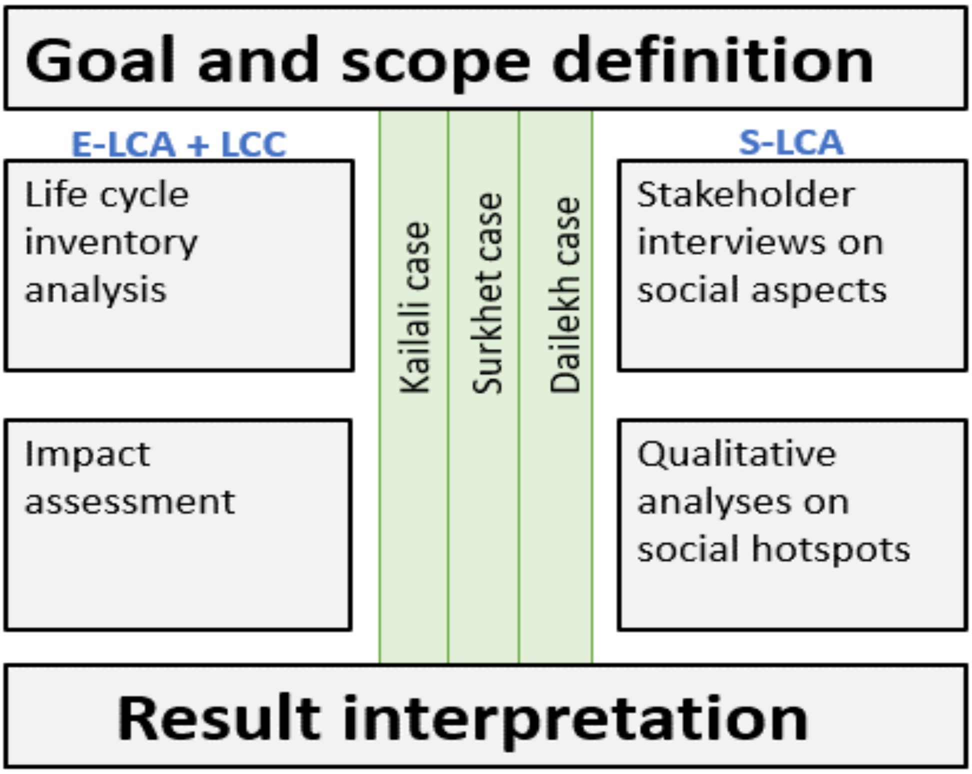

Figure 1. Life cycle sustainability assessment of three goat meat production systems in Nepal

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Environmental, technological, and economic evaluation of precision agriculture farming: A review of the life cycle assessment and costing literature

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Keywords: precision agriculture, crop production, life cycle assessment, environmental impact

1. INTRODUCTION

Precision agriculture (PA) technologies are an emerging innovation domain for the agriculture sector. The emergence of PA is mainly attributed to the rapid expansion and availability of network connectivity, new sensor developments, and data collection/generation over the past few decades (Toth and Jóźków 2016, King 2017). While there are many potential benefits are associated with PA technologies, skepticism persists and adoption remains low, indicating that more research and knowledge translation/transfer is required to demonstrate the feasibility and usefulness of these technologies (Franzen et al. 2016, Colaço and Bramley 2018, Balafoutis et al. 2020). Assessing PA crop production using life cycle assessment (LCA) and economic/life cycle costing (LCC) studies allows for the consideration of all environmental and economic aspects related to the PA production chain when considered at a systems level. Research at this intersection is notably lacking, hence being the motivation for this review paper with a global perspective to understand the current state of environmental and economics research with respect different crop production methods (orchard, vegetable, broad acre, etc.), regions, and types of PA technologies assessed. Identifying elements/practices within conventional agriculture which largely contribute to environmental impacts is necessary to help prioritize where PA technologies should be implemented for maximum benefits. The review answers the following sequential research questions: 1) What are the primary environmental impacts associated with open-field crop production, and what specific aspects of open-field crop production contribute most to those impacts? 2) From a life cycle perspective, what PA technologies address the most environmentally material concerns, and how does their use compare to conventional practices with respect to environmental impacts? 3) Are there economic benefits associated with PA compared to conventional practices?

2. METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) method (Moher et al. 2009) was utilized to identify and process relevant literature. Peer-reviewed journal articles were identified from the Web of Science Core Collection using keywords for each research question. Results were limited by year (2003-2023), document type (scientific article), subject type (open field crop agriculture), language (English), and assessed for inclusion/exclusion criteria defined for each research question.

3. RESULTS AND DISCUSSION

Fertilizer use/production and associated field emissions are the leading cause of environmental impacts in many LCA impact categories, energy and pesticide use also contributing significantly (Table 1). These findings are in agreeance with recent LCA studies which found that the use and production of fertilizer inputs and machinery were the major contributing factors to environmental impacts and GHG emissions on fruit farms. For most LCA environmental impact categories, the utilization of PA practices lowered the impacts as compared to the conventional practice (Figure 1). Variable rate technology (VRT) is highlighted as a promising subset of PA technologies in terms of environmental impact reductions, as well as economic benefits to producers.

4. CONCLUSIONS

Fertilizer (use, production, and other related upstream environmental impacts) is a leading contributor to overall environmental impacts of crop production, thereby making VRT nutrient management an important focus of PA. VRT addresses many environmental concerns stemming from crop production while also demonstrating economic benefits.

5. ACKNOWLEDGEMENTS

Thank you to Dr. Joy Agnew and Roy Maki from Olds College of Agriculture & Technology and Dr. Vivek Arulnathan from the University of British Columbia – Okanagan.

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Table 1. Table of frequency (%) of association between leading causes and impact categories in the LCA studies reviewed. Impact categories are presented in this graph are the six most encountered. Results are displayed for mass based funcional unit (tonne or kg), and area based funcional unit (ha) LCA studies.

Impact Category	**Leading Cause (% of occurrences)**	
	Mass based FU studies	**Area based FU studies**
Climate Change	fertilizers/field emissions (77.2%), energy use (16.0%)	fertilizers/field emissions (86.4%), energy use (13.6%)
Acidification	fertilizers/field emissions (81.1%), energy use (9.4%)	fertilizers/field emissions (69.2%), energy use (30.8%)
Eutrophication	fertilizers/field emissions (81.0%), energy use (9.5%)	fertilizers/field emissions (80%), energy use (20%)
Ozone Layer Depletion	fertilizers/field emissions (47.1%), machinery (20.6%)	fertilizers/field emissions (66.7%), energy use (16.7%)
Freshwater Ecotoxicity	pesticides (39.5%), fertilizers/field emissions (36.8%)	fertilizers/field emissions (66.7%), pesticides (33.3%)
Human Toxicity	fertilizers/field emissions (57.4%), pesticides (16.2%)	fertilizers/field emissions (75.0%), other (25.0%)

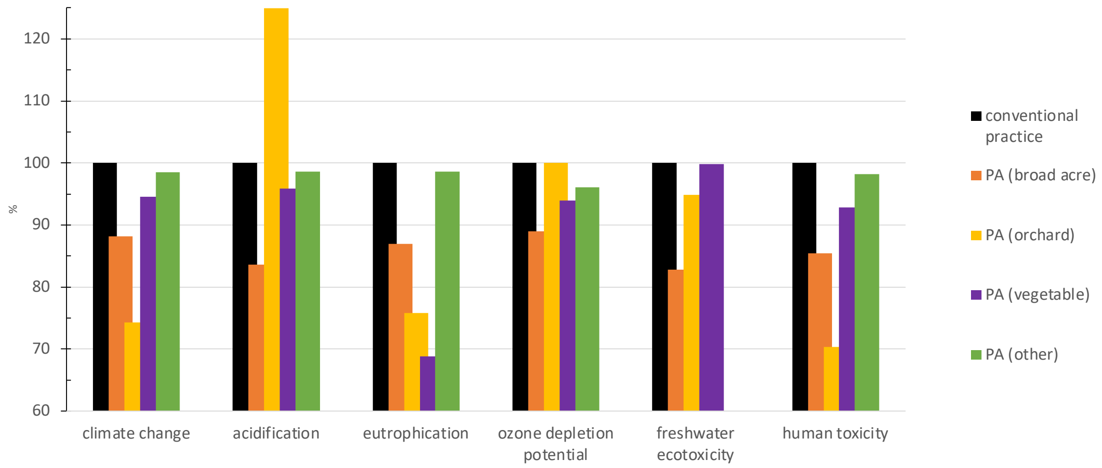

Figure 1. Average % difference in environmental impacts between PA and conventional practice for different crop types.

Integration of agroecology and soil health in LCA

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Assessing Sustainability of Land Use: The SHARInG-MeD project

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1. INTRODUCTION

The research project –'Soil Health and Agriculture Resilience through an Integrated Geographical information systems of Mediterranean Drylands' (SHARInG-MeD) aims to assess the sustainability of land use and soil management in cropping systems in terms of soil health and soil degradation, and to integrate the analysis of soil properties and the environmental impact of agricultural management at both the plot and regional scale, in order to provide information on soil and environment degradation processes. This contribution focuses on the main issues of the methodological aspects linked to the way of combining environmental and economic indicators with those referred to land use in the Mediterranean area. The aim is to achieve a holistic sustainability assessment according to the Life Cycle Assessment (LCA) approach, commonly adopted for analysing farms and agro-food industries that need to valorise and certify their agro-food productions (Bauman & Tillman, 2004; Curran, 2012; Russell et al., 2005).

2. METHODS

The LCA methodology will be used in the SHARInG-MeD project field experiments for analysing the relationship among physico-chemical, biological and agronomic indicators, and the environmental and economic ones of Mediterranean crops. In particular, the LCA approach will be adopted in the selected areas for both sampling and collecting all variables at the wide scale, and identifying the relationship between agronomic practices, in particular the soil degradation drivers, and the economic and environmental impacts of the land use. As for the phase of life cycle inventory, all inputs and outputs will be collected with the aim to create a dataset. These inputs will be tailored to the specific experiments comparing conservation agriculture to conventional agriculture, application of organic amendments or comparison of contrasting land uses, including cultivated and natural areas (respectively Corine Land Use system 2 vs. 3). By the use of a bottom-up approach, starting from the agricultural practices, all the information referring to equipment and machineries as well as fertilisers and pesticides will be gathered. Particular attention will be paid to the water consumption. On one hand the water footprint will be calculated at inventory level (Hoekstra, 2017; Mekonnen & Hoekstra, 2011; Pfister et al., 2017), on the other hand, as for impact assessment, the impact assessment method AWARE will be applied for evaluating water scarcity (Boulay et al., 2018). As concerning the system boundaries, the “cradle to farm gate” approach will be adopted, by considering as functional unit both the area (hectare) and the quantity of product (yield). The inventory phase will be carried out by the use of questionnaires and data collection in field, with the aim to gather the main amount of primary data. In case of lack of primary data (e.g. data about production processes of specific fertilizers or pesticides) secondary data coming from databanks (such as Ecoinvent®) will be used; in alternative estimated data or literature data could be used. The cut-off rules will be defined according to the relevance of input and output to the overall life cycle or difficulty of obtaining some particular data (such as those covered by patents). After that, the quality of data will be calculated according to the Product Environmental Footprint (PEF) guidelines (EC, 2018). In the Data Quality Rating (DQR) six criteria are considered: technology representativeness, geographical representativeness, time representativeness, completeness, parameter uncertainty and methodological appropriateness and consistency. All the life cycle of the experiments and scenarios of soil management will be modeled by the use of a LCA software, such as “Sphera LCA for Expert” (https://sphera.com/). The same life cycle approach will be used for collecting economic data with the aim to determine Second Level Contribution Margin and Life Cycle Costing (Nemecek et al., 2015).

3. RESULTS AND DISCUSSION

As concerning the environmental life cycle assessment, the results will be calculated by adopting the impact categories, and the normalization and weighting factors suggested by the PEF guidelines (Ojala et al., 2016). According to the aims of SHARInG-MeD all the relationships between environmental impacts and agricultural practices affecting soil health or degradation will be determined and key factors for land use evaluation will be individuated. At that point, the environmental indicators will be combined with the economic ones in order to achieve a single indicator able to express the “economic value” (in terms of gains) of the environmental impacts for each agronomic scenario.

4. CONCLUSIONS

This paper illustrates the methodological issues faced for the assessment of environmental sustainability as part of the SHARInG-MeD project. The huge variability of data could be a main issue to be managed. However, despite of these limitations, the solutions hypotheses to prevent soil degradation coming from the LCA could certainly represent a reference for all practitioners and experts in the sector with a view to future projection, especially in consideration of a possible implementation of certification schemes for sustainable agriculture.

5. ACKNOWLEDGEMENTS

SHARInG-MeD project is a Research and Innovation Action funded under the call PRIMA-MED call 2022 topic 1.2.1, grant agreement number 2211References.

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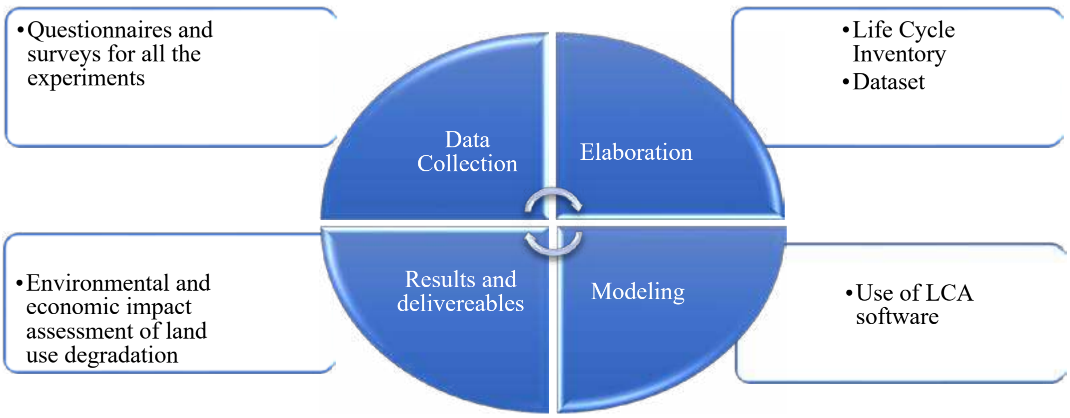

Figure 1. Conceptual matrix of the sustainability assessment of soil degradation in the SHARInG-MeD project.

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Charting a research agenda for modelling agroecological practices in Life Cycle Assessment: insights from an interdisciplinary collaboration

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1. INTRODUCTION

Life Cycle Assessment (LCA) has limitations in capturing diverse agroecological practices, particularly in respect to soil quality, ecosystem services, and biodiversity preservation. Current issues include insufficient inventory data and gaps in the cause-effect chain understanding of specific practices and soil indicators across geographies. The focus on mass output of LCAs may penalize agroecological practices, due to lower yields in extensive farming systems. While the Environmental Footprint (EF) method assesses soil parameters in the Land Use (LU) impact category, other soil aspects still need to be explored [1]. This research aims to overcome these limitations by developing a research agenda for LU modelling that considers various agroecological practices.

2. METHODS

A comprehensive list of agroecological practices applicable to LU has been compiled from EU policy documents, repositories and reviews [4][5][6]. This list was compared with LU flows in inventories for the EF. As a second step, an interdisciplinary collaboration between LCA experts and soil scientists has been established to address possible new developments, needs and further research gaps. Operationally, this entails conducting a meta-analysis of quantitative evidence related to different agroecological practices linked to specific soil quality parameters, followed by an analysis exploring the potential improvement of characterization factors (CFs) that take into account agricultural practices when assessing the impacts of land occupation and transformation (Figure 1).

3. RESULTS AND DISCUSSION

First analysis shows that working towards a more inclusive modelling approach for agroecological practices requires a modular and flexible approach, through which agroecological practices and land use flows could be modelled together.

The main hindering factor to the implementation of such an approach is the lack of generalizable quantitative data linking specific agroecological practices to specific effects on soil health. Another important limiting factor that needs to be tackled is the spatial scale and specificity of soil parameters compared to the needs of LCA, which currently requires CFs aggregated at national level. This stresses the need for LCA to move towards more regionalised assessments, to provide meaningful results for spatially dependant impact categories. This work is the initial stage of a line of research to provide a more accurate LCIA methodology for Land Use in farming systems, by acknowledging the need for, as well as relying on, close interdisciplinary collaboration.

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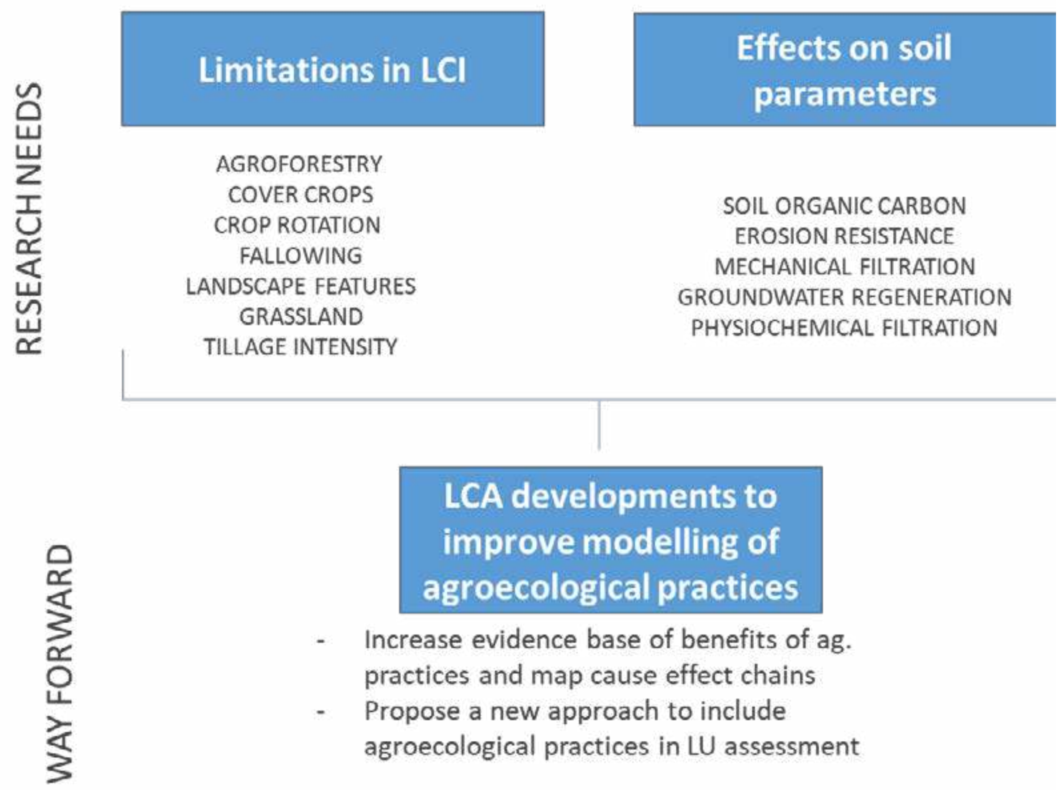
Figure 1: Scheme of the work proposed



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Environmental trade-offs of Bio-Based Fertilizers application: Adaptability of non-LCA impacts and methods into LCA

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1. INTRODUCTION

Multiple initiatives advocate the use bio-based fertilizers (BBFs) to reduce the use of mineral fertilizers by circular economy in agricultural systems. However, the entire life cycle of these products, from production to field application, needs to be assessed from an environmental perspective to prevent undesired trade-offs. Life Cycle Assessment (LCA) is the most common method for evaluating the environmental performance and trade-off of a product. However, LCA does not fully covers all the environmental concerns of BBFs' application. This research aims to identify the most cited non-LCA environmental concerns caused in the BBFs application stage, the most used non-LCA tools and methods as well as their coupling with the LCA.

2. METHODS

The critical analysis has been developed through i) the identification of main environmental concerns with a bibliometric analysis in the Scopus® database; ii) an individual review of the state-of-the-art of the concerns; and iii) a detailed analysis of the adaptability of the methods and indicators into LCA methodology. From the result of the scientometric analysis, 114 publications was reviewed, reporting the main concern assessed, the methodology and tools used in the analysis and the impact sign of the results (possitive or negative). A posterior search on the topics was performed in specialized literature (databases Scopus and Google Scholar, technical guidelines, documentation (in the case of electronic tools), and initiatives from international organizations. Finally, a detailed analysis was conducted on case studies incorporating new methodologies or innovations for the inclusion of these concerns in the Life Cycle Assessment (LCA) approach. This last analysis highlighted advantages and limitations.

3. RESULTS AND DISCUSSION

Table 1 summarises the most important environmental concerns (impacts or benefits) of the application of the BBDs not fully covered by LCA. Affections to soil properties and heavy metals are undoubtedly the most frequent concerns assessed. However, in the case of soil affection, it also interacts with the organic carbon sequestration and Soil Organic Carbon dynamic: a growing concern due to the potential role in climate change mitigation.

Soil modelling is a promising methodology for estimating the impact of affections on soil properties and the dynamics of soil organic carbon (SOC) sink and carbon sequestration; RothC has been adapted on several occasions to evaluate manure-based products. This approach can be coupled with Life Cycle Assessment (LCA) thinking in studies due to the availability of regional-level data. However, some models tend to represent the transformations in a simplified way, which is a disadvantage. To measure the impacts on biodiversity, recent developments have primarily advanced in the coverage of life cycle impact assessment (LCIA) methods (e.g., GLAM, LC-Impact, etc.). the non-LCA methods most used were GLOBIO and IUCN, and at the moment, they are not able to capture all the environmental pressures to develop accurate metrics; to couple with LCA is necessary to develop methods that account for the ecosystem services. Commonly, methods applied in the LCA (e.g., USEtox, etc.) for assessing the ecotoxicity of heavy metals are simple and generate results with great uncertainty. For this reason, human risk assessment and fate models have been used for the identification of potential health hazards caused by the presence of heavy metals associated with different stages of a BBF's life cycle. It is important to recognize the limitations and uncertainties associated with human risk assessment in LCA, such as the limited understanding of long-term effects and the interactions and cumulative effects.

4. CONCLUSIONS

The present communication identified the environmental concerns of the BBF application that are out of the boundaries of the LCA methodology. There is still controversy about the effect of some of them as well as with the quantification methods. The development degree is variable among categories. However, there are initiatives to introduce most of them into LCA.

5. ACKNOWLEDGEMENTS

Authors acknowledge the funding of the European project NOVAFERT (G.A. Nº 101060835)

Table 1.-Summary of the main environmental concerns assessed and the impacts sign.

Environmental concern	Importance	Trade-offs sign	Nº references
Affections on soil properties (physical and chemical)	BBFs can induce modifications in soil properties. There is some evidence in favour mainly in physical properties, and biological activity, however, it has been reported risks associated with decreasing efficiency of soil nutritional management.	Positive or negative	19
Heavy metals	Heavy metals can result in damage to ecosystems and human health. Thus, current legislations are oriented to prevent environmental impacts and human risks.	Negative	17
Soil carbon sink and sequestration	Carbon dynamics in soils are complex. The introduction of organic matter from BBFs rebounds in a better soil structure and higher carbon stocks.	Potentially positive- (under discussion)	8
Biodiversity	BBFs application has been related with a higher soil and ecosystemic Biodiversity due to the increment of the soil health. However, the presences of xenobiotics can alter the balance.	Positive or negative	8
Organic emerging contaminants	Organic pollutants (pharmaceuticals, antibiotics, flame etc.) in the BBFs application may lead to bioaccumulated soil and crops or leached to the groundwater, causing potentially severe risks to human health and the environment.	Negative	8
Microplastics	MPs can damage to human health and affect ecosystem services. Main issue is the accumulation on water reservoirs and biota.	Negative (magnitude under discussion)	2
Odour	Emissions of odours, like ammonia, impacts air quality and causing disturbances in the nearby community. Decomposition of organic matter is related to the release of harmful substances.	Negative	2

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Species richness of vascular plant species of regenerative farms in the Netherlands as a basis for updated land-stress based biodiversity impacts within life cycle assessment

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1. INTRODUCTION

Intensely managed agricultural soils have lost much of its structure, carbon, and biology through practices such as tillage, use of heavy machinery, inputs of pesticides and inorganic fertilizers, and the overall lack of soil protection (Rli, 2020). Regenerative agriculture (RA) has gained increasing popularity in recent years as a potential approach to decrease the environmental impacts of food production, regenerate soils, and potentially increase biodiversity (Schreefel et al., 2020). Biodiversity impacts of agricultural practices can be assessed using life cycle assessment (LCA) (Verones et al., 2020). Many life cycle impact assessments (LCIA) include a limited amount of land use types, including: annual crop, permanent crops, pasture, urban, and (intensive and extensive) forestry (Verones et al., 2020) for a maximum of three land-use intensities (Scherer et al., 2023). To fully understand the biodiversity impact of RA, CFs representing farmland biodiversity on RA are required.
In our study we assessed the potential biodiversity impact of RA in comparison to conventional farming practices by measuring species richness of vascular plants species found within RA and conventional farms. The results can be used to update land-stress related characterization factors within LCA.

2. METHODS

To estimate the difference in the diversity of vascular plant species within regenerative farms in comparison to conventional farms, we applied plot-scale biodiversity monitoring surveys in the Netherlands for both cropland and pastureland within fields an on field edges. The Netherlands has a highly productive agricultural sector and despite its small size is the second largest exporter of agricultural produce (Ministry of Agriculture, 2024). Species richness of the farmlands was measured using transect sampling with a 25-meter-long line along which species were recorded. The transect lines were placed both across and along crop strips to account for both the diversity of crop species and non-crop species. Farm were visited during the spring of 2023.

3. RESULTS AND DISCUSSION

Table 1 shows preliminary results of the study. Regenerative agricultural farms had a significantly greater species richness both within fields as well as on field margins for croplands. For pastures there was only a significant difference between species richness within fields but not on field edges. The latter could potentially also be explained by the generally lack of field edges on pasture lands and thus a low N. Large variation on species richness within regenerative farms were visible with small cropland farms having the highest species richness.

4. CONCLUSION

Species richness on RA farms is greater than for conventional agricultural practices. The results presented in Table 1 can be used to calculate new CFs specific to RA using species richness of (semi-)natural areas. This allows for a fair assessment of biodiversity impact caused by land use and land-use change of RA within LCA studies and can help the answer the question whether RA provides a biodiversity-friendlier method of producing food.

5. ACKNOWLEDGEMENTS

This research has been funded by the Strategic Research Council project "Biodiversity Respectful Leadership (BIODIFUL)" (grant number 345884).

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Figure 1. Assessing species richness of vascular plants on a regenerative agricultural farm field in the Netherlands.

Practice	Farm type	Measuring location	Average	SD
RA	Cropland	Field	17.8*	13.7
Conventional	Cropland	Field	2.8	2.2
RA	Cropland	Field edge	17.5*	8.5
Conventional	Cropland	Field edge	5.3	4.7
RA	Pasture	Field	11.0*	5.9
Conventional	Pasture	Field	4.7	2.4
RA	Pasture	Field edge	13.6	6.9
Conventional	Pasture	Field edge	9.2	1.9
* Significant difference between RA and conventional practices with P < 0.05				

Table 1. Species richness of vascular plants of regenerative and conventional farms

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Modelling the environmental impacts of Swiss mixed agroforestry systems

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1. INTRODUCTION

Farming systems are under increasing environmental pressure due to the climate and biodiversity crisis. In this context mixed agroforestry systems are suggested as potential solutions to increase circularity of nutrient flows and productivity of the land used for agriculture, while at the same time storing carbon in biomass and soils to mitigate climate impacts. Few studies have assessed the environmental performance of mixed agroforestry systems within European farms and models for doing so are scarce. In this study, a life cycle assessment (LCA) model "FarmLCA" (De Baan et al., 2024) was further developed to include agroforestry and reflect the most recent methodologies for estimating carbon sequestration in soil and biomass. Here we present these developments and their applicability on Swiss agroforestry farms, co-producing fruits, milk, meat and other crops.

2. METHODS

Two sub-models, quantifying changes in soil carbon and in woody biomass, were implemented in the FarmLCA model. For soil carbon, the IPCC Tier 2 methodology (IPCC, 2019) was used, assessing the dynamics of different soil carbon pools, such as active and passive C-pools. For C-storage in woody biomass, we chose the Tier 1 methodology proposed by Cardinael et al. (2018). As recommended by ISO 14044 for LCA we propose a biophysical allocation for tree-management impacts to the fruits and close-by grassland only. The area used by single fruit trees within the fields was calculated using the approach proposed by Hemery et al. (2005) as shown in **¡Error! No se encuentra el origen de la referencia.**. This approach should more accurately distribute impacts between crops, trees and livestock in mixed systems. Following development, FarmLCA was used to model seven real Swiss farms. They combine growing high-stem fruit trees within pasture- or cropland, mixed with dairy or beef cattle systems.

3. RESULTS AND DISCUSSION

The adapted model was able to analyse the very heterogeneous agroforestry farms (see

Table 1), both in terms of the degree of specialization (i.e., proportion of different income streams), input dependency (i.e. N self-sufficiency) as well as resource management (i.e. nitrogen use efficiency). Depending on the farm, 0.5-575% of a farm's greenhouse gas emissions were offset by carbon stored in soil or woody biomass. This range underlines the importance of transparent assumptions when dealing with biomass carbon as emission offset measure. To analyse the environmental performance of such multi-functional systems, selecting appropriate functional units (FU) and performance indicators is challenging. Allocating impacts is an additional challenge, where disentangling management inputs, as performed here, is recommended (Figure 1), but requires further testing and validation.

4. CONCLUSIONS

We tested a novel LCA approach to assess impacts within agroforestry systems. The soil carbon and biomass modules in the FarmLCA are useful add-ons to assess the carbon dynamics in various farming systems. Since carbon storage in agricultural systems can strongly impact carbon footprints, but is highly dynamic and potentially reversible, a discussion is needed on the temporal dimension of carbon storage and how it should be treated within LCAs.

5. ACKNOWLEDGEMENTS

We thank Laura de Baan for the constructive feedback throughout the project. This work has received funding from the EU Horizon 2020 research and innovation programme under the following project: MIXED (grant agreement No. 862357).

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Table 1. Overview of farm characteristics. Farms are sorted by livestock income proportion. LU: livestock units. NUE: nitrogen use efficiency.

Variable	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
Area (ha)	14.6	33.2	24.2	7.6	34.0	29.9	20.4
Arable land (%)	-	56%	-	-	68%	51%	39%
Permanent grassland (%)	94%	39%	98%	24%	30%	27%	56%
Agroforestry (%)	6%	6%	2%	76%	2%	22%	5%
Livestock density (LU/ha)	3.02	0.63	2.63	-	-	0.97	1.07
Crop revenue (% of total)	18%	72%	1%	100%	100%	75%	42%
Livestock revenue (% of total)	82%	28%	99%	-	-	25%	58%
N self-sufficiency fertilisers (%)	85%	94%	69%	0%	5%	83%	89%
NUE (kg N export/kg N import)	0.16	4.27	0.46	0.35	0.55	1.59	1.41
Climate change, short term, no carbon models (kg CO2 eq ha-1)	27216	8583	30265	1689	3643	8237	5972
Climate change, short term, with carbon models (kg CO2 eq ha-1)	26738	8538	29979	-8022*	3242	7647	5379

**Only valid for first 20 years after orchard establishment, and requires interpretation, depending on the long-term future of the orchard and the embedded carbon which can easily be lost back to the atmosphere.*

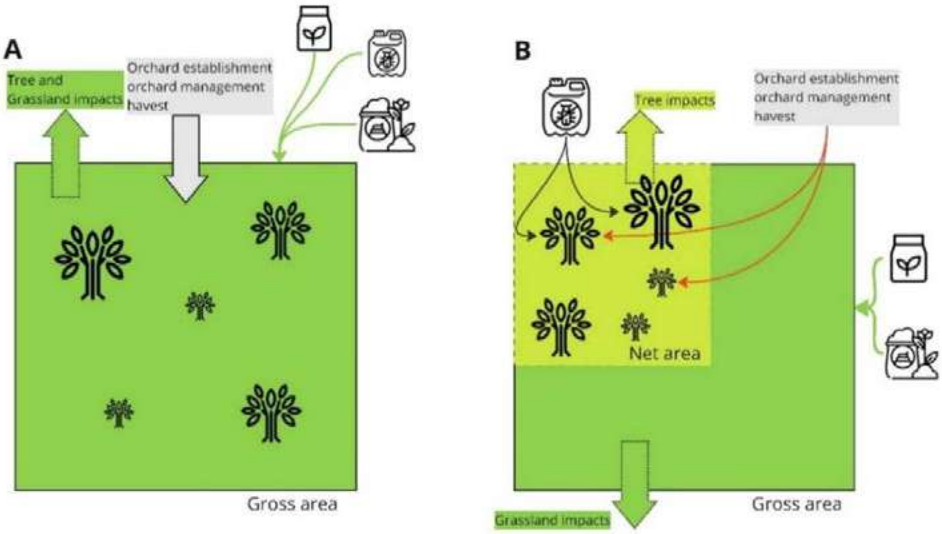

Figure 1. Allocation of environmental impacts of field management on mixed grassland and fruit trees: (A) per-plot approach: impacts are allocated to both outputs (tree and grassland); (B) approach proposed by Hemery et al. (2005): impacts of tree-management (e.g. pesticide application) are allocated to trees only, net area of trees is calculated.

Using participatory approaches for the development of LCA methodology aiming at assessing crop-livestock interaction and legume-based cropping systems

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1. INTRODUCTION

Globally, civilisation faces challenges related to agricultural systems, these include numerous environmental impacts (e.g. biodiversity loss, soil- and water-pollution). Life cycle assessment (LCA) has been effective in assessing agricultural impacts (Nemecek et al., 2023). Methodological flaws identified were soil carbon sequestration, animal welfare, biodiversity loss, nutrition, and greenhouse gases (GHG). Ecosystem services (ES) were also poorly integrated into LCA (Goglio et al., 2023; Taelman et al., 2024). Participatory approaches were successful in developing environmental assessment methods for livestock systems (Mullender et al., 2020). Here we discuss: i) participatory approaches for the harmonization of LCA in crop-livestock systems; and ii) methodological opportunities to identify how ES benefits and indicators may be integrated in LCA of legume-based cropped systems.

2. METHODS

Methodological harmonization for the LCA of livestock systems and products was achieved using a participatory approach involving 21 experts based on a modified DELPHI method. Screening general and specific criteria were identified using anonymous survey among experts with targeted discussions to refine the criteria and define scale value for each criterion (Goglio et al. 2023) (Figure 1). The integration of ES in the LCA of legume-based cropping systems will be based on historic data and knowledge, current peer-reviewed literature and research project reports. Then, a participatory approach with an expert panels will be set up to assess the suitability of the identify

Ecosystem services (ES) and ES indicators to be integrated in LCA of legume based cropping systems and products. For both developments an external expert review is previewed (Figure 1).

3. RESULTS AND DISCUSSION

The research study carried out for the harmonization of livestock systems was successful in identifying key methodological gaps, and in developing screening criteria (Figure 2). For most topics considered, a compromise between method accuracy and ease of application needed to be found. For biodiversity and animal welfare, another important challenge was how methods can be applied with consistency along the value chain (i.e., agricultural production, transport, food processing, *etc.*). Similar issues are anticipated for the integration of ES in the LCA of legume-based cropping systems. Additionally, the need for a quantitative metrics for LCA ES integration and for animal welfare was also identified.

4. CONCLUSIONS

This research presented two research studies related to the harmonization and development of LCA methodology for livestock systems and ES integration in LCA of legume-based cropping systems. This approach could be adopted for LCAs of other agricultural systems and products.

5. ACKNOWLEDGEMENTS

This work is supported by the European Commission projects: PATHWAYS (https://pathways-project.com/) (Grant Agreement number 101000395), and LegumES (www.legumES-project.eu) (Grant Agreement number 101135512). JHI is supported by the Rural and Environment Science and Analytical Services (RESAS), a Division of the Scottish Government.

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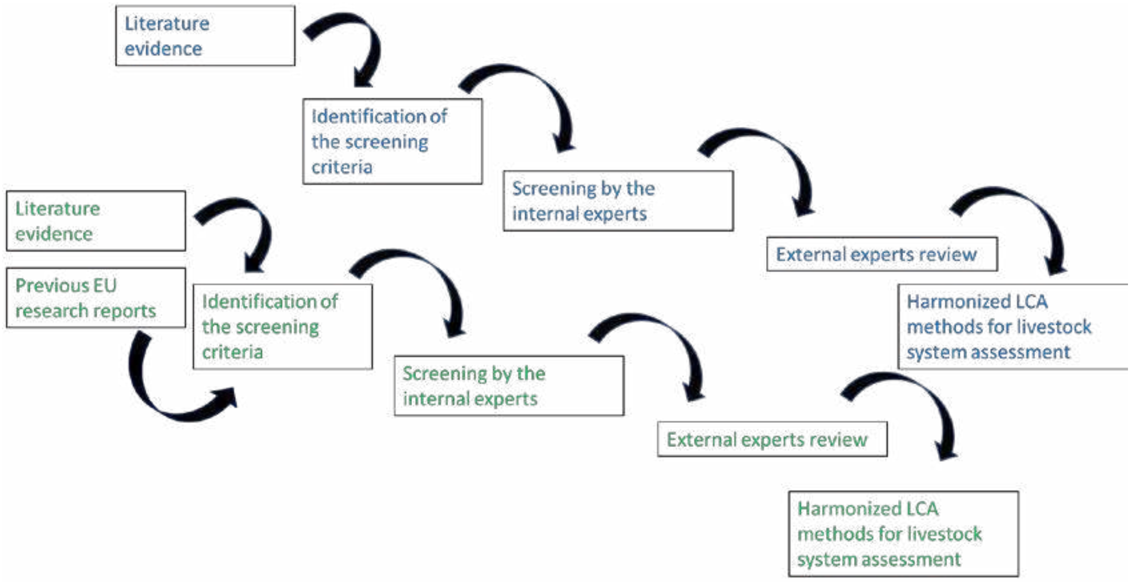

Figure 1. Description of the various steps of the harmonization and development process for LCA methods related to the livestock systems (Blue) and for the integration of ecosystem services in the LCA of legume-based cropping systems (Green)

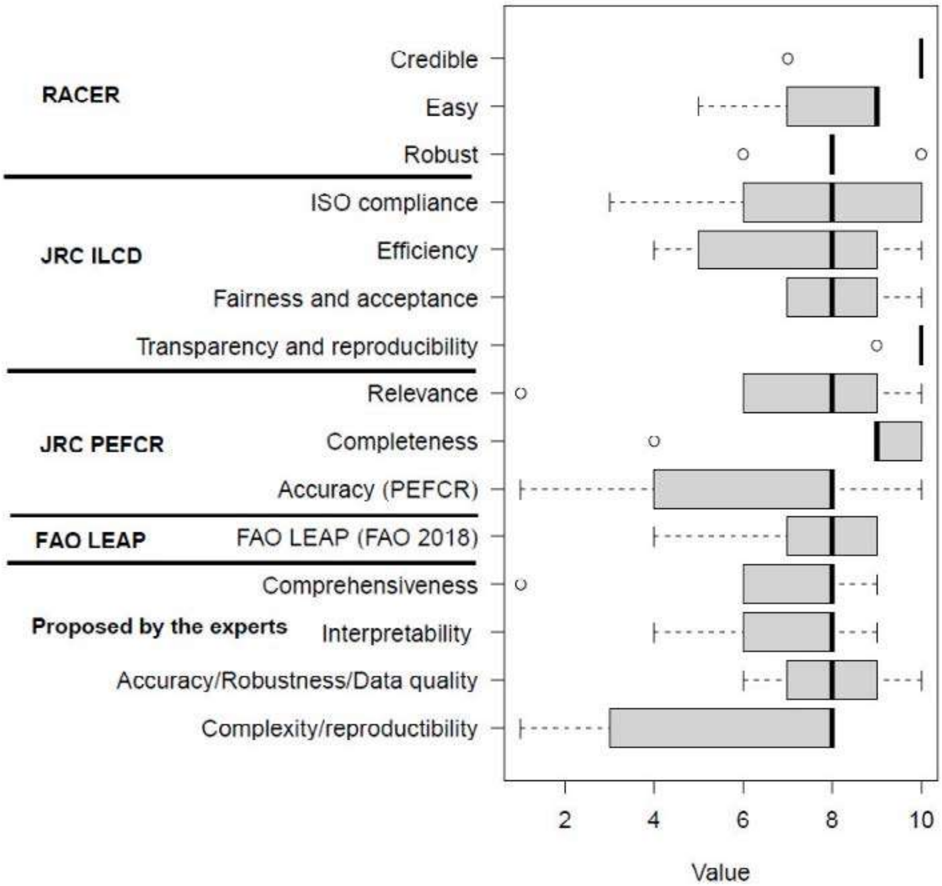

Figure 2. Box plot of the LCA expert responses for the criteria selection to assess LCA methods for livestock systems, and products with the highest importance (boxes: 1st and 3rd quartiles; dark lines: median; error bars: maximum and minimum values; high values: high importance; low values: low importance). The criteria reported in this figure belong to various frameworks (e.g., RACER) or were formulated by the experts. Outliers responses more than 1.5 times the inter-quartile range away from the box are shown with hollow circles (Goglio et al., 2023)

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Estimating SOC change rates from agricultural management. A systematic review and meta-analysis of long-term experiments

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1. INTRODUCTION

Soil Organic Carbon (SOC) loss from farmland is a key threat to soils since it influences the capacity of the land to provide ecosystem services regulating agriculture and exacerbates climate change. To preserve and restore SOC in agricultural land, policy initiatives targeting soil health in the EU and across the globe recognise the importance of sustainable soil management. Often collectively referred to as conservation or regenerative agriculture, practices for the sustainable management of soil include, among others, reduced tillage, organic amendments, and diversified rotations.

While the environmental benefits associated with conservation practices is qualitatively broad, their potential to sequester SOC remains challenging to quantify. Estimates of net change in SOC stocks rely on either change factors derived statistically from a broad pool of agricultural experiments, or process-based SOC modelling. Statistical approaches often confound SOC change relative to a control and net gains over time in SOC stocks (Don et al., 2024). On the other hand, assumptions regarding historical SOC levels and time horizon of change greatly influence the rates at which SOC stocks develop in process-based modelling (Joensuu et al., 2021). In addition, available tools to estimate SOC development often consider the management of arable land too coarsely to be suited for lifecycle studies of conservation practices.

This study aims to quantify the net effect on SOC stocks from multiple management interventions comprising tillage, fertiliser application, use of amendments, and crop rotations through a systematic review and meta-analysis of long-term field experiments.

2. METHOD

A systematic review has been conducted according to the protocol established by Haddaway et al. (2016) to find long-term time series in field studies spanning over 30 years in temperate and cold climates. Long-term data series allow us to calculate net change rates of SOC stocks, which we use in a meta-analysis to determine the effect of different and combined agricultural management practices on SOC stock development.

3. RESULTS AND DISCUSSION

Most long-term agricultural experiments lose SOC over time, which is telling of the declining trends in conventional agriculture. Our relatively simple method predicts markedly narrow ranges of net SOC change rates under different management regimes (Fig. 1). Although individual interventions reduce SOC loss, only combined interventions across all four groups of management considered could effectively restore SOC. The relevance of studying responses to combined interventions is further stressed by the evidence against additionality in our results.

3.1 Applicability of our findings

Our evidence base includes 209 long-term time data series in arable land from temperate (including bordering semi-arid) and cold regions in Europe and North America. Despite high spatiotemporal variability in SOC often attributed to external factors such as climatic variables or elevation, our meta-analysis allows reliable conclusions on the influence of the management groups reviewed on SOC development over the long term with an evidence base spanning a wide range of climate conditions, soil types, initial SOC content and experiment durations.

4. CONCLUSIONS

Our estimates of SOC change rates from management address the drawbacks from previous statistical approaches, offering simple, yet reliable, factors to account for SOC change in regional-scale lifecycle studies of agriculture. Applying diverse interventions for SOC preservation can unleash the potential for agriculture to become a carbon sink in climate change mitigation efforts while safeguarding agricultural yields for future generations.

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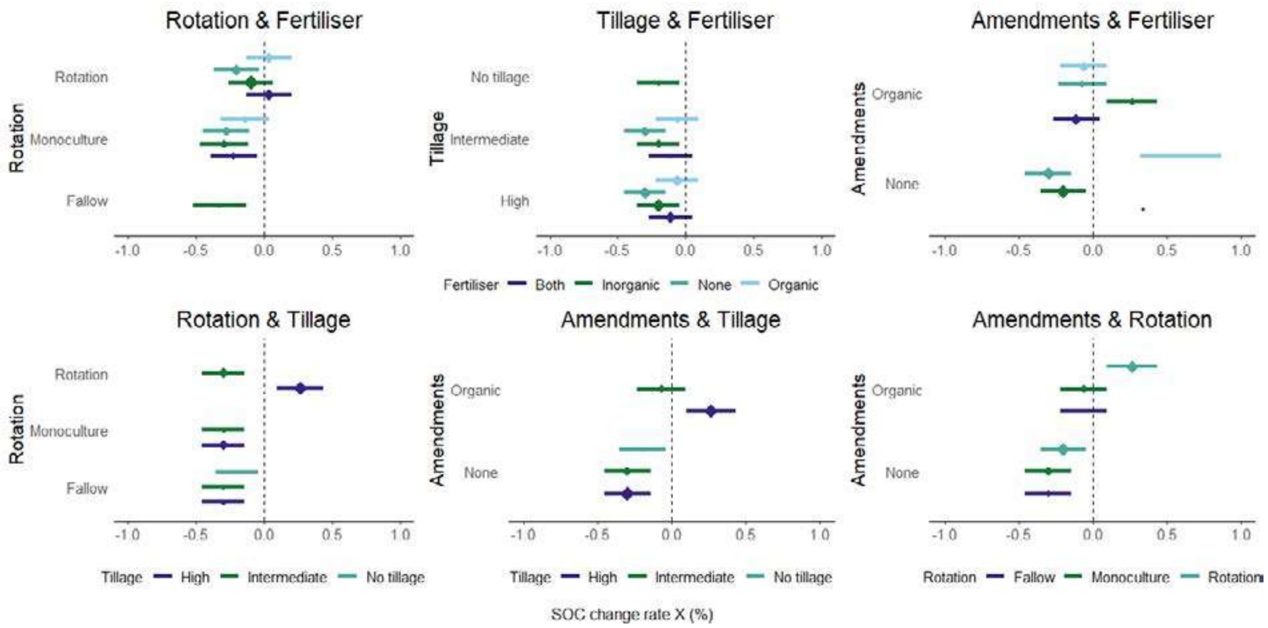

Figure 1 - 95% confidence intervals of the estimated SOC change rates across pairs of groups of management

Sustainability in fisheries and aquaculture systems

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

Identifying current trends in the environmental impacts link ed to fishmeal and fish oil production in Peru

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Keywords: feed; fishmeal; fish oil; reduction industry; sustainable fisheries.

1. INTRODUCTION

Fishmeal and fish oil (FMFO) production is a critical raw material produced for the aquaculture sector, especially for feed preparation, which is typically composed of an important dose of fishmeal and lower amounts of fish oil (Kok et al., 2020). Feed has been identified as one of the main contributors to environmental impacts in the aquaculture sector (MacLeod et al., 2020). As worldwide demand for farmed seafood steadily increases, Peru has become a major player in the aquaculture sector. The vast stock of *anchoveta* (*Engraulis ringens*) makes Peru the main FMFO producer worldwide, representing ca. 20% of total production in 2020 (FAO, 2022). In this context, the main objective of the current study is to estimate the environmental impacts linked to the reduction industry in Peru, by analyzing 4 different plants of a major FMFO producer using Life Cycle Assessment (LCA) methodology. Results intend to provide an update of previous LCA studies conducted in Peru for the same purpose, analyzing the technological changes in the industry and their effect on environmental impacts, as well as to include new impact categories such as plastic pollution.

2. METHODS

Four FMFO production plants located along the Peruvian coast were assessed. The analysis includes the productive phase from the fishing of anchoveta (extractive stage) to the conversion to the final product (transformation stage). The study also analyses the subsequent transport to the port of destination. Two separate functional units were considered: 1 tonne of fishmeal, and 1 tonne of fish oil. Detailed Life Cycle Inventories (LCIs) for each plant were generated using primary data from the FMFO producer. For fishing, it includes the fuel use intensity (FUI) and related landed catch, the inputs (i.e., oil, coolants, fishing gear) consumed during fishing, vessel maintenance and construction. For the transformation stage, all the materials used were included, as well as the quality and performance (FMFO product/anchoveta) of the anchoveta. Finally, transport to the importing countries is included. The study includes a full accountability of life cycle impact categories using ReCiPe, as well as damages linked to plastic emissions.

3. RESULTS AND DISCUSSION

The results show that the quality of the raw material and the energy matrix used during transformation are the main drivers of the variability in environmental impacts. For instance, the fat content of anchoveta was up to 4 times lower in 2019 for landings at a plant in southern Peru, which caused that plant to dominate in all impact categories for fish oil. In contrast, for the same year, the fishmeal yield in southern Peru was similar to the other plants, leading to a similar but higher impacts than the other plants, mainly due to its heavy reliance on residual fuel oil during the transformation process. Although the Peruvian anchoveta fishery is one of the most efficient in the world in terms of FUI, the fishing stage was the main contributor for most impact categories (80%). In the case of GHG emissions, the transformation phase is the most important, averaging ca. 58% of the total, when only fishing and transformation are considered. However, transport to the destination port can contribute up to 40% of the total GHG emissions if included within the system boundaries. Nonetheless, the FMFO production processes analyzed show a better environmental performance as compared to other aquafeed products in the literature. Finally, it is estimated that approximately 310 t of macroplastic waste from fishing gears and 650 kg of primary microplastics were emitted to the ocean from fishing.

4. CONCLUSIONS

Quantity (stock availability) and quality (fat content) of the fishing stock play a major role in the environmental performance of FMFO production. Moreover, it has been shown that the energy matrix used in the reduction process has great influence on several impact categories, mainly global warming. Nonetheless, although Peruvian FMFO remains as one of the lowest ecological footprints amongst animal feed, future work is needed to understand the effects that climate change and ENSO have on this industry.

5. ACKNOWLEDGEMENTS

The authors thank the Natural Environment Research Council (NERC) of the United Kingdom for financial support via the “Reducing the impacts of plastic waste in the Eastern Pacific Ocean” project (NERC reference: NE/V005448/1), the Austral Group of the Austevoll Seafood Company and Fernando Miranda. The authors also thank the Dirección de Fomento de la Investigación (DFI) at the Pontificia Universidad Católica del Perú for funding project PI0859.

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LCA of artisanal fishing in the Union of the Comoros

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1. INTRODUCTION

Only a handful of African fisheries (including foreign fleets fishing in African waters) have been assessed trough LCA, and a relatively lower number of LCAs have been published on small-scale fisheries worldwide. Indeed, very few small-scale African fisheries have been studied with LCA (Avadí and Acosta-Alba, 2021; Le Gouvello et al., 2022; Ziegler et al., 2011).

A key inventory item in fisheries LCA, often determinant of their environmental impacts (Avadí and Fréon, 2013; Avadí and Vázquez-Rowe, 2019), is the fuel use intensity (FUI = fuel consumed/t fish landed) (Parker et al., 2018). Moreover, a thorough mapping of the value chain is known to facilitate environmental and sustainability assessments (Acosta-Alba et al., 2022; Avadí and Acosta-Alba, 2021).

This work focuses on the fisheries-energy nexus of the small-scale fisheries operating in the Union of the Comoros (hereafter referred to as "the Comoros").

Fishing in the Comoros is intended to supply the local market. With a population of around 800 000 spread over three islands (Grande Comore, Anjouan and Mohéli), and a landed volume of between 20 and 23 kt/year, 25-29 kg of fresh fish are available annually per capita.

Various types of gear are used in the country: lines (used by hand, trolling or longlining, be it vertical or horizontal), fishnets, and "others" (underwater gun, rods for octopus fishing on foot, octopus pots). Fishnets are less common, as its use is banned in some areas, particularly at Mohéli. Passive gear, especially vertical longlines, is often used in the vicinity of fish aggregating devices (FADs). Trolling is the most widespread fishing strategy. Motorised fibreglass boats, regardless of their size, are commonly referred to as *Vedettes*. Non-motorised, paddle-propelled outrigger boats (2-4 m long wooden or fibreglass) are referred to as *pirogues*.

There is a network of anchored FADs potentially accessible to artisanal and traditional fishing in the Comoros, most of them installed by the National School of Fishing and Merchant Shipping. There is no longer any industrial or semi-industrial fishing in the country.

The main species targeted are large pelagics (Yellowfin tuna/*Thunnus albacares*, Skipjack tuna/*Katsuwonus pelamis* and Bigeye tuna/*Thunnus obesus*, which together accounted for 73% of catches in 2020), as well as various demersal fish (4% of catches in 2020) (DGRH, 2021).

A mapping of the fisheries value chain in Comoros was produced in the context of a study completed in 2023 and financed by a programme funded by the European Commission (VCA4D - Value Chain Analysis for Development 2016–2022, https://capacity4dev.europa.eu/projects/value-chain-analysis-for-development-vca4d). The main actors, economic and material flows were identified (**¡Error! No se encuentra el origen de la referencia.**), as well as comprehensive data collected to inform environmental and socio-economic analyses, following the VCA4D methodology (Fabre et al., 2021). This work presents the environmental component of this larger assessment, focusing on the primary value chain link (fisheries), to quantify the environmental sustainability of Comorian fisheries from the (mainly energy use-related) perspective. A longer version of this work is, as of January 2024, under review at the IJLCA.

2. METHODS

The scope of the study covers fish from the sea to the landing point. Distribution activities are excluded, as they were determined to be negligible in terms of contribution to additional impacts between the landing points and the Comorian consumers' plates, amounting to ~1% (Dabat et al., 2023). The functional unit is 1 t of whole fish, without any in-depth analysis targeting the edible portion, which is around 60% for tuna (P. Tyedmers, U. Dalhousie, pers. comm.).

No allocation of impacts between fish species was made, due to a lack of data at the necessary level of detail (catches by species x fuel consumption x boat x main gear).

Impact comparisons were made with alternative sources of protein and with products from similar fisheries.

Uncertainty data was compiled for each island x boat x gear combination, in terms of triangular distributions for each key inventory item, namely annual captures, annual trips, as well as fuel and lubricating oil consumption per year per boat and per landed t. Parameter uncertainty was propagated with Monte Carlo.

Two life cycle impact assessment methods were retained: the European Commission's EF 3.0 (Zampori and Pant, 2019) and ReCiPe 2016 (v1.1 Endpoint World H/A [Hierarchist/Average]).

The official DGRH nomenclature for boats and gear was retained:

- JAK-PAL/TRA: 9 m Vedettes using vertical longlines (PAL) or trolling (TRA).
- G18: all 6 m Vedettes.
- G18-FIL: 6 m Vedettes using fishnets (FIL).
- G18-LIG/PAL: 6 m Vedettes using handlines, horizontal and vertical longlines.
- G18-TRA: 6 m Vedettes using trolling.
- GAP-LIG/PAL: pirogues using handlines and vertical longlines.

3. RESULTS AND DISCUSSION

The analysis of inventory data shows that, in line with the literature on the energy cost of fishing (e.g. Parker et al. 2018), active gears imply higher fuel consumption per t of fish landed, and therefore a higher fuel use intensity (FUI), which implies higher environmental impacts.

The impacts of an "average" tonne of fish, i.e. the average of the impacts associated with all the boat x gear combinations, and weighted by the catches attributable to each combination, show that G18-TRA and the island of Anjouan dominate the national results. There are noticeable differences between islands and between gears. These impacts represent damage mainly targeted at human health.

The most important impact categories contributing to the EF 3.0 single score in relation to fishing activities (not shown) are those associated with fuel combustion.

Systematically, the impacts of trolling are the highest, except for Grande Comore, an aberration that may be explained by fishing strategies, distances travelled, the effectiveness and proximity of FADs, etc. (and even by the quality of the data). JAKs (9 m) have higher impacts than G18s (6 m), which can be explained by differences in fishing strategies: JAKs normally go much further, and spend much more fuel because of the time spent travelling to/from fishing grounds, as well as the greater power of their engines (2 x 40 hp vs. 1 x 15 hp of G18).

The relationship between the use of FADs and FUI is not straightforward. FADs in principle minimise the time spent searching for fishing grounds, but it has been reported that for purse seine fleets, the percentage of catches associated with the use of FADs is positively correlated with an increase in FUI (Parker et al., 2015).

The vast majority (98%) of the impacts of fishing by Vedettes are due to fuel consumption. Given that Anjouan-based fishers were responsible over the period 2016-2020 for 57% of national catches (67% in 2020), and the fact that trolling seems to be favoured by these fishers, the impacts of "average" fish in the Union of the Comoros are determined by the performance of Anjouan fishing. Thus, fish from Anjouan is responsible for 79% of the impacts of the average fish in the country, followed by fish from Grande Comore (16.5%).

The impacts of fish captured by pirogues are due to the supply of fishing gear (74% of impacts, due to very frequent renewal), and to the manufacture of the boats (especially those made of fibreglass: ~20% of impacts). These impacts are insignificant compared with those of the motorised Vedettes.

In terms of fuel efficiency, the Comorian fleet remains inefficient (

Figure 1). With a FUI of between 845 l/t for G18s and >1200 l/t for JAKs, it spends much more than the average of African fleets (385 l/t), global fleets targeting large pelagics (430 l/t), and fleets targeting tuna (purse seiners) in the Indian Ocean (300-466 l/t, depending on the species) (Parker et al., 2018, 2015). Comorian FUI is also higher that Tanzanian small-scale fisheries': purse seiners targeting small pelagics (83-95 l/t), longliners (180-400 l/t), ringnetters (295-300 l/t) and gillnetters (180-188 l/t) (Le Gouvello et al., 2022). There are many reasons for this low efficiency, probably due to a combination of factors: kerosene is less efficient than diesel, distances to be travelled to find FADs, fishers' preference for trolling (a very fuel-intensive fishing strategy), etc.

4. CONCLUSIONS

Comorian fisheries seem less efficient than other regional small-scale fisheries and feature higher environmental impacts than alternative animal protein sources available in the country.

The impacts of Comorian fisheries on climate change are relatively high compared with other sources of animal protein and with other fishing fleets in the region. The widely adopted practice of trolling, highly energy intensive, dominates Comorian fisheries. Passive gear-based fishing strategies also feature higher than expected energy-related impacts.

Given the cost of public investment on FADs, the fragility of the devices, and the supposedly significant impact of the FAD network on domestic tuna fishing yields, data on FADs is essential for decision-makers.

Given the importance of fisheries for economic growth, employment, food security and the development of coastal areas in the Comoros (Dabat et al., 2023), it is important to improve the overall energy efficiency of the fleet: engine and boat maintenance, optimised boat construction, adapted fuels and oils, optimised travel strategies, as well as maintenance of FADs and more efficient FAD technologies.

5. ACKNOWLEDGEMENTS

The author was founded by the VCA4D - Value Chain Analysis for Development 2016-2022 programme, through grant agreement 2016/375-804. The author acknowledges his team members and the countless Comorian stakeholders who gave their time and data.

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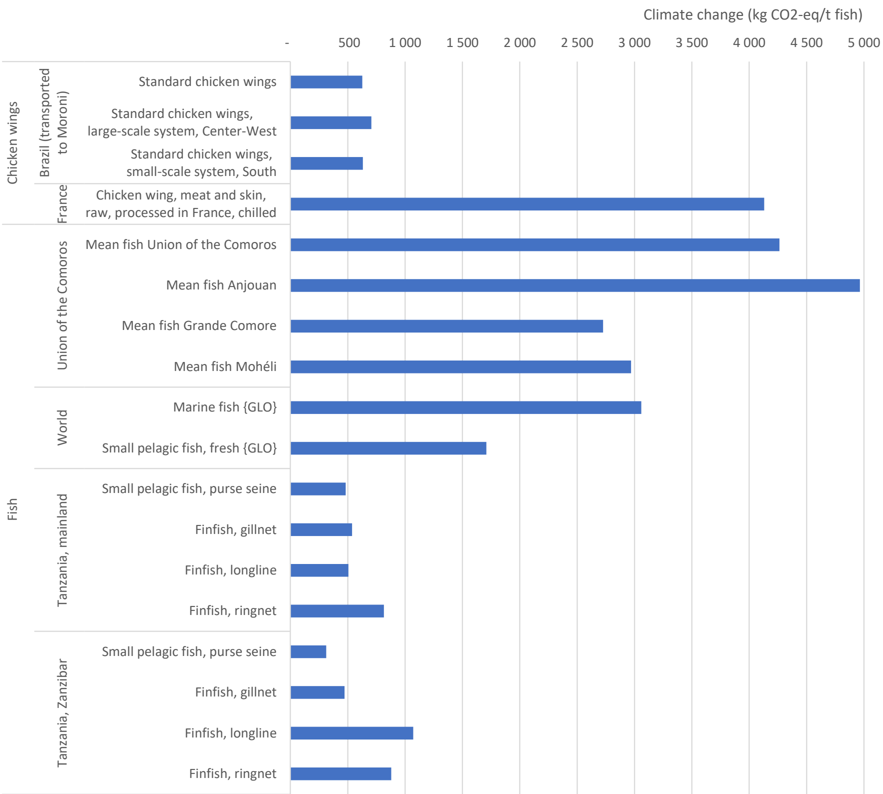

Figure 1. Comparison of impacts (climate change, in kg CO2-eq/t) of different sources of animal protein potentially available in the Union of the Comoros, including local and non-local fish at point of landing

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Navigating the environmental impacts of Manila clam production chains starting from wild and hatchery-produced seed

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1. INTRODUCTION

Italy is the world's second-largest producer of Manila clam (*Ruditapes philippinarum*) from aquaculture (23 thousand tons worth 212 million euros in 2021). Manila clam production volumes have begun to decline over the past 10 years in part due to a decreased availability of wild seed that clam farmers rely on. This has led Italian farmers to purchase seed from hatcheries. The Manila clam supply chain based on hatchery seed brings benefits to farmers, ensuring continuity of production, but with higher production and environmental costs. As the supply of wild seed is expected to decline further due to the effects of climate change and habitat degradation, it is important to evaluate the environmental impacts of current production chains (wild seed and hatchery-based seed), to identify the hotspots and possible strategies to contain the impacts. The study also sought to consider the unique ecosystem services of bivalve, that is the potential carbon storage via shell formation resulting from the balance of the carbon deposited as $CaCO_3$ into the shell and the CO_2 released during the same process.

2. METHODS

Two case studies of Manila clam production were investigated by applying the Life Cycle Assessment (LCA) methodology (CS-A, CS-B). CS-A refers to a conventional production chain that relies on wild spat collection. CS-B refers to the production chain dependent on hatchery seed. The following processes have been considered: 1) seed procuring (from the wild or hatchery), 2) growth-out phase, and 3) depuration. The Functional Unit was 1 kg of clam, shell included. A mass allocation principle was applied. Foreground data were collected through questionnaires and interviews with the technical personnel. The Ecoinvent 3.9.1 database was used to gather background data. The Life Cycle Impact Assessment (LCIA) was carried out using SimaPro 9.1.0.7 (PRé Consultants), adopting the ReCiPe 2016 (H) method. A scenario analysis covering three possible situations was carried out for CS-B to evaluate possible mitigation strategies. To estimate carbon flows associated with shell formation (i.e., oceanic carbon storage and CO_2 released through biocalcification), the following equations were used [1, 2]:

- Oceanic carbon storage= $CaCO_3$ mass shell × (CO_2 molecular mass/ $CaCO_3$ molecular mass)
- Released CO_2= shell mass × Ψ × % $CaCO_3$ shell × (CO_2 molecular mass/ $CaCO_3$ molecular mass), where Ψ is the ration of CO_2 released/$CaCO_3$ precipitate, assumed to be 0.6.

3. RESULTS AND DISCUSSION

The LCIA results for the two case studies are shown in Table 1. In CS-A, the phase that contributed the most to all the impact categories is the combined wild seed supply and growth-out phase (63-87% contribution). For CS-B, the hatchery seed production represented the main driver of FE and ME (about 56-57%), while the growth-out phase predominately affected GW (66%), HT (43%), and FS (64%). Depuration was the phase that contributed the least in both CS-A and CS-B. Fuels, electricity, and antifouling paint were the inputs that contributed most to the environmental impacts in the different chain segments of the two case studies. The scenario analysis carried out for CS-B demonstrated that switching to electricity from renewable sources and reducing fuel use during the rearing phases (e.g., through boat electrification) would substantially reduce GHG emissions (up to -6% and -47%, respectively). Finally, the computation of carbon flows associated with biocalcification is shown in Table 2.

4. CONCLUSIONS

For the first time, a Manila clam production chain entirely based on seed produced in a hatchery was analysed through LCA, together with a conventional production chain. Given the expected decline in wild spat seed availability, this is the first attempt to design the sustainable clam production chain of the future. In addition, the case of the Manila clam is one example of how the peculiar ecosystem services offered by bivalve aquaculture are not adequately defined and integrated into LCA methods. Further efforts of the research community are required to develop standard methods to fill this gap.

5. ACKNOWLEDGMENTS

This work was supported by the Italian Ministero dell'agricoltura, della sovranità alimentare e delle foreste through the project VALUE-SHELL (grant number J86B19001870007).

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Table 1. Life Cycle Impact Assessment for the three case studies.

Impact category	Unit	CS-A	CS-B
Global warming (GW)	kg CO_2 eq.	0.854	1.052
Freshwater ecotoxicity (FE)	kg 1.4-DCB eq.	0.026	0.051
Marine ecotoxicity (ME)	kg 1.4-DCB eq.	0.034	0.065
Human carcinogenic toxicity (HT)	kg 1.4-DCB eq.	0.025	0.032
Fossil resource scarcity (FS)	kg oil eq.	0.256	0.310

Table 2. Computation of the carbon flows occurring during shell formation.

Case study	CS-A	CS-B
CO_2 released by biocalcification (kg CO_2 kg^{-1} clams)	0.154	0.144
Stored oceanic carbon in shells (kg CO_2 eq. kg^{-1} clams)	0.240	0.229

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Can the transition from mono- to polyculture reduce aquaculture environmental footprint? An LCA approach proposed within the BLUEBOOST project

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1. INTRODUCTION

The increased intensive aquaculture production of recent decades raised concerns about its environmental effects, i.e., decreased water quality, depletion of natural resources, and greenhouse gas emissions. Aquaculture impacts are, however, frequently lower than those of other foods derived from animals [1]. Integrated Multi-Trophic Aquaculture (IMTA) combines fed aquaculture (e.g., fish) with non-fed aquaculture (e.g., shellfish). Its application aims at reducing nutrient and carbon emissions by using a circular approach: the combined production of higher-trophic and lower-trophic species might reduce waste released into the environment and increase the overall productivity of the system. The BLUEBOOST project will develop six monocultures to commercially scaled IMTAs that consider a wide range of low trophic species and environmental conditions. LCA will be used to evaluate and optimize the environmental sustainability of the systems. To date, only a few LCA studies have dealt with IMTAs [2-5], facing some methodological dilemmas related to modelling such multifunctional systems. We discuss possible methodological approaches for the environmental evaluation of IMTA systems.

2. METHODS

The six IMTAs will be developed from existing monocultures by integrating species from different trophic levels (e.g., algae, invertebrates, detritivores and filter feeders, and fish), in both marine and freshwater (Figure 1). Challenges that arise when applying LCA methodology to IMTA systems include complex multi-species functional units, differing production cycles between species, and species having different needs in terms of material and energy inputs, which can be difficult to separate. An additional challenge will be providing a comprehensive picture of all aspects that contribute to increased circularity in aquaculture systems (e.g., product and waste circularity, nutrient and carbon charges), which are often not investigated by LCA applied to animal production. LCA will be used to first assess the impacts of the monocultures, and then quantify the effects and improvements of integrating low-trophic species in the implemented IMTAs. Finally, principles for upgrading an experimental case study into an optimized commercial production will be developed.

3. RESULTS AND DISCUSSION

The BLUEBOOST project poses some methodological issues and offers the opportunity for the development of various LCA approaches. The first choice is the functional unit, which has to consider the diverse co-products and their intended use (e.g., food, feed). Different approaches include multiple functional units for different co-products or a single unit for all (e.g., wet weight, protein content, or monetary value of the products). Second, the different production cycles of co-farmed species and their material and energy needs must be screened. Third, the allocation principle adopted. The pros and cons of such methodological choices will be weighed. The expected outcomes of the project will include the environmental footprint assessment of the monoculture and implemented IMTAs, as well as their Life Cycle Inventory. The impacts delivered by BLUEBOOST will hopefully aid the transition towards climate-neutral and sustainable aquaculture.

4. CONCLUSIONS

BLUEBOOST would fill knowledge gaps that exist in the conceptual development, practical implementation, and regulation of IMTAs.

5. ACKNOWLEDGEMENTS

BLUEBOOST is funded under the European Union´s Sustainable Blue Economy Partnership (Project nº SBEP2023-725)

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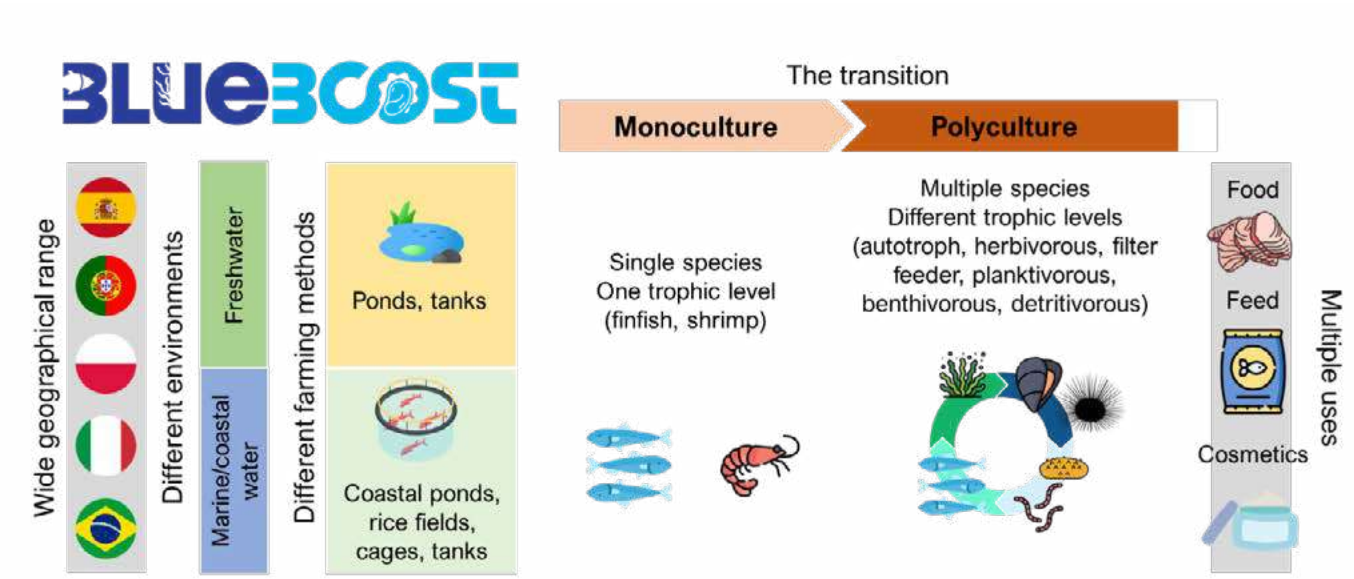

Figure 1. Transition from mono- to polyculture systems

NOT PRESENTED

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Hidden water scarcity footprint of salmon aquaculture feed in Iceland

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1. INTRODUCTION

Blue transformation is the sustainable shift of aquaculture to provide a solution to global food security, and environmental and social well-being. Iceland is aiming toward a more sustainable aquaculture development. Currently about 45,000 tonnes of salmon are produced in ocean-based farming, and 2,000 tonnes in land-based settings (*Statistics Iceland*, n.d.). The land-based production is expected to reach more than 40,000 tonnes in the next few years. While Iceland´s natural geographical advantages allow for access to sufficient clean water for fish farming, the country relies fully on importing plant-based aquafeed ingredients from water-scarce countries. A recent systematic literature review of environmental impacts of aquaculture, identified aquafeed as one of the main contributors to quantitative water use (Vasquez-Mejia et al., 2023). This study aimed at quantifying the hidden water scarcity footprint of aquafeed for land-based and ocean-based salmon farming in Iceland in the reference year 2021.

2. METHODS

A cradle-to-farm-gate LCA study was performed, with a focus on aquafeed needed during the whole salmon life cycle production in land and in ocean farms in Iceland. The following processes were included: farming of green aquafeed ingredients, fishing of fish ingredients, transportation of plant ingredients, and processing of aquafeed (plant-based ingredients, fishmeal and fish oil). Primary and secondary data were used to calculate the average fish diets used at the national scale, as well as the origins of the ingredients. Data sources varied for land-based and ocean-based operations. For national land-based salmon production (1,951 tonnes in 2021), primary data on aquafeed composition and origin was scaled up from the AccelWater project which represent 86% of national production. For ocean-based salmon farming (44,504 tonnes in 2021), feed is largely imported from Norway (Sturludóttir et al., 2021). Therefore, aquafeed composition was estimated based on major Norwegian aquafeed producer's study (Aas et al., 2022). The origin of specific ingredients used for aquafeed was estimated using FAOSTAT trade database (*FAOSTAT*, 2024). When an ingredient was estimated to be imported from more than one country, the quantities needed for aquafeed production were assumed to come from the selected sources proportionally. The functional unit of this study is to provide all the aquafeed required to farm salmon in land and ocean in Iceland in the year 2021. Water scarcity footprint (WSF) was calculated using AWARE (Boulay et al., 2018) using attributional LCA in SimaPro 9.3. All data handling and visualization was conducted in R Studio.

3. RESULTS AND DISCUSSION

3.1 Water scarcity footprint and hotspot analysis

The WSF of aquafeed used for land-based and ocean-based salmon farming in Iceland for the year 2021 was 5893,104 m^3 and 28,037,520 m^3 respectively (Figure 1). In other words, for each tonne of salmon farmed in land and in ocean, the WSF associated with the feed was 304 and 630 m^3 respectively. The AWARE results difference can be associated with a larger number of ingredients used in ocean-based and the uncertainty associated with their origin. Corn meal for land salmon diets is the largest contributor to AWARE (70.4%), while wheat is the largest contributor to ocean farmed salmon diets (73.6%).

3.2 Water scarcity footprint by ingredients country of origin

A close-up analysis into wheat gluten for ocean-grown salmon, indicates that more than 60% of it is imported from China and less than 10% comes from Denmark or Netherlands (Figure 2). However, the WSF of producing 1 tonne of wheat gluten is 5,330 m^3 if farmed in China, while it is 46 m^3 and 36 m^3 if produced in Netherlands and Denmark respectively (Figure 2).

4. CONCLUSIONS

This study allows to map and visualize how dependent Icelandic aquaculture is on plant ingredients from other countries with higher water scarcity. Efforts to reduce the water use in the aquaculture sector could be focused on the hidden water use associated with feed.

5. ACKNOWLEDGEMENTS

This study was funded by the AccelWater project (European Union's Horizon 2020 Research and Innovation programme under grant agreement No 958266), BlueGreenFeed project (European Union´s Horizon 2020 research and innovation programme under the grant agreement No 817992), and Sustainable Healhy Diets (Rannís, Strategic research and development program 2020-2023 societal challenges)

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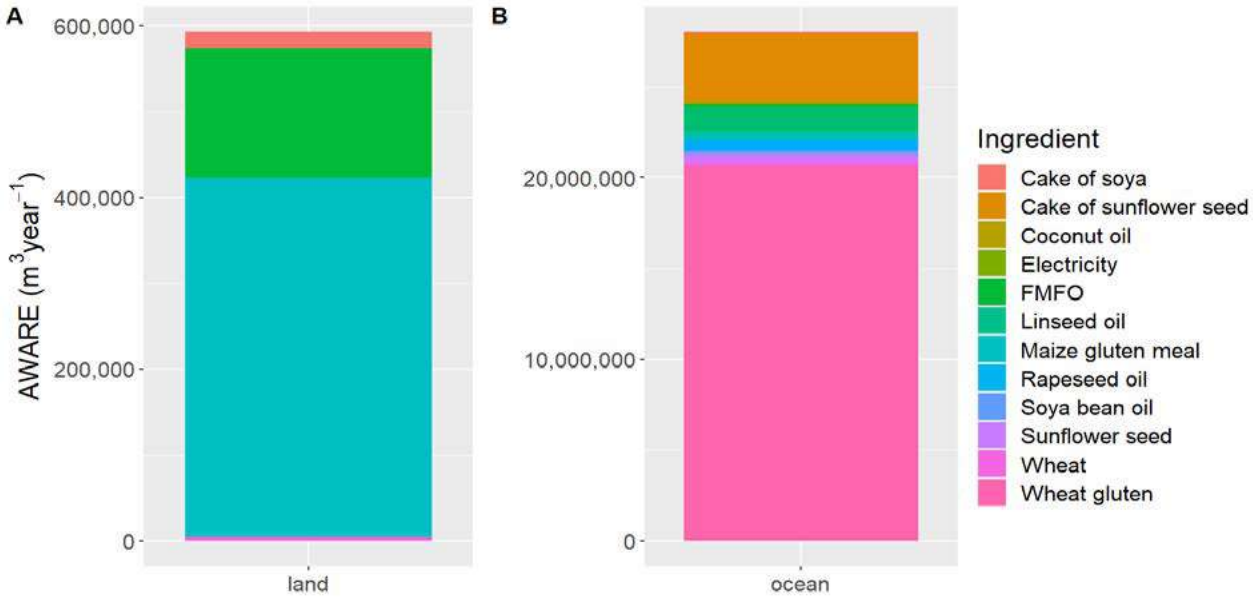

Figure 1. Water scarcity footprint hotspot of aquafeed needed to farm salmon in land (A) and ocean (B) settings in Iceland for the whole production in 2021. The AWARE results difference can be associated with a larger number of ingredients used in ocean-based and the uncertainty associated with their origin

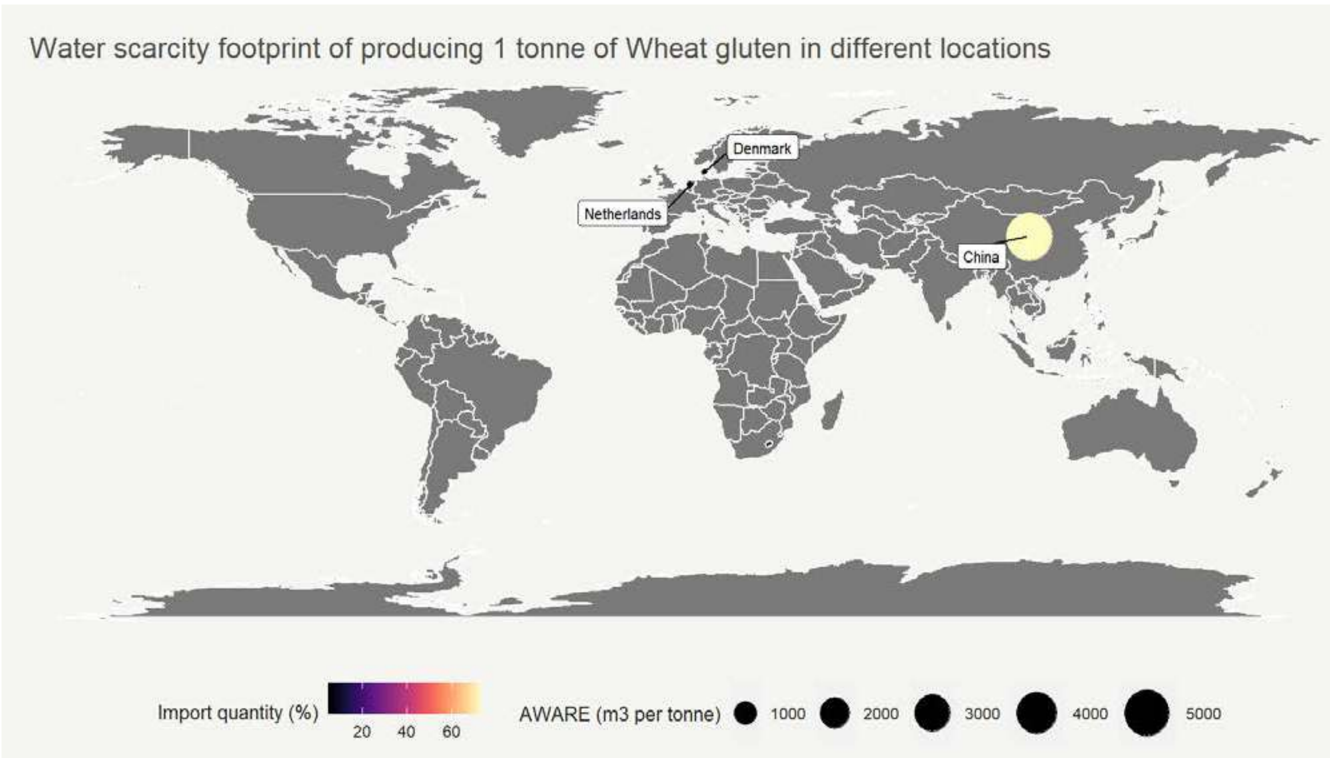

Figure 2. WSF of producing 1 tonne of wheat gluten in different locations. Production in China has a larger WSF than Denmark or Netherlands. Still, it is the major exporter for salmon aquafeed production in Iceland

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Sustainability Assessment of Octopus industry in Portugal: An Environmental Life Cycle Perspective from Two Key Regions

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1. INTRODUCTION

Common octopus (*Octopus vulgaris*) fishery using pots and traps is the most important and valuable small-scale fishery in Portugal, with significant socioeconomic implications (Pita et al., 2015; Rangel et al., 2019). This activity is particularly relevant in the Algarve region, where the largest national fleet dedicated to fishing this resource is located (Sonderblohm, 2016). The common octopus is the most significant species in this region, not only in terms of landings but also in terms of first sale value. In 2022, 3315 tons of common octopus were landed at the Algarve auctions, generating a total first-sale value of 27.8 million euros. This landing quantity accounted for 41.9% of the total unloaded in Portugal and 44.5% of the total first-sale revenue generated nationwide (INE, 2023). The objective of this study is to identify and quantify the major sources of environmental impact to the octopus' industry from the Algarve into 2 fishing areas and to identify opportunities for improvement and reduction of current environmental impacts.

2. METHODS

Selection of two areas of the Algarve, windward and leeward for sampling was based on known differences in their fishing grounds (Sonderblohm, 2016). The study conducted a life cycle assessment (LCA) methodology following the ISO 14040 and 14044 standards. The scope of the study includes the stages of octopus capture, evisceration, freezing, and transport to the market (cradle-to-gate). The environmental analysis was conducted using 1 kg of eviscerated and frozen octopus as the Functional Unit. The analysis considered the fuel used by the fishing fleet, energy for freezing and preservation, packaging materials, water, and energy consumption in the whole process. The study used the baseline CML method as the impact methodology. It examined standard environmental impact categories, as well as direct biological aspects related to fishing activity: Abiotic Depletion, Acidification Potential, Eutrophication Potential, Global Warming Potential, Marine Aquatic Ecotoxicity Potential, Photochemical Ozone Creation Potential, and Terrestrial Ecotoxicity Potential.

3. RESULTS AND DISCUSSION

The study shows that fuel consumption during fishing operations has a significant impact on several categories due to its high energy intensity, particularly Global Warming Potential. In contrast, post-harvest activities have a relatively low impact on all categories.

4. CONCLUSIONS

The octopus' fishery is a crucial sector in Portugal's maritime economy, especially in the Algarve region. To reduce environmental impacts, it is recommended to optimize fuel consumption and adopt more efficient fishing technologies. Its significant contribution to the national economy, through both landings and first-sale revenues, highlights the need for continued research and sustainable management practices to ensure its longevity and prosperity.

5. ACKNOWLEDGEMENTS

This work was supported by the SEE2SEE project: https://sea2see.eu/, (Programme Horizon Europe).

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Environmental performance of oyster farming technologies in Maine, USA

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1. INTRODUCTION

Cultivating oysters and mussels has a long history in many geographies and cultures globally and today a large variety of different species is being farmed using primitive to complex farming techniques. Farmed shellfish avoid many environmental pitfalls of other, higher trophic, farmed species which are often connected to use of limited feed resources, increased nutrient discharges or animal welfare concerns (Grefsrud et al., 2021) and, due to their filter feeding nature they have the potential to mitigate local eutrophication impacts (Aubin et al., 2018). These characteristics have led to a growing interest in farmed shellfish for increased marine protein production while limiting environmental impacts.

Oysters have a strong cultural footing on the American east coast and oyster farming in tidal environments is a growing industry in Maine. This study aims at establishing illustrative carbon footprint baselines for diverse scales of oyster farming and practices in the region. Results will identify emission hot spots within farming, processing and distribution and will be used to guide farmers and other stakeholders towards optimised production systems and expansion pathways. This is an ongoing project finishing May 2024.

2. METHODS

The system boundaries are defined as cradle-to-wholesale gate and the functional unit of *1 kg market size oyster, distributed to key market* is used. Using intermittent functional units at key points in the production system, the carbon footprint of oyster spat and oysters at farmgate and processing will also be analysed. The temporal scope is set to three years to account for multi-year production cycles and reduced influence of environmental fluctuations affecting farming success. Impact assessment calculation will be done using the IPCC 2021 GWP100 calculation method.

3. RESULTS AND DISCUSSION

Results from this analysis will cover the greenhouse gas emissions of farmed oysters produced by four farms at different production scales and using variations of tidal oyster farming technology. Through the identification of emission hot-spots, comparisons between the systems and general findings for the investigated regions can be made. This information will be used to guide the ongoing expansion of oyster farming in Maine by supporting sustainable choices and further understanding of their own systems and environmental impacts among the farmers.

To contextualise the results on a broader scale, a comparison of greenhouse gas emissions (GHG) from oysters farmed in Maine with other animal-based foods will be made on a per kg protein basis.

4. CONCLUSIONS

This study furthers the understanding of GHG emissions related to oyster farming generally and using different technologies and provides guidance for sustainable future expansion of the sector.

5. ACKNOWLEDGEMENTS

This study is funded and guided by Island Institute, a non-profit organization focusing on supporting sustainable development of Maine's coastal communities and economies. We thank the participating oyster farmers for their time and willingness to share data from their production.

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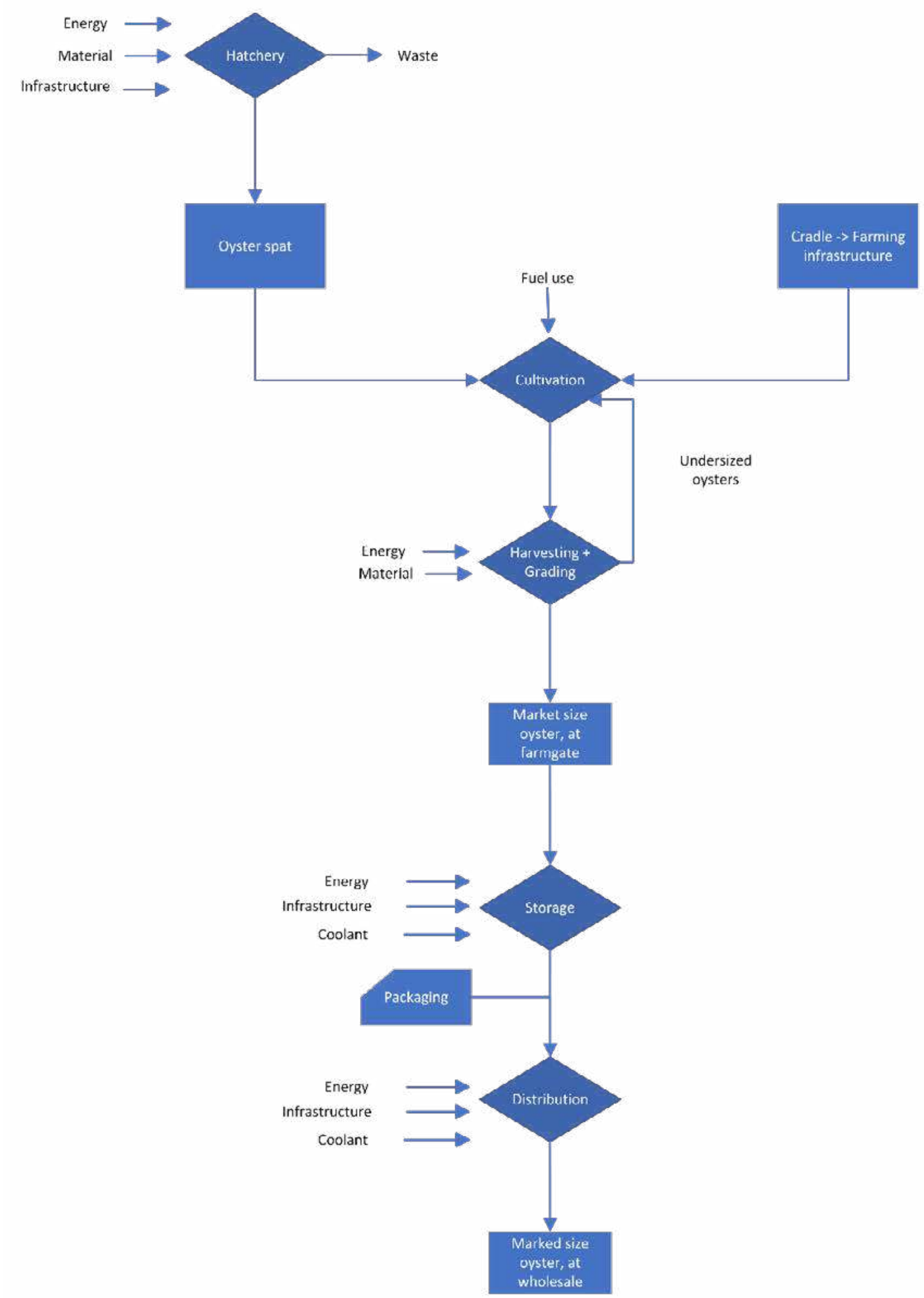

Figure 1. Flowchart visualising the different steps, inputs and outputs of the investigated oyster farming systems.

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Constraints in supply of marine capture fish: empirical evidence and substitution effects

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1. INTRODUCTION

Fisheries stand as a global pillar in meeting the world's nutritional demands, providing a significant share of the population's food supply, as well as important nutritional values. Over the last decade, per capita fish consumption has witnessed a noticeable increase (FAO 2022), emphasizing their increasing role in human diets. However, the environmental implications of this heightened demand are emphasized by the carbon-intensive nature of fish production (Parker et al. 2018).

Despite the surge in consumption, the production of marine capture fish has shown a noticeable stagnation, in contrast to the escalating growth observed in aquaculture (Figure 1). This disparity highlights the need to explore the dynamics influencing the footprint of fisheries, especially when formulating dietary recommendations based on their environmental performance (Thrane et al. 2009). While models based on production often guide seafood consumption choices, a discrepancy exists between the information provided to consumers and its actual effect. The prevailing model approach, based on average production data and frequently used in guidelines for responsible consumption, overlooks the inherent limitations of fisheries—a sector dependent on "wild hunt". Unlike other food products, increasing production directly for this sector is challenging. Global catch data from the last 30 years show minimal potential for expansion, while the current production volumes pose already great pressure to the marine ecosystem.

The primary goal of this study is to bridge this gap by adopting a consequential approach to the assessment of environmental performance of wild-caught fish products. With this study, we seek to establish an assessment framework and deliver recommendations to effectively address how emissions associated with fish consumption are generated.

2. METHODS

The causal mechanisms between seafood demand and supply - and related climate impact - are not yet comprehensively understood and are not reflected in current seafood Life Cycle Assessments (LCA). The challenge is thus to better understand to what extent and where the supply of marine capture fish is constrained as well as how consumer demand shifts when seafood supply cannot increase. Regarding constraints to supply, consequential theory assumes that due to resource limitations, there is virtually no marginal supply of marine capture fish (Weidema 2003). On the second element, consequential theory suggests that constrained products are substituted by functionally equivalent ones (Weidema et al. 1999). Aquaculture seems a logical candidate (Concito 2021), but in many contexts, demand may as well shift to meat or even to plant-based food sources.

In this study, we employ a multidisciplinary approach, combining various qualitative and quantitative methods. We use a top-down approach to analyse historical catch data and fishing quotas for main commercial species in Denmark. This data is sourced from Danish statistics providers. In addition to our data-driven approach, we conduct interviews with Danish Producers' Organisations to gain insights into the complexities of the fish supply chain and sector limitations. These interviews serve not only to inform but also to validate our findings. By presenting our model, which incorporates supply-side complexities, to industry experts, we seek affirmation and refinement to ensure its accuracy and relevance. Furthermore, our methodology includes a review of scientific literature, encompassing studies on consumer preferences on food sources. This review allows us to explore potential substitutions within the fish domain, which are crucial for consequential modelling.

3. RESULTS AND DISCUSSION

The expected result is a framework that will allow us to build consequential demand and supply models for commercial fish species. The identification of constraints and substitution choices has the potential to identify the specific sectors that, by supplying the extra demand through - most likely - a market mix of food products, bear the carbon emissions triggered by increases in demand for seafood.

Preliminary results from both data analysis and interviews show that the quota system is the main limitation to increase marine capture fisheries production, while other species may be limited by the difficulties in avoiding "choke species". Other cases showed unused quotas, where lack of profitability plays an important role. When quotas do not constitute a constraint, limitations are related to lack of fishing capacity or different consumption habits by consumers. The model presented in figure 2 shows in which situations fish production is limited and where are the opportunities for continued supply. This model is being validated and improved using the interviews with the industry. The different pathways of this model can be applied to the most important species as starting point for consequential modelling. Further interviews with retailers in addition to results from literature are expected to provide a model for the substitution part of the approach.

We aim to demonstrate how fish products do not exist in an isolated system but are part of a global market, where increases or decreases in demand will trigger the production in other sectors providing products with the same functionality. This work will provide a solid foundation for building consequential models in the context of fish products. While these models are well demonstrated for other food products, their application in the fisheries sector still relies on weak assumptions. Finally, while providing a critical analysis of current assumptions used in LCA model of fisheries, we also deliver recommendations to make better consequential models in LCA. The insights provided by consequential models can be beneficial for policymakers and those who want to influence impact by steering consumption, because they better explain the effects of making purchasing recommendations.

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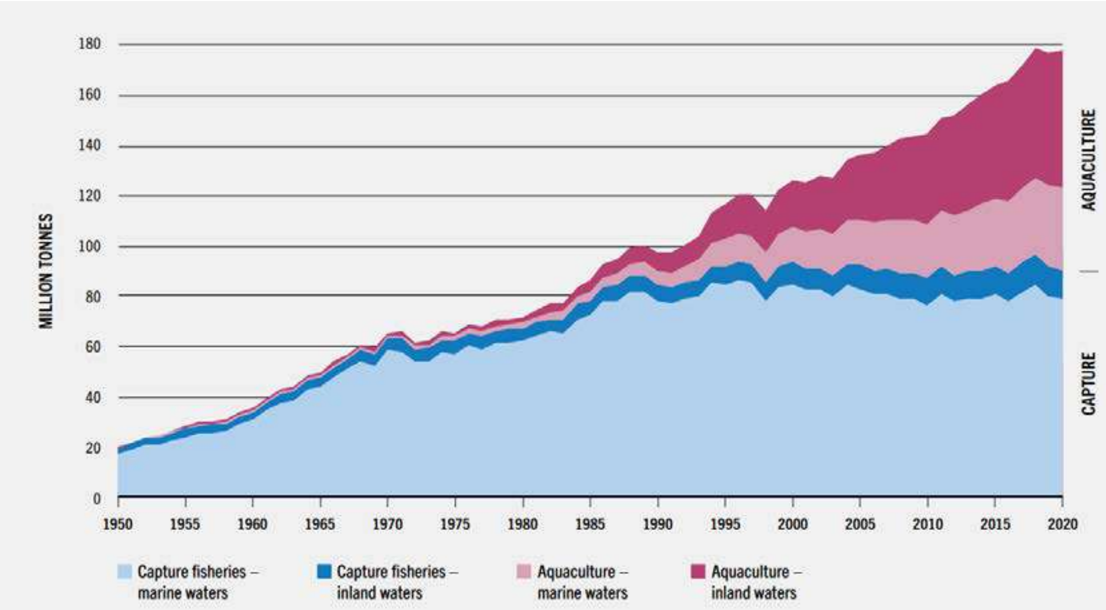

Figure 1: Production trend of fisheries and aquaculture (FAO 2022). The global landings of wild fish have stabilised since around the 90s. The global production of aquaculture does instead show an increasing trend.

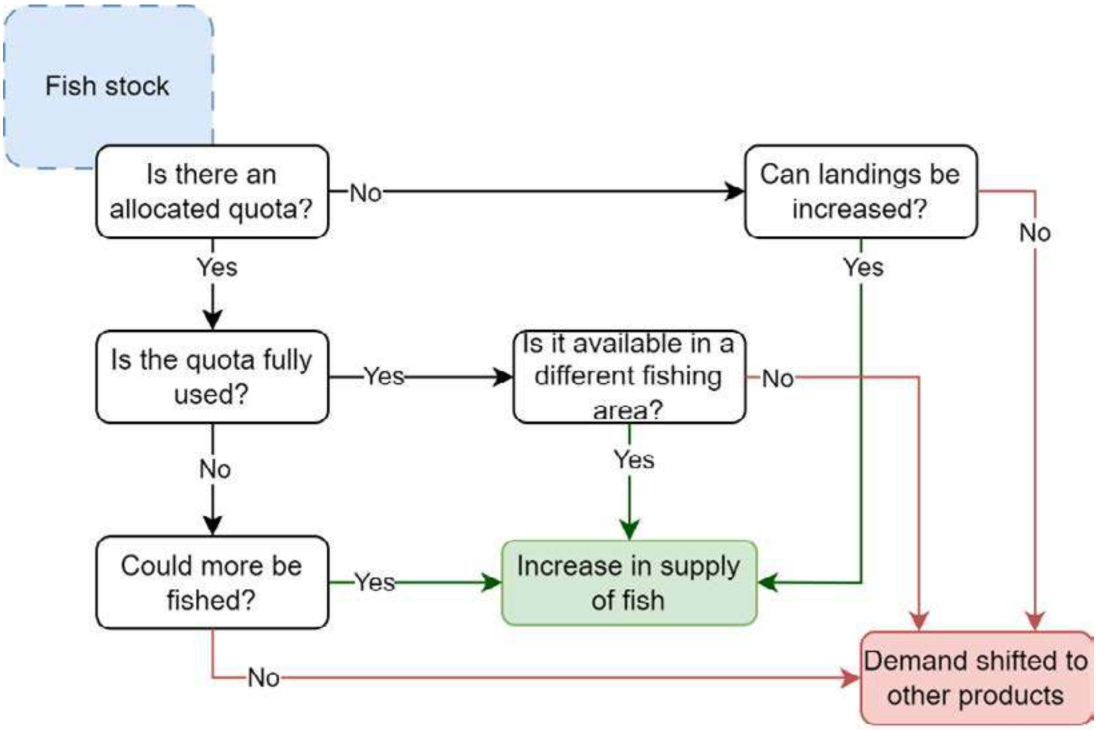

Figure 2: Decision tree describing different paths of limitation and supply for generic fish species.

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LCA of fish oil production: inclusion of biotic resource depletion in impact assessment

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1. INTRODUCTION

With a production of 87.5 million tonnes, animal aquaculture is a growing sector. Far from being a substitute, it adds up to fisheries catches, by increasing the pressure on forage fish stocks that are used as feed (through fish oil and fish meal). Currently, Life Cycle Impact Assessment methods don't take into account overfishing, which is a major impact pathway of the so-called "overexploitation" driver of biodiversity loss according to (IPBES, 2019). However, recent developments in LCIA propose a method to assess impact of biotic resources use (Hélias et al. 2023); this method uses statistical data of biomass and catches, and biological reference points.

The goal of this study is to benchmark impacts on biodiversity of fish oil production, using two contrasted fish stocks: Peruvian anchoveta (*Engraulis ringens*), in Peru Northern-Central (FAO 87.1.13-14; 87.1.23-24), and Atlantic herring *(Clupea harengus*), in Western Baltic (FAO 27.3.20-24). This benchmark add up to the other impacts pathways related to "ecosystem quality" as proposed in ReCiPe 2016 method (Huijbregts et al., 2017), in addition to the Biotic Resource Depletion method (Hélias et al., 2023). The functional unit is 1 kg of omega-3 oil, and impacts are expressed in species.year.

2. METHODS

Full LCIA is performed using ReCiPe 2016 (Huijbregts et al., 2017) to which impact on Biotic Resource Depletion is added (Hélias et al., 2023). For the latter, a "single-species approach" will be used due to the low level of bycatch of forage fish fisheries (Wermeille et al., 2024). For life cycle inventory, generic data was taken exclusively from Agri-footprint version 6.3 with updates regarding fish oil yields and market prices for co-products. LCIA results will be obtained using SimaPro software, version 9.5.0.0. For Biotic Resource Depletion characterization factors computation, statistical timeseries and biological reference points were obtained from historic IMARPE (Instituto del Mar del Perù) stock assessment publications for anchoveta (Acuña et al., 2021; IMARPE, 2023) and from ICES (International Council for the Exploration of the Sea) stock assessments for herring (ICES, 2024).

3. RESULTS AND DISCUSSION

Work on this project will be conducted from February to April 2024, hence results are still at a very early stage but will be ready for the conference. An example of how results will be presented is shown in Figure 1. Expected results are a relatively low impact of anchoveta's exploitation due to its high health and abundance compared to other impacts and high impact of herring's exploitation due to its overfishing status and low abundance. Discussion will be focused on operationalisation of the integration of Hélias et al. (2023) into an endpoint method.

4. CONCLUSIONS

This study proposes an operationalization of data collection and computation of impacts on biodiversity through Biotic Resource Depletion, cumulated with other impacts on biodiversity. The case study on anchoveta and herring enable a benchmark between maximum and minimum impacts that can be expected for forage fish production.

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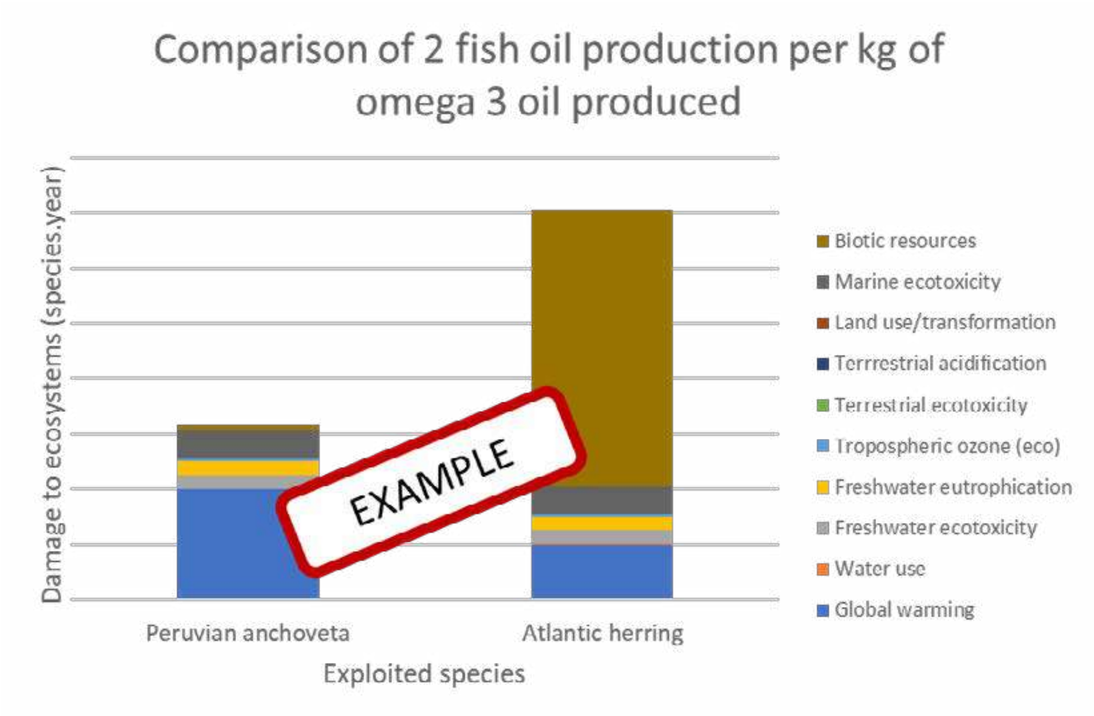

Figure 1. Example of comparison between the use of Peruvian anchoveta and Atlantic herring for the production of omega 3 by fish oil. Values are expressed in species.year using ReCiPe 2016 Endpoint method, area of protection: “Damages to ecosystems” to which impact of Biotic resource depletion is added.

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Evaluating the Environmental Performance of Salmon Aquaculture with Microbiome Application

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1. INTRODUCTION

Fisheries and aquaculture play a crucial role in addressing global food security and nutritional needs. Among the extensively cultivated fish species, atlantic salmon holds particular significance, constituting 32.6% of the total finfish in marine and coastal aquaculture as of 2020 (FAO, 2022). However, the substantial production of fish raises environmental concerns and exposes the aquatic ecosystem to diseases caused by microbial agents. To tackle these challenges, microbiome-targeted interventions present a promising solution, offering the potential to mitigate environmental impacts and enhance productivity (Quero et al., 2023). This study analyses the environmental sustainability of atlantic salmon fish by employing an innovative microbial application, aiming to provide insights into the potential benefits of such interventions in the context of aquaculture practices.

2. METHODS

This study aimed to evaluate and enhance the environmental sustainability of salmon fish product chains through microbiome-tailored circular actions, focusing on improving the Norwegian atlantic salmon food chain. The functional unit is the production of 1 kg of salmon fish live weight (LW). System boundaries include the life cycle of salmon chain from cradle to gate, involving feed production, transportation of feed, and fish production stages. Feed production includes agricultural farming of crops, production of marine and micro ingredients, and chemicals, transportation of these inputs, and industrial processing. Fish production involves eggs hatching to produce juveniles, followed by fish farming, with wastewater sludge transported to a biogas production facility. The vaccination is administered in anaesthetic bath. A microbiome intervention, i.e., exposure to a live culture of probiotic bacterial strains, is also introduced by applying microbiome to half of the fish, while the other half remains without microbiome treatment, both groups kept separately with no difference in treatment. Primary data is directly collected from the fish farm in Norway, supplemented by secondary data from Johansen et al. (2022) as well as ecoinvent and agri-footprint databases. Environmental impact assessment is conducted for global warming, freshwater and marine eutrophication using the ReCiPe 2016 (v1.08) midpoint hierarchist, while the human toxicity (cancer and non-cancer) and freshwater ecotoxicity categories employ the USEtox (v2.12) method through SimaPro software (v9.5).

3. RESULTS AND DISCUSSION

The microbiome-treated salmon (Mic-salmon) resulted in reduced lice level and increased growth compared to the conventional salmon production. However, conventional salmon production exhibits lower environmental impacts, despite a slightly lower output. This is because Mic-salmon require approximately 9% more feed per kg LW (Table 1). The major contributor to environmental impacts is found in the feed production stage, particularly in agriculture crop cultivation. Subsequently, the use of chemicals and materials, and electricity during salmon production stage also plays a significant role (Figure 1). A closer look at the feed production (Figure 2) reveals that crop-based ingredients, including proteins and oils, contribute substantially across all impact categories. Notably, marine eutrophication and freshwater ecotoxicity is primarily attributed to crops. The transport phase of feed production inputs, which heavily relies on fossil-based energy, emerges as a notable contributor in few impact categories. Additionally, marine ingredients, including both oil and protein sources, also contribute to global warming and mainly carcinogenic human toxicity.

4. CONCLUSIONS

In conclusion, despite notable improvements in both productivity and quality (reduced lices) observed in Mic-salmon compared to conventional salmon, the overall environmental performance measured with chosen impact categories does not exhibit improvement primarily due to increased feed requirements. Crop-based ingredients stand out as significant contributors to environmental impacts, followed by chemicals and materials production and electricity use. Addressing the optimization of feed requirements, both in terms of quantity and composition, in Mic-salmon could prove instrumental in enhancing both food security and the overall sustainability performance of salmon fish.

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Table 1. Conventional and Mic-salmon fish production and environmental impact results

Category	Unit	Salmon	Mic-salmon
Fish weight	kg/ animal	4.84	5.03
Feed	kg/ kg LW	0.81	0.89
Dead fish before slaughter	No./ million	2.33E+03	3.02E+03
Global warming	kg CO_2 eq/ kg LW	3.82	4.09
Freshwater eutrophication	kg P eq/ kg LW	1.78E-03	1.86E-03
Marine eutrophication	kg N eq/ kg LW	2.55E-03	2.80E-03
Human toxicity, cancer	cases/ kg LW	3.68E-10	3.80E-10
Human toxicity, non-cancer	cases/ kg LW	8.32-10	9.09E-10
Freshwater ecotoxicity	PAF m^3 day/ kg LW	11.59	12.71

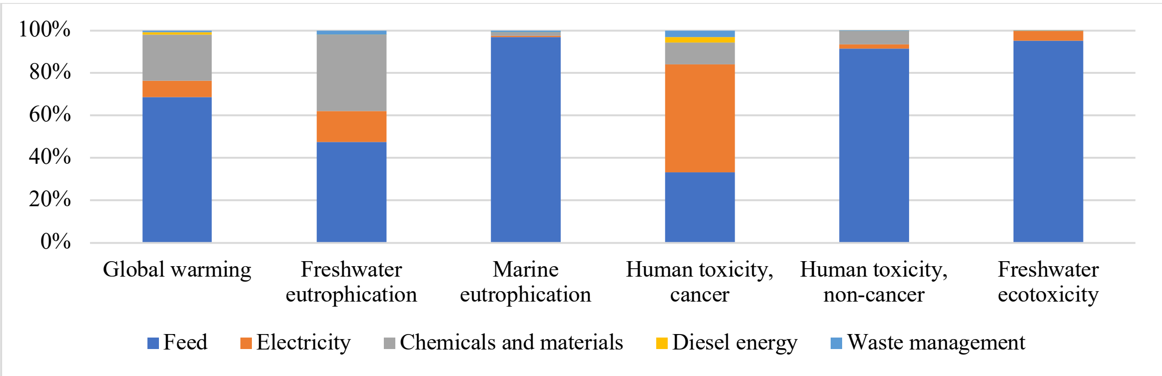

Figure 1. Contribution of different stages towards environmental impacts of salmon fish

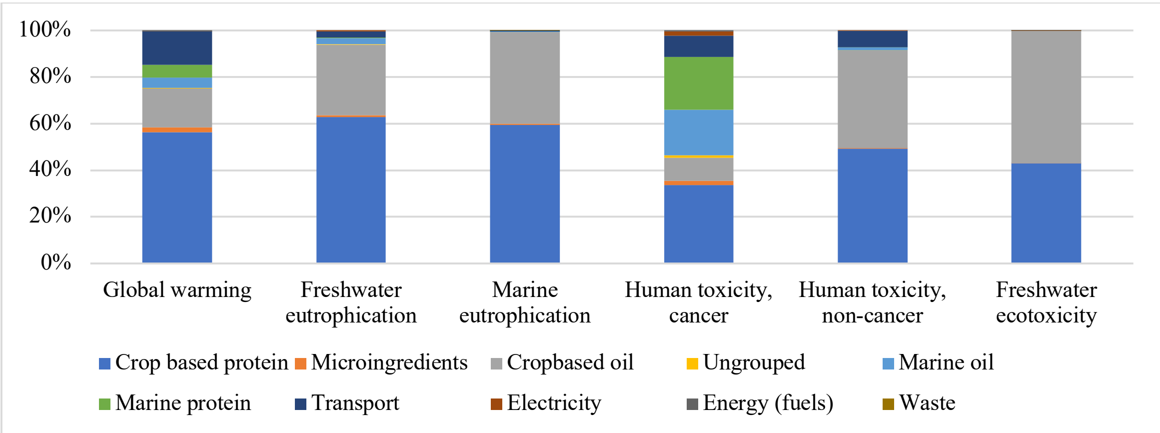

Figure 2. Contribution of different stages towards environmental impacts of salmon fish feed

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Assessing Environmental Impacts: Mussel Imports at La Spezia Farms

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1. INTRODUCTION

In the current global context, the food industry faces increasing environmental challenges related to the production, distribution, and consumption of food. In this complex scenario, valorizing seasonality and the consumption of local products is crucial not only for the agricultural sector but also significantly for seafood. Respecting the production cycles of marine species is essential to ensure their well-being and the regeneration of their habitats. Overfishing and the destruction of ecosystems have reduced fish populations, pushing towards aquaculture, whose production has increased by 609% from 1990 to 2020 [1]. Although aquaculture offers significant advantages, such as access to animal proteins and job creation, it also entails substantial environmental impacts depending on the species farmed and the location of the facilities. Among the forms of aquaculture with the least environmental impact, mussel farming is particularly effective: mussels feed by filtering organic particles from the water, requiring no feed or additives, thus reducing impacts on ecosystems [2]. However, it is necessary to improve some production processes to make this farming even more sustainable. This study aims to examine, through life cycle assessment (LCA), the environmental impacts related to the importation of mussels on the mussel farms of La Spezia (Italy). The goal is to identify future strategies to mitigate environmental hotspots, promote the consumption of local products, and integrate mussels into sustainable diets.

2. METHODS

Using Life Cycle Assessment (LCA) methodology, in line with the international ISO 14040 and ISO 14044 directives, this investigation delved into the environmental impact linked with mussel farming operations [3]. Focusing on the municipalities of La Spezia, Lerici, and Portovenere in the Liguria Region (Italy), this study marked the inaugural LCA analysis of bivalve cultivation within the region. This systematic approach allowed for a comprehensive examination of various lifecycle stages, encompassing activities from “cradle to gate”. Phases under scrutiny comprised seeding and monitoring, farming, harvesting, processing, purification, and packaging. For this life cycle analysis, primary data were collected through a series of direct interviews with representatives of the "Cooperativa Mitilicoltori Spezzini", on-site observations, and in-depth analyses of the cooperative's databases. These data include details on the cultivation techniques employed, resource utilization, waste management strategies, and processing practices adopted by the cooperative. Regarding secondary data, these were mainly acquired through the Ecoinvent database (version 3.8), to cover aspects for which primary data were not available. The chosen functional unit for analysis was the annual mussel production of the cooperative's 81 members in 2022, ensuring all input and output metrics were referenced to this standard. Utilizing Simapro 9.5 software, environmental impact potentials were computed using the CLM-IA baseline V3.07 characterization method.

3. RESULTS AND DISCUSSION

The impacts of mussel farming in La Spezia are clearly visible in Figure 1, which highlights 11 impact categories. It is notable that the "farming" phase significantly contributes to these impacts. In the "farming" phase depicted in Figure 2, impacts arise from four factors: the use of plastic material for cultivation nets, the importation of *Mytilus Galloprovincialis* from Galicia (Spain), equipment, and the utilization of boats for farming maintenance. It is evident that the majority of the impacts of this phase are, however, linked to "imported products" due to the use of refrigerated road vehicles from Galicia.

4. CONCLUSIONS

The preliminary results highlight the critical role of refrigerated transport in importing mussels from Galicia to La Spezia as a primary impact stage in this study's life cycle assessment. This import is essential to meet the Italian market demand for mussels during the winter months when local products are not available. These findings underscore the need for more seasonally sensitive distribution to enhance the sustainability of this product, which is inherently environmentally and nutritionally palatable.

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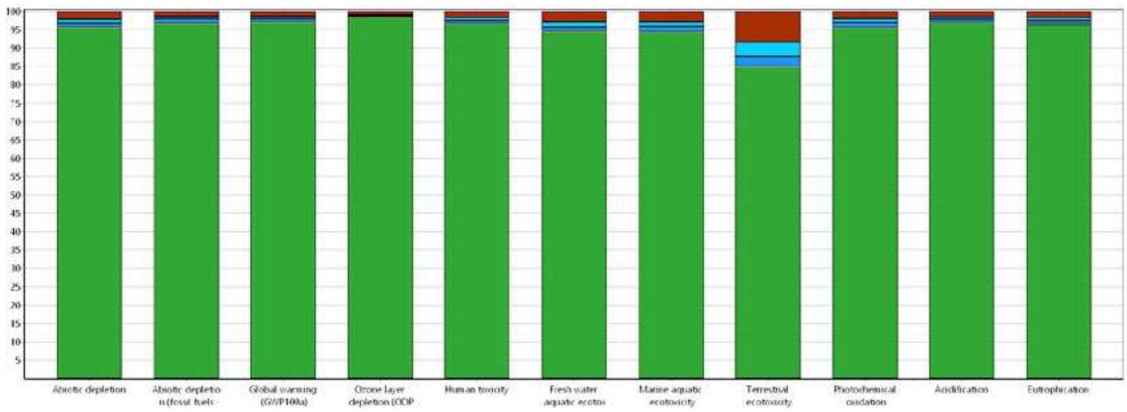

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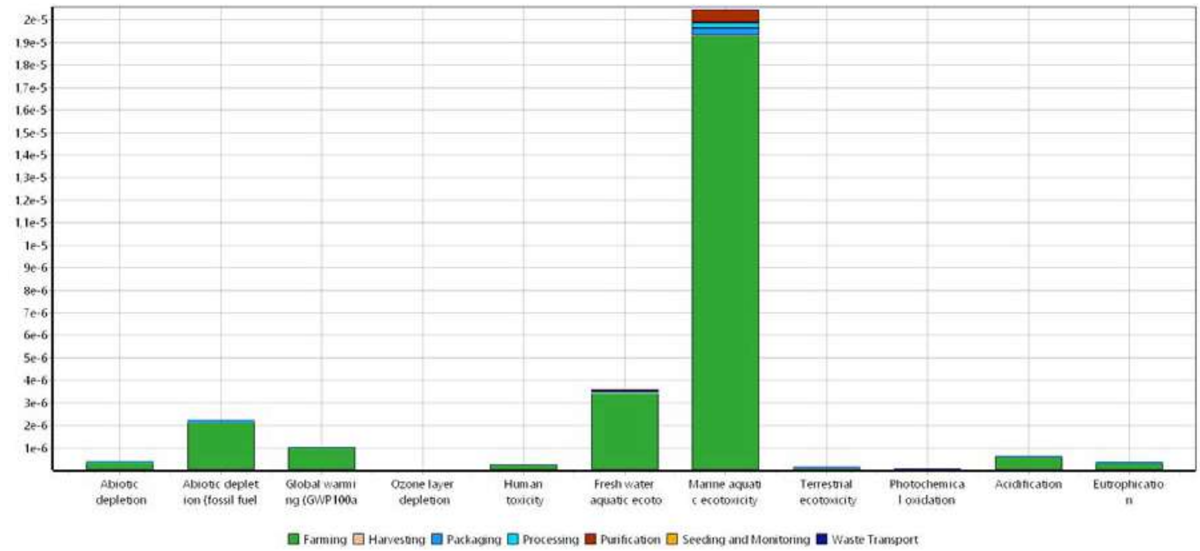

Figure 1, Life Cycle Impact Assessment of Mussel Production in La Spezia, CML-IA Baseline V3.07 Results a) Characterization b) Normalization

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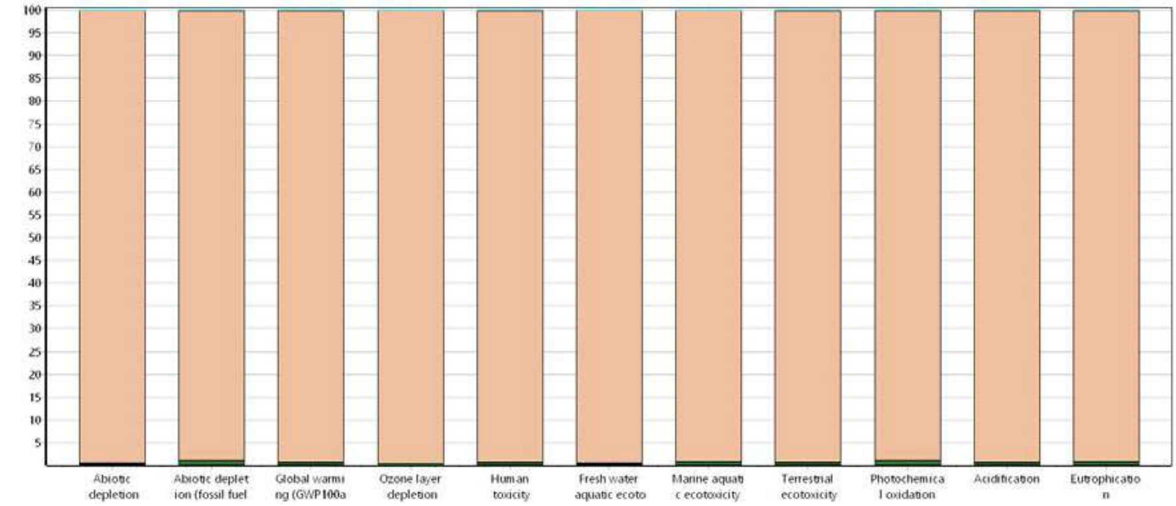

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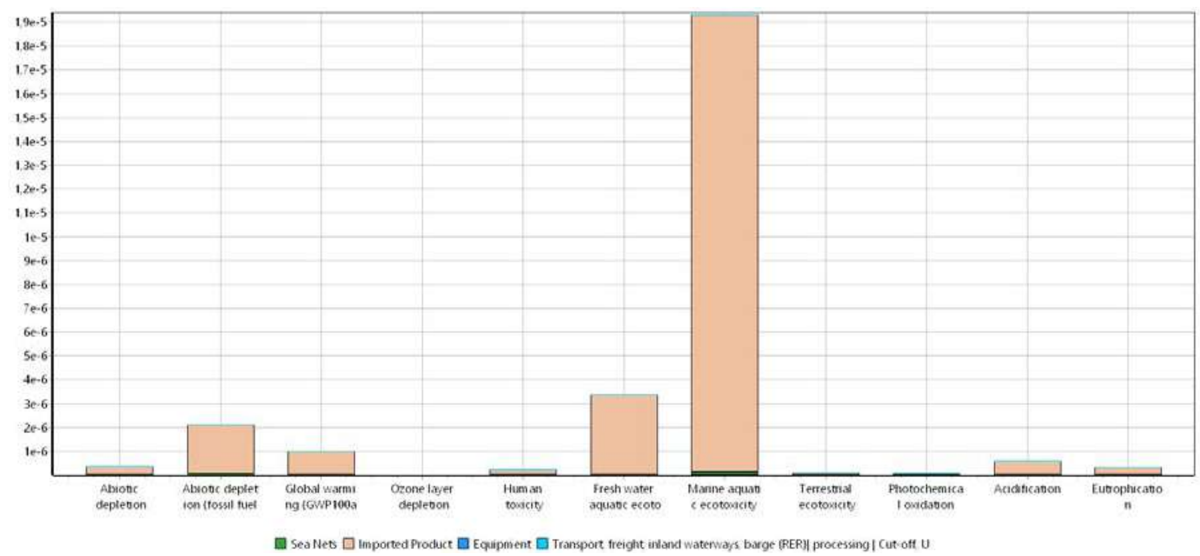

Figure 2 Analysis of the FARMING phase of Mussel Production in La Spezia, CML-IA Baseline V3.07 Results a) Characterization b) Normalization

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Comparative analysis of vertical aquaponic versus hydroponic production: a Life Cycle Assessment (LCA) study

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1. INTRODUCTION

The reduction of land availability intensifies the need to improve the utilization of existing production areas. Dual production systems, such as aquaponics, provide multiple benefits due to an increase of number of products from the same area, but at the same time obey the principles of circular economy through the reuse of resources and waste. However, it is important that their operation is examined in terms of environmental impact, while the most suitable tool for this purpose is the LCA method. In this study, a comparison of the environmental impacts between aquaponic and hydroponic baby lettuce cultivation was carried out, with the aim of identifying the hotspots and improving the sustainability of these production systems.

2. METHODS

The aquaponics system examined was developed in a vertical arrangement and included the greenhouse cultivation of baby lettuce (*Lactuca sativa* L.) in peat substrate in floating system, and the rearing of Rainbow Trout *(Oncorhynchus mykiss* W.) in the underground area of the greenhouse (Case 1), while the comparison was made with the corresponding cultivation in a classic hydroponic solution (Case 2). Inputs included greenhouse and fish farm construction materials, rainwater, peat, seed trays, fish feed, and electricity, while outputs included lettuce leaves, fish weight gain, and N and P emissions from fish waste. System boundaries were defined as cradle-to-farm gate, while mass allocation was applied between fish and lettuce in aquaponics. 1 kg of lettuce was chosen as the functional for the two cases. Environmental impact assessment was conducted in the categories presented in Table 1, by using ReCiPe 2016 Midpoint (H) v.1.06 method, in SimaPro v.9.4.0.2 software.

3. RESULTS AND DISCUSSION

As shown in Figure 1, it emerged that in all the environmental indicators examined, the effects of lettuce cultivation in the aquaponic system were much greater than those of hydroponics. From the separate analysis performed for Case 1, it appeared that the main hotspot was electricity consumption to supply oxygen to the fish (38.1-49.8% for most impact categories), while fish food consumption contributed by 32.9% on the LU indicator, clay bricks for the construction of the basement by 41.9% on the MRS and peat by 42.3% the WC. Indicatively, Carbon Footprint of Case 1 was calculated at 70.3 kg CO_2-eq/kg of lettuce, while in Case 2 at 8.1 kg CO_2-eq/kg of lettuce. The comparison between different studies in terms of impact categories values could not lead to safe results, due to the strong differentiation of the systems in each study. However, it is worth mentioning that electricity has appeared as a hotspot in the majority of similar works [1], which intensifies the need to find solutions to intercept its effect, such as replacing grid energy with photovoltaic energy [2] or optimizing mechanical equipment.

4. CONCLUSIONS

From the present work it emerged that growing baby lettuce in aquaponics have much greater effects than the corresponding hydroponic culture, however, it is worth considering the benefit of the simultaneous production of fish and vegetables in the same area and the re-utilization of wastewater. Future research is important to focus on reducing the impact of specific inputs, such as the use of alternative energy sources, but also examining the system from an economic point of view, in order to approach sustainability as much as possible, both environmentally and economically.

5. ACKNOWLEDGEMENTS

This research has been co-financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T1EDK-00756).

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Table 1. Values of impact categories for the two cases

Impact category	Unit	Case 1	Case 2
Global warming (GW)	kg CO_2 eq	7.03E+01	8.14E+00
Stratospheric ozone depletion (SOD)	kg CFC_{11} eq	2.79E-05	2.40E-06
Ionizing radiation (IR)	kBq Co-60 eq	1.94E+00	3.72E-01
Ozone formation, Human health (OFHH)	kg NO_x eq	9.63E-02	1.24E-02
Fine particulate matter formation (FPM)	kg PM2.5 eq	1.42E-01	1.36E-02
Ozone formation, Terrestrial ecosystems (OFTE)	kg NO_x eq	9.78E-02	1.26E-02
Terrestrial acidification (TA)	kg SO_2 eq	3.00E-01	2.90E-02
Freshwater eutrophication (FE)	kg P eq	1.32E-01	9.06E-03
Marine eutrophication (ME)	kg N eq	7.75E-03	4.96E-04
Terrestrial ecotoxicity (MEC)	kg 1,4-DCB	1.80E+02	2.27E+01
Freshwater ecotoxicity (FEC)	kg 1,4-DCB	6.05E+00	4.84E-01
Marine ecotoxicity (MEC)	kg 1,4-DCB	7.97E+00	6.44E-01
Human carcinogenic toxicity (HCT)	kg 1,4-DCB	8.52E+00	1.32E+00
Human non-carcinogenic toxicity (HNCT)	kg 1,4-DCB	1.48E+02	1.14E+01
Land use (LU)	m^2a crop eq	8.93E-01	1.42E-01
Mineral resource scarcity (MRS)	kg Cu eq	2.08E-01	4.27E-02
Fossil resource scarcity (FRS)	kg oil eq	2.21E+01	2.67E+00
Water consumption (WC)	m^3	8.87E-01	4.12E-01

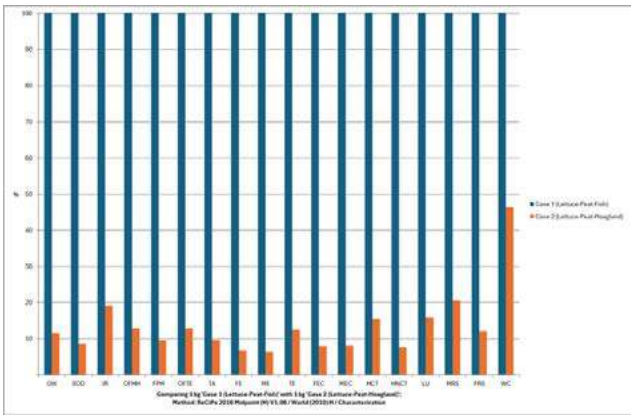

Figure 1. Comparative environmental analysis of the two cases

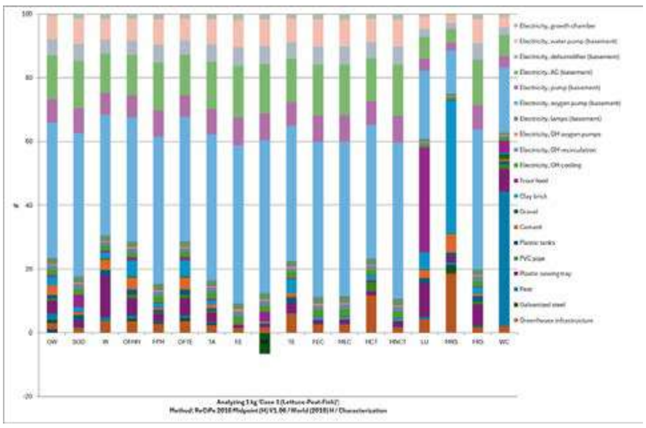

Figure 2. LCIA of Case 1

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Evaluating the environmental impacts of seaweed cultivation and derived products

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1. INTRODUCTION

The exploration of alternative sources for biomass, feed, and food is critical for advancing sustainable agriculture. Seaweed can provide renewable biomass that can facilitate a transition from fossil fuels to a sustainable blue-green bioeconomy (Chong et al., 2023). Nevertheless, no comprehensive review of life cycle assessments (LCAs) pertaining to seaweed has been identified, encompassing both cultivation and its processing into different products to assess environmental impacts. This study serves as an entry point to fill this gap. The objectives of this study are therefore twofold: (1) to examine existing LCA studies on seaweed cultivation and its potential applications, and (2) to outline key methodological challenges encountered in conducting LCAs for the seaweed value chain.

2. METHODS

This study employed online databases such as Scopus and Google Scholar to retrieve both qualitative and quantitative data from eligible studies for this review. The collected data were then categorized into different environmental impact categories according to the types of seaweed-based products.

3. RESULTS AND DISCUSSION

This study offers a comprehensive assessment of the environmental implications linked to both seaweed cultivation and derived products, with a particular emphasis on LCA studies. A notable observation is the significant disproportion in the geographical distribution of LCA research. Despite Asia producing more than 90% of the global seaweed, it only contributes to 24% of LCA studies, whereas Europe, with less than 1% of seaweed production, accounts for about 70% of such research. Current cultivation practices are associated with the potential for negative emissions when considering biogenic carbon sequestration. However, there is a need for further investigation into carbon balances and losses. Seaweed exhibits promising prospects to provide products such as food, fertilizers, bioenergy, feed, cosmetics, and for construction, and thereby facilitating the establishment of a circular bioeconomy. The main emissions hotspots identified include infrastructure production, fuel use for transportation, energy consumption for drying seaweed, and for the processing stage. Key obstacles in seaweed LCA research encompass mainly the absence of standardized methodologies for diverse production systems, the impact of cultivation on local ecosystems, and data constraints.

4. CONCLUSIONS

Seaweed has the potential to improve sustainability in various sectors, including food, bioenergy, feed, materials (e.g., construction), cosmetics, and fertilizer. However, several challenges contribute to the complexity of conducting life cycle assessments for seaweed. These challenges include limitations in data availability, diverse production systems, difficulties in modeling some specific impacts such as on biodiversity, or local marine ecosystems, and comparability with land-based alternatives. Major emission hotspots throughout the seaweed cultivation and application lifecycle include energy-intensive drying and preservation processes, infrastructure production, and processing phases. To enhance environmental sustainability, this study recommends focusing on extending the lifespan of infrastructure material, recirculating by-products, and adopting renewable energy sources for processing and drying. Continued research and development in seaweed cultivation and utilization are necessary to fully realize its potential as a sustainable resource of biomass.

5. ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by the Sea-Soil project “Value creation and ecosystem services of European seaweed industry”.

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Assessing cumulative fishing impacts on marine ecosystem quality

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1. INTRODUCTION

Various anthropogenic drivers affect terrestrial, freshwater and marine biodiversity. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) identified five main direct drivers: land/sea use change, climate change, direct exploitation, pollution, and invasive alien species (IPBES 2019). The importance of each driver varies between the three realms. The oceans are mainly affected by direct exploitation and climate change, whereas the other realms show a different hierarchy (i.e. dominated by land use change) (Jaureguiberry et al. 2022). This study proposes a new life cycle impact assessment method to address the impact of direct exploitation (i.e. fishing) on marine ecosystems.

2. METHODS

To quantify the quality difference of a given area of marine ecosystem over time, the fuzzy modelling approach of the Biodiversity Value Increment method for land use is applied to the marine realm (Lindner et al. 2021). The five criteria defining the quality are the five main drivers identified by the IPBES. The drivers are weighted based on the dominance hierarchy, which Jaureguiberry et al. (2022) quantified. In this study the quality for the driver “direct exploitation” is assessed for all marine ecoregions of the world (MEOW). The affected area is the whole marine ecoregion, and the timeframe is one year.

To quantify the cumulative biodiversity value contribution of “direct exploitation” a soft AND aggregation is used. The contributing parameters are all available stocks in the MEOW, based on stock assessment data from the Sea Around Us database (Pauly et al. 2020). The value contribution of each stock is assessed using a contribution function with the depleted stock fraction (DSF) as input: DSF = 1 - B/K, where B is the biomass of the stock and K is the maximal carrying capacity.

3. RESULTS AND DISCUSSION

The weighting factors for the IPBES drivers are: direct exploitation (0.282), climate change (0.251), pollution (0.211), land/sea use change (0.173), and invasive alien species (0.083). The quality aspect of the MEOWs affected by the cumulative fishing pressure ranges from 0.07 to 0.77, as can be seen in Fig. 1. In general, the results correlate with other studies, showing low quality values for regions, which are known to be heavily fished, and vice versa.

The marginal and average CFs cover a wide range (see Fig. 2), with most values (first to third quartile) lying within a range of 0.78-40.73 and 0.59-30.72 BVI*m²*year per kg of catch for marginal and average respectively.

4. CONCLUSIONS

The proposed method is a first step towards integrating marine biodiversity impacts, like direct exploitation, into the overall BVI framework. It provides a set of marginal and average characterization factors per kg catch for 2082 stocks in 223 marine ecoregions worldwide. Further development is still needed to validate the results. Case studies, using these CFs to compare the biodiversity impacts of land- and sea-based food products are still ongoing and are expected to be finished by July 2024. A marine ecoregion factor, which puts the impacts of all marine ecoregions in context, is still under development.

5. ACKNOWLEDGEMENTS

We thank the BioVal-team for the constructive discussions and the Federal Ministry of Education and Research for the funding.

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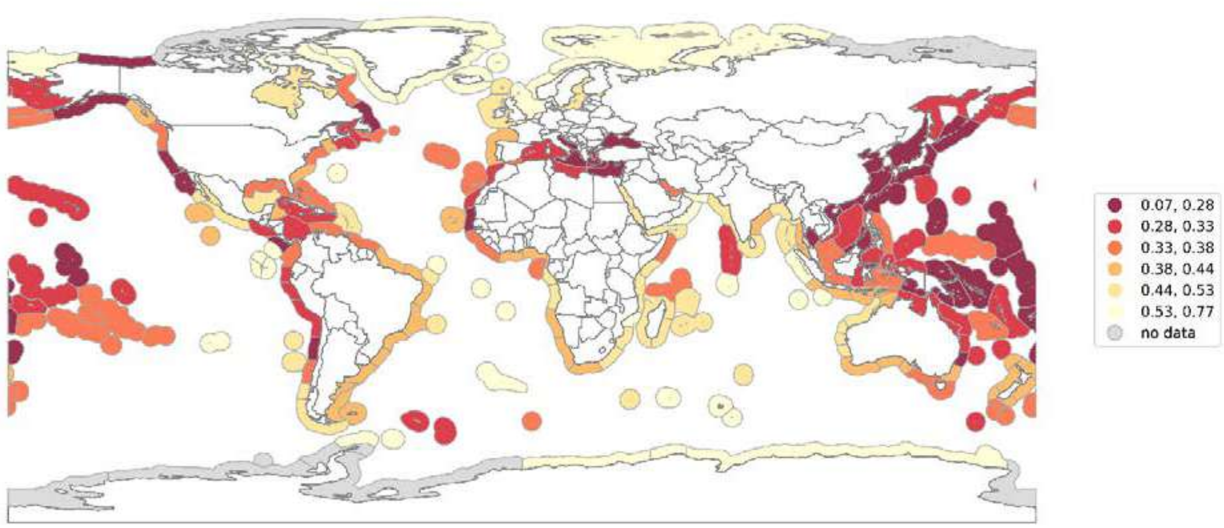

Figure 1. Choropleth map of the aggregated quality of all MEOWs based on the cumulative impact of direct exploitation (i. e. fishing pressure). Values are dimensionless.

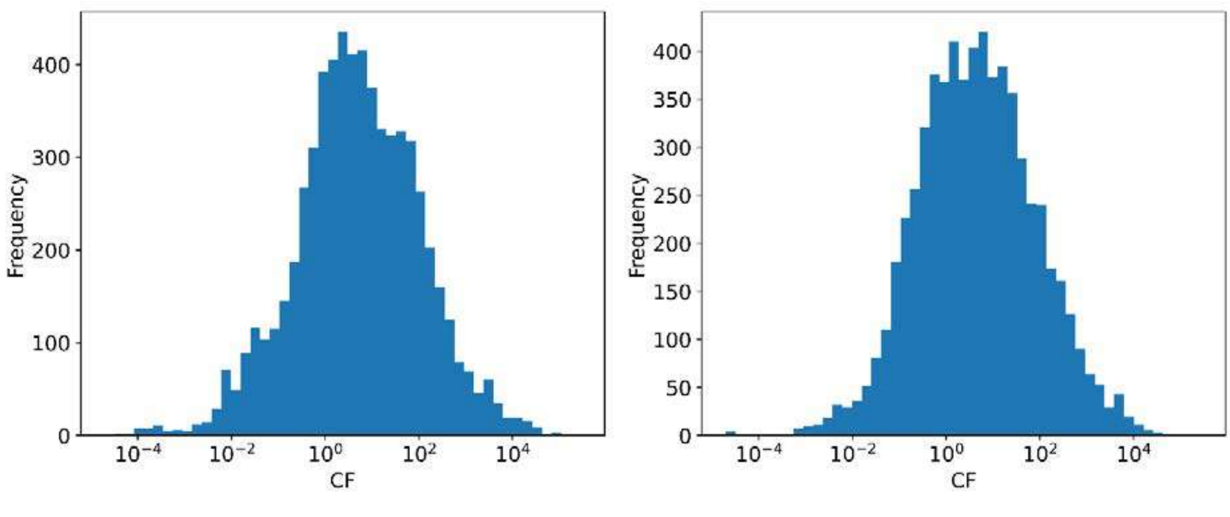

Figure 2. Histograms of the calculated characterization factors; left = marginal CFs, right = average CFs. CF values in BVI*m²*year per kg catch.

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Assessing the environmental impacts of conventional and organic scenarios of rainbow trout farming in France

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1. INTRODUCTION

Rainbow trout is a major farmed fish in France and globally, with 953,000 tonnes produced in 2021, primarily in freshwater environments. Traditional trout farming faces challenges like limited space, freshwater scarcity, and sustainability concerns. The increasing demand for sustainable products has sparked interest in organic aquaculture, which prioritizes environmental practices and animal welfare. As consumer demand for sustainable and environmentally friendly products grows, there is a rising interest in organic aquaculture, which aims to integrate best environmental practices, natural resource preservation, and high animal welfare standards (Ahmed et al., 2020). Nevertheless, the environmental impacts of organic aquaculture have been poorly investigated until now.

This study aimed to compare the environmental impacts of conventional vs. organic rainbow trout farming through a Life Cycle Assessment. To do that, we modeled a trout farm, practicing conventional or organic rearing rainbow trout production. Our model allows us to simulate a production farm in France.

2. METHODS

The farm model, developed using R freeware was designed to simulate rainbow trout aquaculture, either under conventional or organic production scenarios, in a hypothetical flow-through farm built based on 2022 survey data gathered from trout farms in France (Table 1). Parameters and constraints for conventional and organic production scenarios integrated survey data, scientific literature, and industry specifications. French production specifications (CIPA, 2023) and organic production regulations (MAAP, 2010) were specifically used. An attributional LCA followed ILCD standards, using the farm model to conduct a life cycle inventory for both scenarios. Agribalyse 3.0 and Ecoinvent 3.8 databases provided data for the assessment, aligned with international standards. Impact assessment used ReCiPe 2016 Midpoint (H) version 1.07 (Huijbregts et al., 2017).

3. RESULTS AND DISCUSSION

Our life cycle impact assessment revealed that organic farming significantly reduced environmental impacts per tonne of trout in seven of the nine selected impact categories. Notably, freshwater ecotoxicity exhibited the most significant difference, with organic systems showing a 35% decrease. The only exceptions were freshwater eutrophication and water dependence, where organic production led to higher impacts per tonne of trout. In conventional farming, emissions amounted to 14 kg of P eq./tonne, whereas in organic farming, the emissions were slightly higher (15 kg of P eq./tonne). For water dependence, one tonne of trout in the conventional system mobilized 128 103 m^3 vs. 185 103 m^3 in the organic system (Figure 1).

Overall, caution is advised when comparing impacts per tonne of trout, as organic systems have lower production capacity due to reduced rearing densities and inputs, impacting water dependence and freshwater eutrophication. The use of a surface-based functional unit (m^2y) suggested similar or slightly lower water dependence and freshwater eutrophication in organic production, emphasizing the need to consider production capacity differences for a comprehensive evaluation of environmental performance in organic and conventional systems.

4. CONCLUSIONS

We demonstrated the environmental benefits of organic trout production at the farm level. Thus, we revealed that organic farming significantly reduced environmental impacts per tonne of trout in seven of the nine selected impact categories included in LCA.

5. ACKNOWLEDGEMENTS

The authors thank all the fish farmers involved in this study for organizing the visits and taking time to answers all our questions and sharing their data and perceptions.

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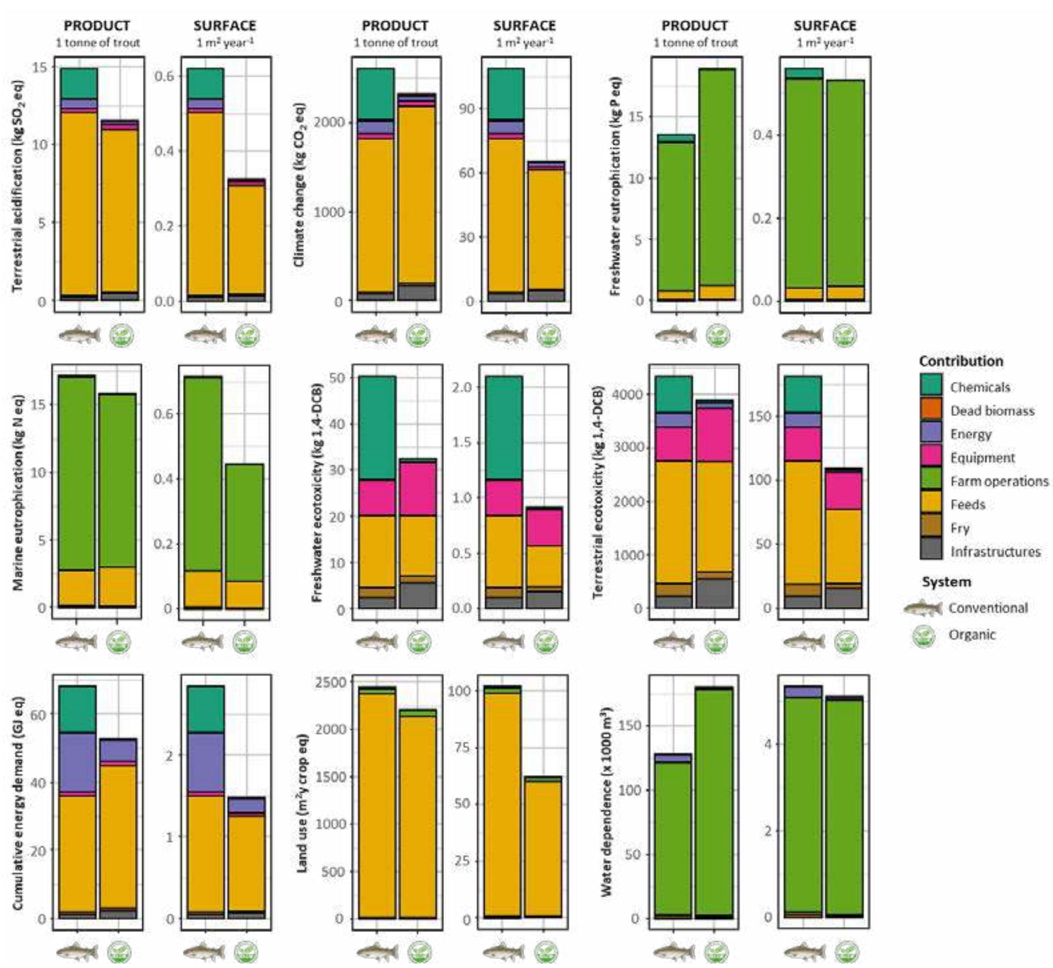
Parameter	Conventional	Organic
Production (t $year^{-1}$)	300	203
Rearing duration (d)	737 ± 2	913 ± 4
FCR	1.3	1.3
Mortality rate (%)	15	15
Number of batches per year	3	3

Table 1. Type of trout farms considered in the two different scenarios.

Figure 1. Contribution of each input or production step in environmental impacts in conventional and organic trout production systems. Results are expressed per tonne of trout at market size (product-based) or per m^2y (surface-based).



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Sustainability of luxury food: LCA of sturgeon caviar and meat

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1. INTRODUCTION

Italy is the leading producer of caviar from aquaculture in Europe (62 t in 2022, 35% of the European production; Eurostat, accessed on 20/05/2024). The caviar production chain is complex and characterized by great temporal variability depending on species. Males and females are initially grown without producing any profitable commodities because of late sex determination (3-8 years). Then, males are slaughtered for meat production, while females are farmed up to 8 to 18 years old when eggs are suitable for caviar production. Despite the large body of studies on the environmental impact of agri-food supply chains, the caviar production chain has never been assessed. To fill this gap, the first comprehensive Life Cycle Assessment (LCA) of aquaculture caviar production was carried out to evaluate its environmental impacts associated and suggest possible mitigation strategies.

2. METHODS

The LCA methodology was used to assess the impacts associated with the production cycle of caviar from four different species of sturgeon: Siberian sturgeon (*Acipenser baerii*), Russian sturgeon (*A. gueldenstaedtii*), white sturgeon (*A. transmontanus*) and beluga (*Huso huso*), farmed in a facility in northern Italy. The following phases of the production chain were identified: (1) hatchery, (2) pre-fattening, (3) mixed fattening of males and females, (4) fattening of females, (5) transport, and (6) processing and packaging of caviar and meat. The functional unit (FU) was 1 kg of caviar. The reference flow was the production of 1 kg caviar and associated meat mass (average 5.9 kg meat kg-1 caviar). The economic allocation principle was applied. For the Life Cycle Inventory (LCI), foreground data referred to one year of production (season 2022/23) were provided by farmers through questionnaires and interviews. The Ecoinvent 3 database was used to gather background data. The Life Cycle Impact Assessment (LCIA) was carried out using the software SimaPro 9.5.0.1 (PRé Consultants), adopting the ReCiPe 2016 Midpoint (H) v.1.08 method and considering the Global Warming impact category. Scenario analyses were also performed to unveil the effects of possible mitigation strategies. The first scenario simulated a 30% and 50% increase in solar energy supply. The second scenario foresaw a reduction of feed use through the removal of male sturgeons at an earlier stage of the production chain by genetic sex determination (Kuhl et al., 2021).

3. RESULTS AND DISCUSSION

Results showed high variability depending on the species, due to differences in terms of caviar price and time necessary to obtain it. Caviar-associated emissions ranged between 52 and 76 kg CO_2 eq. kg^{-1} of caviar, while sturgeon meat varied between 4.8 and 10 kg CO_2 eq. kg^{-1} of caviar (Table 1). The fattening phase (both mixed-sex and only female fattening) is that contributing the most, representing about 78% of the total emissions, while hatchery and pre-fattening contribute always less than 6%, transport and processing 7% and 9%, respectively (Figure 1). The main hotspots of the supply chain were feed and electricity and the scenario analysis showed that Climate Change-related impacts could be reduced by up to 18% through feed reduction and up to 19% by the energy shift (depending on species).

4. CONCLUSIONS

This study represents the first LCA of caviar and sturgeon meat production. Impacts associated with sturgeon fillet production are in line with fillets from other farmed species, while the impacts of caviar production cannot be compared with any other product of the aquaculture industry. Furthermore, due to the long-timescale needed for caviar production, it is crucial to develop strategies to contain the impacts associated with feed use, such as the recent advances in genetic sex determination that could allow an early selection of females, thus reducing feed use for males.

5. ACKNOWLEDGEMENTS

This study was carried out within the project INNOFISH FARM (grant n. J89J21004200001), funded by Ministero dell’Agricoltura della sovranità alimentare e delle foreste.

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Table 1. Results of LCIA in the category Climate Change, divided by species and products. Results referred to the FU of 1 kg caviar.

			Sturgeon Meat		Caviar		
Impact Category	Unit	Species			Caviar (I°)	Caviar (II°)	**Total caviar**
Climate change	(kg CO_2 eq.)	Beluga	**4.85**		74.5	0.3	**74.8**
		White	**4.86**		50.1	0.3	**50.5**
		Russian	**8.15**		45.8	0.3	**46.0**
		Siberian	**9.99**		59.9	0.7	**60.6**

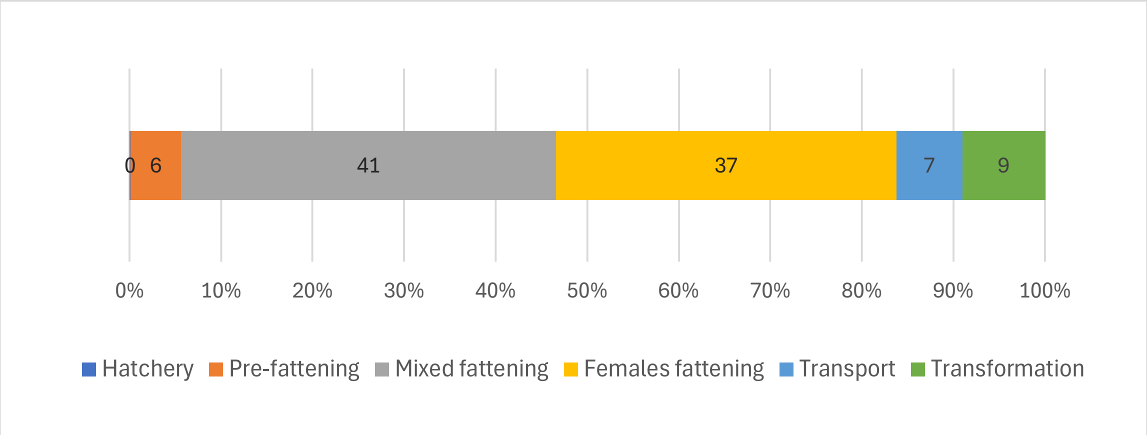

Figure 1. Contributions of the caviar production chain processes to the Climate Change impact category. The bar represents average values among the four species.

LCA and footprint studies explained by companies

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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A tailored carbon footprinting solution to enable farmer engagement and portfolio assessment: A pilot study for Nomad Foods

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1. INTRODUCTION

Nomad Foods, the leading frozen food company in Europe [1], is committed to becoming net zero as part of their Science Based Targets initiative (SBTi). Given that a significant proportion of Nomad Foods emissions are from land-based activity their SBT will be revised under the new Forest, Land and Agriculture (FLAG) requirements [2]. Nomad Foods intends to reduce 45% per ton of product produced across scope 1,2 and 3 GHG emissions and a 25% reduction in absolute terms. Given that Scope 3 emissions represented 48% of the total GHG emissions intensity for 2022 [1], it is essential for Nomad Foods to focus their efforts on the reduction of upstream emissions.

To be able to develop an informed agricultural strategy based on accurate data and to reflect the sustainability efforts of the stakeholders along the upstream supply chain, Nomad Foods wants to move away from using industry-average emission factors to calculate Scope 3 emissions, and into using primary data directly from their suppliers. The wide portfolio of products which amounts to 250 ingredient groups, involving approximately 800-1000 farmers, 30-50 fisheries and 100-200 aquaculture farms could make this challenging. Collecting primary data from each supplier proves to be a strenuous task due to the scale and diversity of ingredients and geographies, lack of streamlined data collection procedure, and lack of in-house carbon footprinting expertise.

Existing carbon footprinting tooling solutions are not suitable as Nomad needs a tool which covers its entire portfolio spanning various countries, meanwhile ensuring the methodological details and underlying data remains consistent. Nomad has therefore opted for piloting a tailor-made tool using SimaPro® Collect so it can be customised to its supply chain, ensuring high robustness and meaningful insights at the farm-level. Importantly, it provides the opportunity for a truly collaborative approach, with farmers' opinions being valued and incorporated into the long-term solution. A critical focus for Nomad Foods, following the outcome of the LCA will be to ensure carbon reduction targets are met without compromising quality and yield.

2. METHODS

Nomad engaged with 43 farmers as part of the pilot, presenting them with the context and explaining the benefits of involvement. A parameterised LCA model was built to enable farmers to provide primary input data. The model was built in SimaPro® Flow and it was linked to a SimaPro® Collect survey that farmers could fill in online (see Figure 1). The parameters were linked to different options intended to represent the entirety of the supply chain (e.g., different countries), thus, the model could calculate simultaneously the footprint of different farms according to the data selected.

3. RESULTS AND DISCUSSION

The SimaPro Collect® survey was filled by 30 farmers from four European countries and their carbon footprint was calculated and analysed in bulk. Different hotspots were identified per geography and crop type, as well as per management practices. The carbon footprints of the farms were delivered to Nomad in a centralised way, through a unique file including all the relevant information.

The ongoing collaboration with farmers from an early stage in a bottom-up approach is crucial for the practicality of the end product. The involvement was made through multiple iterations between the agricultural managers in Nomad and PRé to identify a structure and content that would be clear and appealing for the farmers. This process and the early communication of the data requirements before sending out the survey was essential for farmer engagement. Embedded within the survey were feedback opportunities to ensure farmers' voices can be heard and accounted for in the future improvement iterations.

4. CONCLUSIONS

Tailor-made solutions for data collection such as online surveys (SimaPro® Collect) linked to parameterised LCA models can serve as a good solution to engage farmers in providing data needed for the carbon footprint calculation of agricultural-related products. Tailoring these solutions requires early involvement of the stakeholders to identify aspects that make the data collection process clear and easy to approach.

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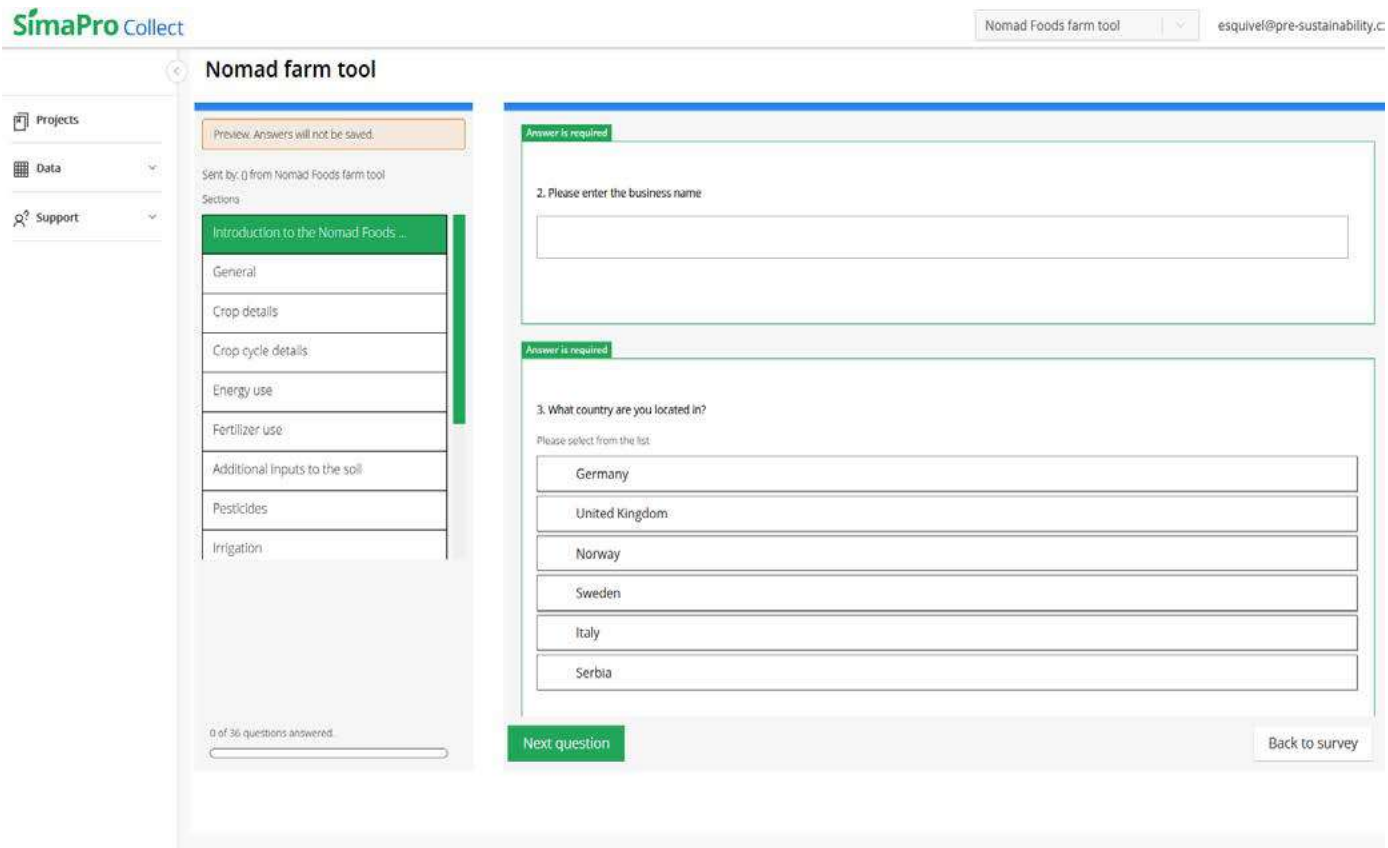

Figure 1. Overview of survey in SimaPro® Collect

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Application and value of life cycle sustainability assessment for food ingredients portfolio

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1. INTRODUCTION

For a company like Corbion, a sustainability-driven global food and biochemicals company, it is of utmost importance to substantiate its sustainability claims using credible and robust methods. Methods such as Life Cycle Assessment (LCA) and Social Value Assessment (SVA) are widely and successfully applied within Corbion. The goal of this presentation is to illustrate the integration and value of LCA within the organization, as well as the main challenges associated with assessing the sustainability of a large number of bio-based products with complex supply chains.

2. METHODS

Over the past years, the lifecycle sustainability assessments have extensively gained importance within the company.. Back in 2017 Corbion developed a methodology for life cycle assessment of its lactic acid-derived product portfolio and performed its first LCAs accordingly. A significant effort has been made to establish robust internal approaches which will enable the organization to perform credible and thorough assessments, ensuring consistency and transparency of the results. This covers, amongst others, strategies to deal with lack of data, proxies and assumptions. In 2022 about 80% of products was covered with a cradle-to-gate LCA. Corbion aims to assess all its fermentation-derived products on LCA by 2025. Two examples will be shared in this presentation, to illustrate the successful implementation of life cycle management - the LCA of lactic acid derivatives production and the LCA of functional blends production.

Internally, business trainings and an LCA communication policy are some steps that have been taken to advocate transparency and prevent misleading communication or interpretation of the LCA results.[1]

[1] EC, Green claims directive, Brussels, 2023

3. RESULTS AND DISCUSSION

Lactic acid is an intermediate product used in many food applications such as preservation and shelf-life extension, mineral fortification and acidification. Lactic acid is produced by fermentation from carbohydrates derived from sugarcane or corn. Corbion's commitment for responsible sourcing was a first and enabling step to achieve traceability and transparency in the supply chains and increase the accuracy of the LCAs performed.

The cradle-to-gate environmental impact of lactic acid production and its derivatives has been assessed and externally reviewed for five Corbion manufacturing sites, in different geographic regions. The results are used internally and externally, engaging various stakeholders and supporting businesses. Internally it is used to understand hotspots and main impacts in the product portfolio, to steer innovation towards more sustainable products, in decision making towards production routes and locations.. Externally the LCA results are used- as part of the products value propositions , to engage with customers, in corporate reporting and for policies alignment, target setting and progress measurement.

The second example focuses on the LCA of functional systems. Functional systems include food ingredient mixes that are used as food additives, flavors, and texture and taste enhancers. The LCA of these products reveals the challenges with data quality when it comes to individual food ingredients and the lack of secondary data from databases or literature.

Nevertheless, the study has identified points of attention and actions that will benefit the assessment and further track and improve products' environmental performance, for which an engagement with relevant stakeholders (suppliers and customers) is required.

4. CONCLUSIONS

Across the entire portfolio, challenges in data collection in the value chain in respect to data quality and consistency, comparability with external references (and communication thereof), and addressing the benefits of the circular biobased products were observed. Moreover, changes in own production processes due to volatile markets (eg. changes in demand and occupancy impacting efficiencies) and due to the progress to reduce our climate emissions (eg. change in energy sources, improving process efficiency) require an LCA study to be up to date and to reflect the current production performance. This impacts business communication and internal resources. Corbion is aiming to address this with scaling up LCA to a large number of products via a digital and automated LCA solution.

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Environmental food impact: semi-specific LCA approach for food sector industrials and their supply chain

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1. INTRODUCTION

Food production systems play a significant role in global greenhouse gas emissions and biodiversity loss. Enhancing sustainable food product systems has thus become imperative, with the European Commission leading discussions to promote human and environmental health through a harmonized sustainable labelling framework, including the Product Environmental Footprint (PEF) methodology. The French government developed method in order to publish an eco-labelling on food products with generic data at the first place. If the use of generic data is a good way to launch a process among food industries in this framework of regulatory requirement, it suffers from limitations such as inability to differentiate impacts within the same food category and to reflect some sustainable practices implemented by farmers and food industries. In response to these challenges, we developed semi-specific Life Cycle Assessment (LCA) method based on the Pareto principle, aiming to capture 80% of impacts with only 20% of variables.

2. METHODS

The methodology presented in this study involves testing our approach using real data to evaluate the environmental impacts of food products. By focusing on key variables, our approach simplifies LCA calculations while maintaining accuracy. This streamlined approach is particularly advantageous for food industrials and their supply chains, as it reduces both the time and financial resources required for conducting assessments. Unlike the comprehensive PEF full LCA methodology, our method offers a cost-effective alternative that allows for the evaluation of a larger number of food products more quickly and with lower costs. This efficiency enables food producers to extend their sustainability evaluations to a broader range of products.

To implement our methodology, we employed Simapro software and the Agribalyse database, which offer environmental impact data for food products in France based on the PEF methodology and full LCA. Utilizing these resources, we identified the primary variables with the largest impacts at each stage of the product life cycle, including input use (such as fertilizers and diesel), water consumption, land use, energy usage, and packaging. These variables, referred to as specific variables, were prioritized for data collection and evaluation in our streamlined LCA approach. Conversely, generic variables, representing less impactful factors, were assigned default values.

To validate our method, we collaborated with food sector industrials, testing our approach against generic data from Agribalyse. Throughout the testing phase, rigorous monitoring ensured the accuracy and reliability of our semi-specific LCA approach, facilitating adjustments as needed to maintain validity. This methodology offers a targeted and efficient means of assessing environmental impacts in food production.

3. RESULTS AND DISCUSSION

We tested our method with industrial partners from different types of products, such as wheat flour, bread, yogurt, and chicken (raw chicken products). Our findings indicate that agriculture often accounts for the majority of the environmental impact in food production, underscoring the importance of simplifying data collection throughout the supply chain. Furthermore, our results highlight the significance of the transformation phase, where data on energy use, water use, and packaging play crucial roles. The environmental impact scores generated using our semi-specific LCA method exhibited good agreement with those obtained using traditional LCA approaches, indicating the robustness and reliability of our approach in assessing sustainability across different food products and production systems. This approach not only enables food producers to evaluate the environmental impact of their products but also facilitates targeted actions to improve sustainability throughout the entire lifecycle of the product. For instance, if we compare results for a chicken meat with generic and with semi-specific data, we observe that the more efficient feed and soy origin (Origin France instead of Brazil) allows the product differentiation and improves its environmental footprint by 30 %.

4. CONCLUSIONS

In conclusion, the semi-specific LCA method offers a promising avenue for advancing sustainability in the food industry by addressing key challenges in current ecolabelling systems.

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Establishing a harmonized environmental footprint approach in the European Fresh Produce industry

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1. INTRODUCTION

Life cycle based methods and tools are increasingly used as decision support tool by companies. However, as long as companies within the same industry use different methods and tools, the entire sector is at risk for greenwashing, uneven market competitiveness and ultimately losing credibility. To tackle this. various industries have taken up the challenge to establish a harmonized environmental footprint approach at industry level. Seemingly important elements for such an approach are a harmonized LCA methodology and LCI-background database, and easy-to-use tools that integrate those two elements.

This presentation reflects on the road of the European Fresh Produce industry in moving towards greener production and sustainable supply of Fresh Produce, by utilizing the power of harmonized life cycle based methods and tools. It focusses on consortium building, the role of industry associations, challenges and barriers.

2. METHODS

The European Commission offers with the Product Environmental Footprint (PEF) method a single set of standards for evaluating the environmental footprint of products. Based on this method, the fresh produce industry published the HortiFootprint Category Rules (HFCR) in 2020 (Helmes et al., 2020). Since then, many companies have started to use the methodology in practice. However, the implementation of the methodology faces several challenges, such as limited comparability of results due to the lack of a harmonized LCI database and the costs of LCA studies. At this moment, there is no opening in the official framework of the European Commission to be "signed off". The fresh produce industry is however eager to proceed in harmonization of the methodology underlying environmental footprinting, and does not wish to wait for an official opening. They have started to develop a so called shadow PEFCR and harmonized LCI database. Industry associations are commissioning projects to develop tools that integrate the method and LCI database.

This process comes however with several challenges: how to establish a representative consortium that is responsible for the development? How to deal with the large variety of companies and interest within the sector? How to navigate between sectoral pragmatism and scientific robustness?

3. CONCLUSIONS

Establishing a harmonized environmental footprint approach at sector level paves the way for impactful and effective mitigation strategies at sectors level, creates a level playing field and increases credibility. It however requires a common endeavor from all actors across the industry.

4. ACKNOWLEDGEMENTS

Acknowledgement is given to the funders of the Public Private Partnership ‘Developing harmonized calculation rules and exploring consumer commination for the environmental footprint of horticultural products’ (BO-61-001-023).

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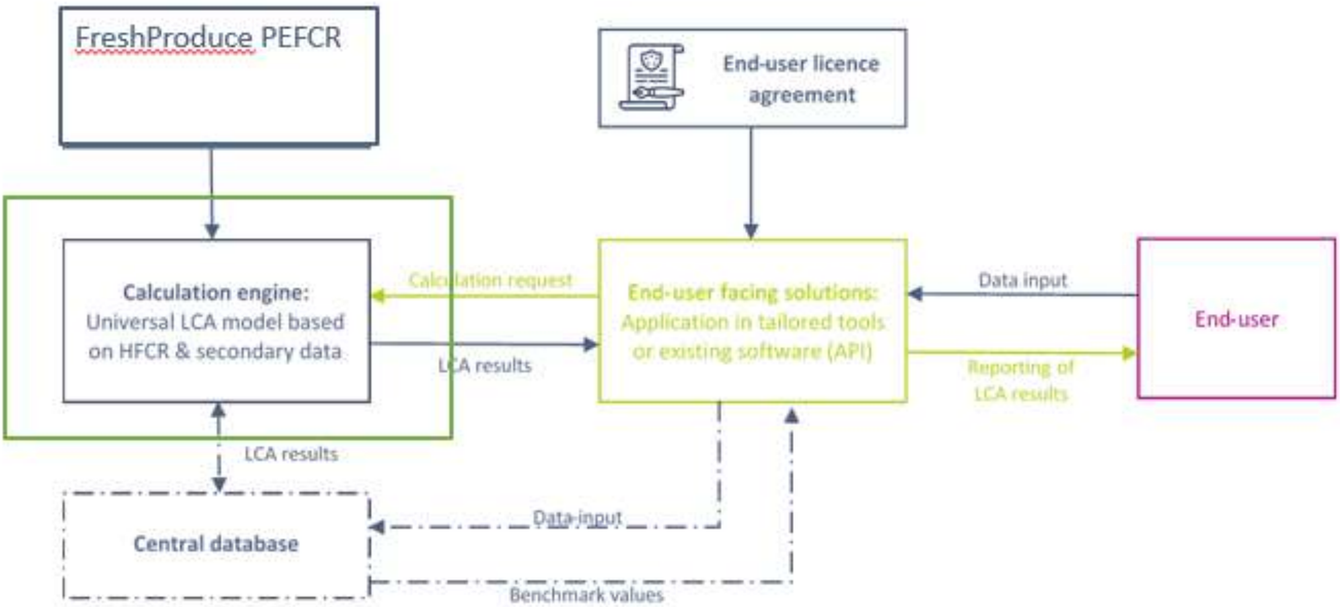

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SMEs experience in assessing the Environmental Footprint using an easy-to-use life cycle-based tool

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1. INTRODUCTION

The planet is under unprecedented pressure. There is a growing body of evidence on how climate change, water scarcity, deforestation and pollution of ecosystems will compromise the future (IPCC, 2019). Food production and consumption have been reported as primary drivers of the human impact on the environment (Sala & Castellani, 2019). Therefore, today more than ever, it is necessary to reduce these impacts, which is why administrations at European, state and local level are developing policies and strategies to guide the agri-food chain towards a more sustainable and healthy food production. In addition, consumers are demanding environmental information about the purchased food products, so retailers are starting to push their suppliers to measure the Environmental Footprint of products.

Within this framework, in 2023, the INGURULABEL project was launched with the aim to assess and communicate the environmental performance of 7 different food products driven by a retailer. The study presented in this manuscript is the testing of Envirodigital tool, an easy-to-use life cycle-based tool developed for the environmental assessment and eco-design of products following the Product Environmental Footprint Category Rules (PEFCR), by SMEs to identify benefits and challenges of assessing environmental impact and the usefulness of the tool in a regular basis within the agrifood sector.

2. METHODS

A stepwise approach was used to get SMEs feedback on the usefulness of measuring product environmental footprint and eco-designing products, as well as using life cycle-based tools. The products selected within the SMEs were those of the retailer's private label brands: beef burger, yogurt, fresh potatoes, breadcrumbs, cookies, cider and wine.

First, training sessions were carried out, on the one hand, on food sustainability, what the environmental footprint is, how it is calculated and its benefits and, on the other hand, to transfer the companies the minimum knowledge required to use the Envirodigital tool.

Second, the environmental footprint of the 7 products was calculated using the tool. The Envirodigital tool transforms company specific data, gathered by the user, into 16 environmental impact categories recommended by the International Reference Life Cycle Data system (ILCD). The whole value chain was considered: primary production, processing, distribution, retailer stage, consumption and end-of-life. Results obtained were based on the reference flow stablished for each product (Table 1).

Third, products were eco-designed after identifying environmental hotspots and agreeing specific environmental improvements strategies with the SMEs. Finally, face to face sessions were held to obtain feedback on how SMEs feel about the environmental footprint and the use of tools for its calculation.

3. RESULTS AND DISCUSSION

The SMEs participating in the project expressed interest in calculating Environmental Footprint. They recognised the importance of prior training before utilizing the tool for studying their products. While SMEs found the tool intuitive and user-friendly, a significant challenge lies in engaging their suppliers and facilitating data acquisition, particularly the larger ones. Notably, the tool’s capability for eco-design was a key feature, as SMEs can assess the implementation of internal actions or improvements in order to enhance their environmental performance.

4. CONCLUSIONS

The use of tools as Envirodigital allows SMEs to be concerned and aware of environmental sustainability, but to accomplish that goal it is critical for the whole value chain to work on it.

5. ACKNOWLEDGEMENTS

The authors thank the participation of SMEs and the Basque Food Cluster. This project is funded by Economic development, Sustainability and Environment department of the Basque Government (013-INNO-EC/22).

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Table 1. Information on the SMEs and products studied.

Activity description	Product	Reference flow
Wholesale of meats, processed meat products and meat by-products	Tray of 4 beef burger (480gr)	1 kg of fresh beef burger packed, distributed, and consumed
Manufacture of dairy products	1 yogurt with blueberry jam (155gr)	125 mg of yogurt packed, distributed, and consumed
Cooperative that processes the production, handling and marketing of fresh potatoes	Mesh of potatoes (2kg)	1kg of fresh potatoes packed, distributed and consumed
Manufacture of breadcrumbs	1 package of breadcrumbs (750gr)	1 kg of breadcrumbs packed, distributed and consumed
Manufacture of cookies, bakery and confectionery products	Tray of cookies (150gr)	1 kg of cookies packed, distributed, and consumed
Family cider house	1 bottle of cider (75cl)	0,75 l of cider packed, distributed and consumed
Family winery of white wine	1 bottle of white wine (75cl)	0,75 l of wine packed, distributed and consumed

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Returnable glass bottles vs single-use alternatives: the case of "Le Fourgon" company

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1. INTRODUCTION

Forty years ago, returnable glass bottles were still a used end-of-life scenario in France, especially for milk delivery companies and brewers. But with massive merchandising, the market has evolved towards single-use plastic bottle packaging. Over the years, returnable bottle washers have disappeared in France to give way to the emerging market, which now represents more than 19 billion plastic bottles yearly. Forty years later, with the climate challenges, 90% of French people agree to restore returnable glass bottles to reduce waste.

Despite recycling solutions, 573 kg of domestic waste are produced annually per person in France, 25% being plastics and glass. 73.6% of plastic is not recycled due to the challenges of sorting and the number of different plastics. At a global level, the production of plastics increased exponentially, from 2.3 million tons in 1950 to 448 million tons by 2015. Plastic production is expected to double by 2050. Annually, about 8 million tons of plastic waste leak into the oceans. It represents the equivalent of setting five garbage bags full of trash on every foot of coastline worldwide.

2. METHODS

In this frame, a life cycle assessment of "Le Fourgon" activities has been realized in collaboration with WeLOOP. This study considers the take-back system of the company, firstly to identify the hotspots and the axes of improvement. Secondly, the goal was to provide a specific comparison with generic single-use alternatives. A parametrized LCA was realized using key environmental aspects to define when the returnable bottle becomes more interesting than single-use plastic bottles. The PEF method, with the Circular Footprint Formula, was used to model raw materials and end-of-life scenarios. The aim of the study was for Le Fourgon to communicate the results of the LCA and the comparison publicly. The study was therefore reviewed by the panel of experts.

3. RESULTS AND DISCUSSION

3.1 LCA Results

Overall single score results give the following conclusions. One or two uses are enough to have a lower impact compared to generic single glass bottles produced worldwide, three uses compared to generic single-use glass bottles produced in France. Three uses of water and milk bottles are necessary to have a lower impact compared to water or milk packed in generic single-use PET bottles. Generic HDPE bottles have higher impacts after 6 uses of the returnable milk glass bottle, while fifteen uses are needed for the returnable glass bottle to have lower impacts than generic TetraPak®. Finally, the returnable beer glass bottle needs to be used four times to have lower impacts compared to the same amount of beer packed in generic aluminium cans.

3.2 Limitations and Suggestions

The study was made for Wambrechies, extrapolating the results for the French market. Extrapolation of the results is possible as the system stays the same for every location. Specific distances might change, but not significantly, as offer stays local. Specific studies for each storage facility would improve the accuracy of the study for the French market.

The study includes comparison of the returnable glass bottle with generic single-use alternatives, based on documents from the European commission (PEFCR and the annex C). It would be recommended to compare this LCA with specific LCAs of different packaging possibilities.

4. CONCLUSIONS

It takes two or three uses of the returnable bottle to have a better environmental footprint compared to single use glass, depending on the country of production. For the PET bottle, the bottle needs to be reused three times.

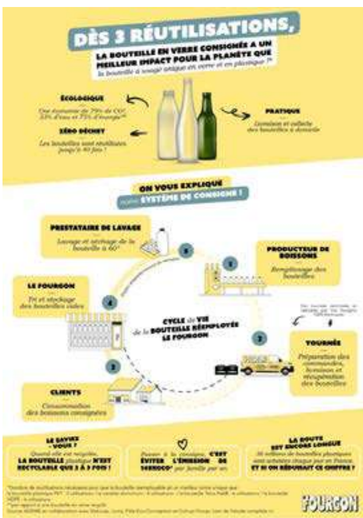

Figure 1. Example of communication of the results of the LCA

5. ACKNOWLEDGEMENTS

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Can Chained Life Cycle Analysis be economically viable?

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1. INTRODUCTION

Chained LCA (cLCA) is a novel LCA approach that aims to enable faster and more accurate analysis of environmental effects by building a distributed system in which the LCA is executed in several points of the production chain by actual chain actors using their primary data. A central advantage of the cLCA method is its ability to utilize in each analysis run the process models and data accumulated through all the previous analyses. Hence, while cLCA entails a considerable initial investment into methodological and technological development, over time the unit cost of life cycle analysis becomes lower as more and more models and data from previous analyses can be utilized. This article explores the preconditions under which cLCA can be economically viable.

2. METHODS

We present a stylized model describing the economic logic of providing the services of cLCA versus traditional LCA. We assume that a service provider executes life cycle analyses of various products for customers (e.g., producers of food items). We include three types of costs: investment cost, fixed cost, and variable cost. Provision of both types of LCA services incur a fixed cost and a variable cost, the latter consisting of labor costs of the LCA expert carrying out the analysis. There exists considerable variation within LCA runs in how much research work is needed for building calculation models and finding related data inputs. We measure this variation in terms of calculation nodes, which consist of a process model and a few data inputs. Hence the variable cost is the product of the number of calculation nodes, the time consumption of researching one calculation node and the wage of the LCA expert. Further, LCA enables the utilization of previous analysis work in the current analysis through an ever-accumulating library of calculation nodes, which can be automatically utilized in subsequent analysis runs. Hence, we assume that as the number of previous analyses increases, the LCA expert's time consumption per analysis decreases. On the other hand, a service provider wishing to offer cLCA cannot do so without first investing to the building and testing of a novel cLCA system. To compare profits of cLCA and traditional LCA over time, we apply discounting (corresponding to a 5 % annual discount rate) and assume that income per analysis is the same in both traditional LCA and cLCA. Economic parameter values are rough estimates based on expert elicitation. The function for the speed of calculation node accumulation was estimated from a simulated dataset and fits well with a logarithmic form.

3. RESULTS AND DISCUSSION

Our initial results indicate that the variable cost of cLCA decreases strongly with the number of executed analysis runs (Figure 1). If the time horizon of the analysis is short, i.e. the total number of analysis is not large, the net present value created by carrying out traditional LCA is higher than the net present value of investing into and carrying out cLCA, because of the assumed heavy initial investment cost. However, when the total number of analysis runs is sufficiently large, the net present value of cLCA equals and then clearly exceeds that of traditional LCA (Figure 2). The number of analysis runs required for the profitability parity is lower, if we take into account that cLCA enables data inputting by the end-user, implying savings in labor costs. With the parameter values used in this study, we find that investing in cLCA is profitable if the number of analysis runs is at least in the range of 60 – 90. Ultimately, the relative profitability of cLCA *vs.* traditional LCA depends strongly on the investment cost, discount rate and the length of the time horizon under scrutiny, as well as the parameters describing the way the cLCA system allows memorizing and re-utilizing calculation nodes. If the cLCA system is already up and running, it could provide LCA results with a fraction of the variable cost of traditional LCA.

As our results are sensitive to parameter values, they should not be interpreted as a definitive answer to the question of economic viability of cLCA. Instead, our results shed light on the central characteristics of cLCA system learning and delineate the profitable application space of cLCA, if central parameter values are known. cLCA requires long-term investment as it takes several years to exceed the profitability of traditional LCA.

4. CONCLUSIONS

Chained LCA has disruptive potential in the LCA industry but still some unsolved challenges.

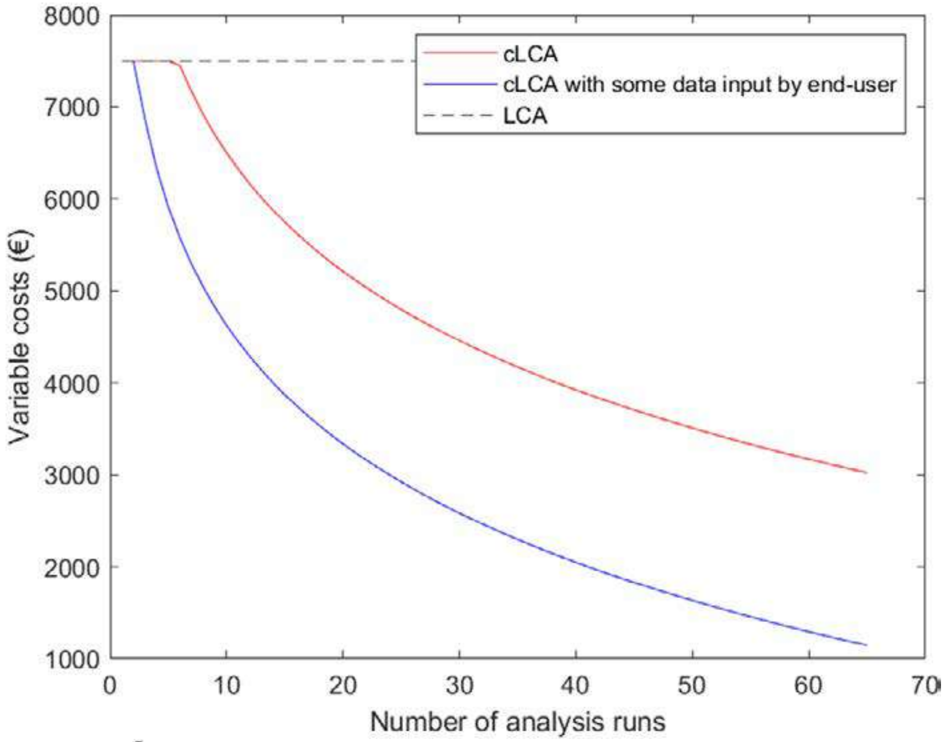
5. ACKNOWLEDGMENTS

None.

6. REFERENCES

None.

Figure 1. The dependence of variable costs on the number of analysis runs.



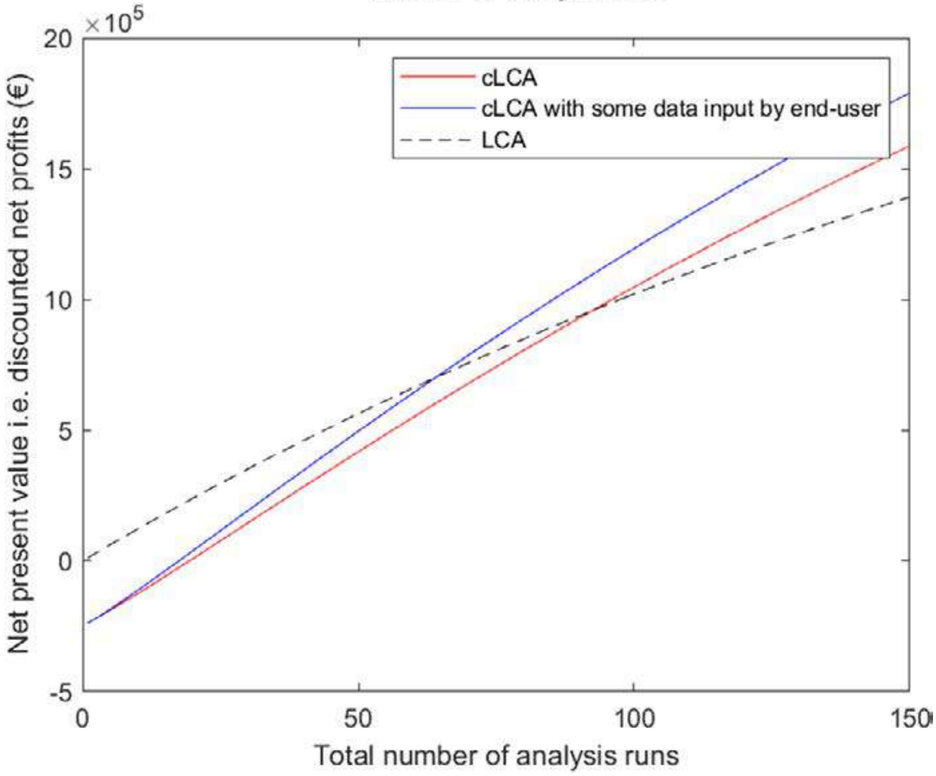


Figure 2. The dependence of net present value of investing in and carrying out the alternative LCA methods on the total number of analysis runs.

Circular food systems

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Circular Economy for Food and Environmental Sustainability: Integrating Plastic Recycling and Banana Waste Valorization in the Canary Islands (Spain) through LCA

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1. INTRODUCTION

Bananas are a major crop in the Canary Islands, accounting for 33% of the total agricultural production and contributing to an annual turnover of €280 million. The Canary Islands produce 52% of all bananas grown in Europe, and the industry employs over 27,000 people directly and indirectly. However, banana production also generates a significant amount of organic waste (pseudostem) that is typically left on the plantation after harvest (EFSA Panel on Plant Health et al., 2021). In light of mounting plastic pollution concerns, the adoption of sustainable waste management practices is crucial for embracing circular economy principles. This is particularly pertinent for island regions lacking waste management infrastructure or recycling industries, where waste disposal options are limited to landfills or mainland transportation.

The Canary Islands in Spain are addressing this environmental challenge by focusing on two key objectives: fostering plastic recycling industries and boosting recycling rates, and reutilizing banana plantation waste (rachis waste), a byproduct of the region's prominent agricultural industry.

2. METHODS

The main goal of this research is to alleviate the impact of landfilling organic waste by promoting the recycling of banana waste into high-value by-products, as well as to use plastic resource more efficiently, in line with the principles of the circular economy. The proposed solution involves combining banana fibers with recycled plastic (from bottle caps), thus improving the sustainability and profitability of banana cultivation, while promoting rural employment.

To create advanced composite materials from recycled plastics and natural fibres (long and short banana fibres), the following steps will be developed: the first one focuses on strategies to obtain competitive recycled plastics (PE and/or PP), the second one on the extraction and treatment of banana fibres by different processes (cutting and peeling, licking, retting, washing and drying) and the third one focuses on improving the mechanical properties by banana fibre reinforcements. Finally, the environmental, social and economic impact of all these processes will be evaluated through a comprehensive Life Cycle Assessment (LCA) analysis.

3. RESULTS AND DISCUSSION

The expected results involve the development of new materials by combining these two components, using various techniques. Subsequently, a comparative LCA will be carried out to find the most eco-efficient combination. It is estimated that, considering the amount of rachis waste generated in the Canary Islands and a fiber concentration of up to 3% by weight, the potential market value of rachis fiber could be between 12.24 and 15.30 million euros per year.

4. CONCLUSIONS

This study aims to promote a circular economy in the Canary Islands, contributing to the valirizaton of waste, and benefiting both the plastic waste and the banana production sectors. To this end, this paper proposes a new innovative strategy to reduce banana food waste and the environmental impact this may cause along the value chain using LCA methodology.

5. ACKNOWLEDGEMENTS

This research was funded by the Spanish Ministry of Science and Innovation, as part of the Ecological and Digital Transition Projects programme, within the framework of the Recovery, Transformation and Resilience Plan through CICEP project (TED2021-131039B-C31).

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Circularity and sustainability metrics for Italian agri-food systems: the CIRCULAGRIS project

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1. INTRODUCTION

Various EU initiatives prioritise agricultural sustainability and integrate the Circular Economy (CE) paradigm. In Italy, where agriculture is a leading sector, specific CE practices need to be evaluated to determine their actual sustainability performance. Indeed, the focus should be on the sustainability implications of CE practices rather than circularity alone. Hereof, scholars emphasise the need to assess sustainability impacts on both company and inter-firm levels (Roos Lindgreen et al., 2020; Walker et al., 2021). In particular, life cycle-based assessment methodologies are deemed suitable for evaluating sustainability in the sector (Notarnicola et al., 2015). However, for assessing CE practices, life cycle-based methodologies need to be further developed. This project aims to grasp the relationship between circularity and sustainability in this sector, identifying metrics and exploring the impact of circular practices on sustainability.

2. METHODS

The project consists of several methodological approaches: (i) identifying suitable circularity assessment methods/indicators for the sector via a systematic literature review; (ii) modelling actual/potential circular systems within three supply chains (wine, olive oil, bread/pasta) by mapping best circular practices in Italy and via a literature review; (iii) applying/testing circularity assessment methods/indicators to modelled systems within each supply chain, supported by data collection; (iv) developing a life cycle-based assessment framework for all sustainability dimensions; (v) assessing individual sustainability dimensions of circular agri-food supply chains using life cycle assessment, life cycle costing, and social life cycle assessment; (vi) correlating circularity and sustainability assessment results to understand if circular systems are more sustainable. This involves comparing the sustainability of circular and linear systems and combining results across the three dimensions. Comparative/scenario analyses will be employed to evaluate how circularity impacts sustainability.

3. RESULTS AND DISCUSSION

The project aims to achieve several key results: (i) development of a framework to assess the sustainability implications of three supply chains in the Italian agri-food sector; (ii) creation of knowledge regarding methodological choices for applying life cycle-based methodologies to food products within circular supply chains; (iii) identification of circularity assessment methodologies and indicators tailored to the agri-food sector; (iv) establishment of an approach linking circularity and sustainability assessment to aid decision-makers in making supply chains more circular while ensuring increased sustainability; (v) identification of best practices, considering sustainability impacts, for structuring wine, olive oil, and pasta/bread supply chains.

4. CONCLUSIONS

CE is a key focus of EU initiatives for a sustainable economy, but transitioning to it may not always enhance sustainability. This is particularly relevant in the agri-food sector, critical for meeting human needs. This research aims to understand the relationship between circularity and sustainability in the sector, identifying metrics and exploring the impact of circular practices on sustainability. The outcomes will address existing gaps in the field by providing methodological approaches to assess circularity and sustainability in agri-food supply chains, enabling actors to assess if their circular supply chains are more sustainable than linear ones.

5. ACKNOWLEDGEMENTS

This study is part of the research project "Towards Circular and Sustainable Agri-food Systems: Metrics for Assessment (CIRCULAGRIS)" PRIN2022 (Prot. 2022JNNJJX), funded by the NextGenerationEU recovery plan and the Italian Ministry of University and Research (MUR).

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An assessment framework to incorporate circularity, sustainability, and systems thinking in transformative food systems innovation

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1. INTRODUCTION

Despite the popularity of Circular Economy as a concept to reshape industrial systems into less environmentally destructive and more socially beneficial forms, tools to evaluate the progression of individual technologies and initiatives within the food system are relatively underdeveloped (Poponi et al., 2022, Saidani et al., 2019, Schmidt Rivera, Balcombe and Niero, 2021). Meanwhile, there is a growing recognition of interdisciplinary and systems-perspectives in food system research and development (Cembalo et al., 2021). Guidance for selecting the "correct" set of indicators for a given context is scant, furthermore, systems perspectives have yet to penetrate into the common practice of sustainability assessment. To fill this gap, we asked which methods have been used in practice to assess circular food innovation; to what extent are these approaches able to consider sustainability and circularity holistically; and finally how assessment methods can integrate system-transition perspectives. To this extent, we developed a framework that combines perspectives from sustainability assessment, circular economy, and systems-transitions theory centred around the life cycle assessment methodology.

2. METHODS

The research approach combines systematic literature search, study and methodology appraisal, and synthesis of a novel research framework. A literature search was conducted in March 2022 to yield academic studies of circular food innovation (centred around the food manufacturing sub-sector) that contained an evaluation of sustainability. We then analysed these studies based on three perspectives: the principal goals of Circular Economy innovation; the constituent dimensions of Sustainable Development; and finally, the characteristics of the multilevel perspective on system innovation. Finally, the findings were synthesised into the novel framework for circular & sustainability evaluation.

3. RESULTS AND DISCUSSION

The literature search yielded 40 papers that fulfilled the criteria, these studies contained assessment approaches from the social science, life cycle assessment, business studies, and other technical approaches (Figure 1). Following the analysis, we find that life cycle assessment (LCA) approaches are able to consider most holistically the various dimensions of sustainability and circularity, however, the flexibility of social science approaches lends themselves to consider more holistically the wider dimensions of socio-technical transitions. Meanwhile, there is an opportunity for an expanded use of sustainability assessment approaches in the design phase of technology, its development and its adoption. We developed a novel sustainability assessment framework integrating sustainability and circularity considerations into systemic technology development and assessment processes (Figure 2).

4. CONCLUSIONS

In lieu of circularity assessment tools, scholars have typically used a range of approaches in the evaluation of circular food innovation. Through the use of an assessment framework centred on LCSA and integrating systems perspectives, sustainability assessments are better able to guide and influence the development of Circular Economy initiatives through the activation of wider socio-technical networks, and thus work towards a more sustainable food system.

5. ACKNOWLEDGEMENTS

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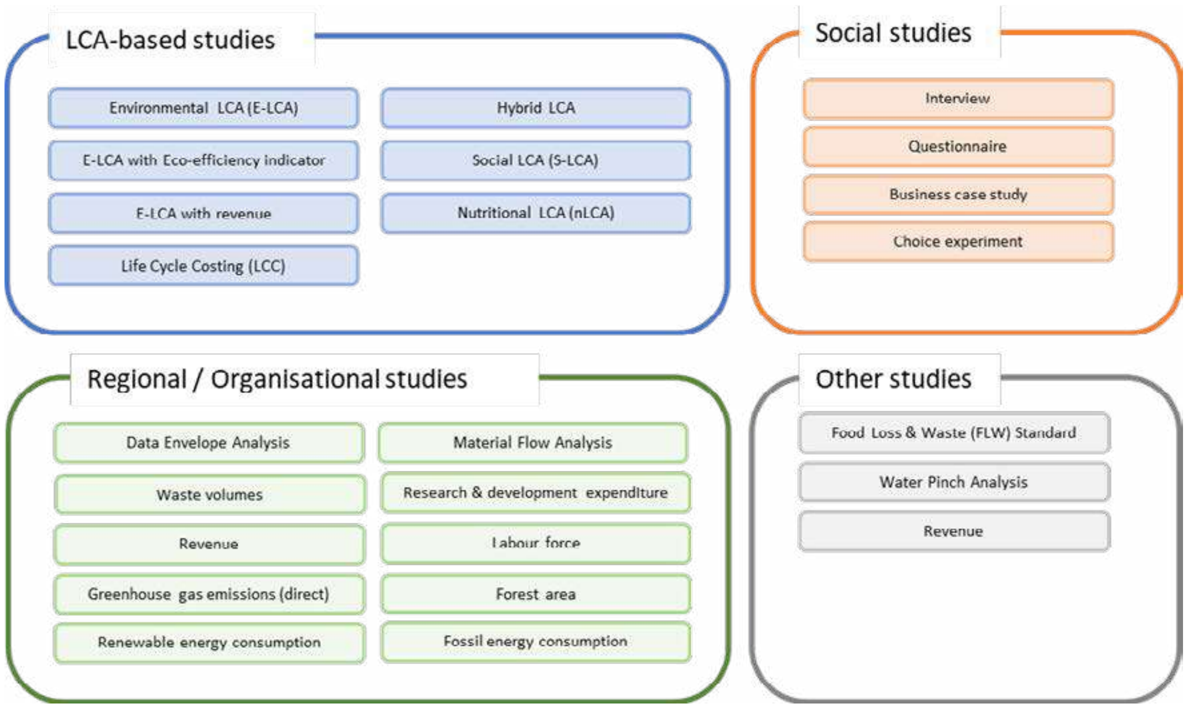

Figure 1. Overview of assessment approaches used by scholars in the evaluation of circular food innovation.

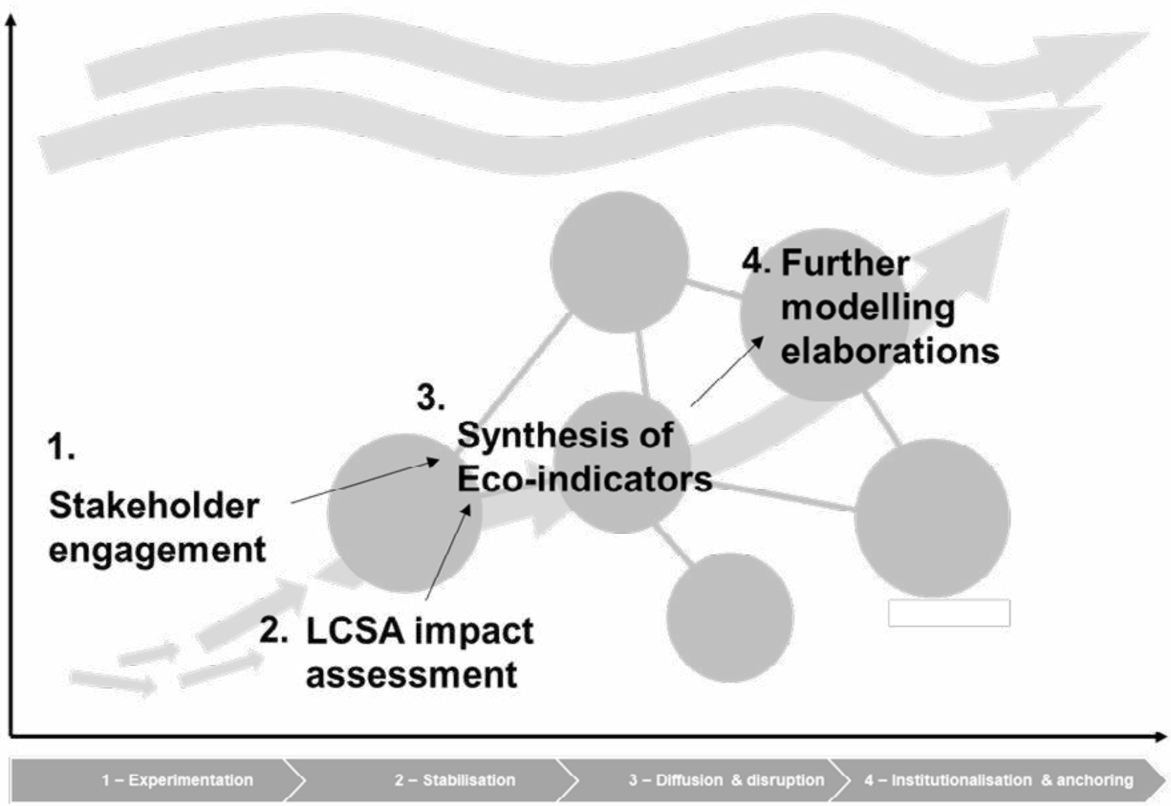

Figure 2. Outline of novel assessment framework that seeks to expand the use of LCA by integrating a foward-looking and inclusive perspective.

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Analyzing the uses of biomass and land at the Agro-Food-Waste System level to assess the environmental benefits of livestock-based circularity

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1. INTRODUCTION

Some authors argue that livestock farming can play a major role in the circularity of Agro-Food-Waste Systems (AFWS) (Van Zanten et al., 2019). Indeed, livestock farming can recycle AFWS co-products, make good use of land that is unsuitable for food crops, and provide useful co-products for other sectors. Assessing the benefits of livestock-based circularity is challenging for practitioners of life cycle analysis (LCA), due to limited knowledge of the actual functions of the co-products, and the fuzzy boundary between wastes and co-products (Dominguez Aldama et al., 2023). The objective of the present study is to highlight these benefits based on the AFWS of French Reunion Island. To this end, we are conducting a territorial LCA of the AFWS in its current state and in a theoretical state without livestock-based circularity. This abstract focuses on the preliminary phase of this LCA: modeling biomass and land uses in the two systems.

2. METHODS

2.1 Analysis of biomass flows in the AFWS in its current state

We first analyzed the circulating biomass flows in the current AFWS to identify all interactions involving biomass, N, P and C between livestock and other sectors. Data were collected from 2017 to 2021 either at source through interviews (e.g. provided by the firms), or calculated based on the literature (e.g. regional studies and databases) (Kleinpeter et al., 2023)

2.2 Modeling biomass flows and land use in an AFWS without livestock circularity

Fate of co-products used by livestock: In an AFWS without livestock-based circularity, the fate of co-products used by livestock is determined by the following rules : (i) When co-products are used for uses other than for livestock in the baseline system, these uses are prioritized (ii) Co-products are used as landfill if no secondary role is included in the baseline system, or if part of the co-product is sent to landfill (assuming that the demand for this co-product from other sectors is already satisfied). The loss of these co-products for the livestock sector is offset by importing products with the same function, i.e. animal feed or bedding.

Fate of co-products produced by livestock: In the current AFWS, all manure and bonemeal are used as soil amendment and crop fertilizer. In the theoretical AFWS with no livestock-based circularity, the co-products are sent to landfill. The loss of these co-products is offset by importing products with the same function. Imports of mineral fertilizer are calculated based on the need for fertilizer for all types of croplands other than grassland, and that account for the application of organic fertilizers other than manure used in the baseline system.

Fate of land use linked to livestock: In the AFWS without livestock-based circularity, grasslands with slopes >30% are considered to be unsuitable for other crops and revert to fallow. Other grassland is used to grow sugarcane at low altitudes (< 700 m) or to grow vegetables at higher altitudes. Imports of food and feed are adjusted to achieve the same levels of human and animal consumption as in the baseline system.

3. RESULTS AND DISCUSSION

Substance flow analysis revealed the circularity of biomass around livestock in both the current system (**Fig. 1**) and in the system without livestock-based circularity (not shown here). The uses of co-products and land use in the two systems are listed in **Table 1**. These results are being used in the ongoing development of the territorial LCA for both systems.

4. CONCLUSION

Analyzing biomass and land use at the AFWS level makes it possible to assess competition between different uses of the same co-product (e.g. bagasse is used by both the livestock and the energy sectors), competition between different co-products that serve the same purpose (e.g. manure and sewage sludge) and competition for land for food and feed production. This analysis is useful for a more accurate evaluation of the environmental benefits of livestock-based-circularity.

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	Uses in the baseline AFWS (current situation)	Uses in the AFWS without livestock-based circularity
Bagasse from sugar-cane	2% for livestock bedding and feed, 98% for energy combustion	100% for energy combustion
Molasses from sugar-cane	7% for livestock feed, 93% to produce rum	100% for to produce rum
Brewer's spent grain	100% for livestock feed	100% sent to landfill
Rice bran	96% for livestock feed, 4% for pet food	100% for pet food
Green waste	5% for co-composting with manure 88% shredded for garden mulch 7% sent to landfill	88% shredded for garden mulch 15% sent to landfill
Land	53% under sugar-cane, 27% grassland, 16% used to grow vegetables, 3% fallow	59% sugar-cane, 32% used to grow vegetables, 9% fallow

Table 1. Uses of co-products and land use in the baseline system and in the system without livestock-based circularity

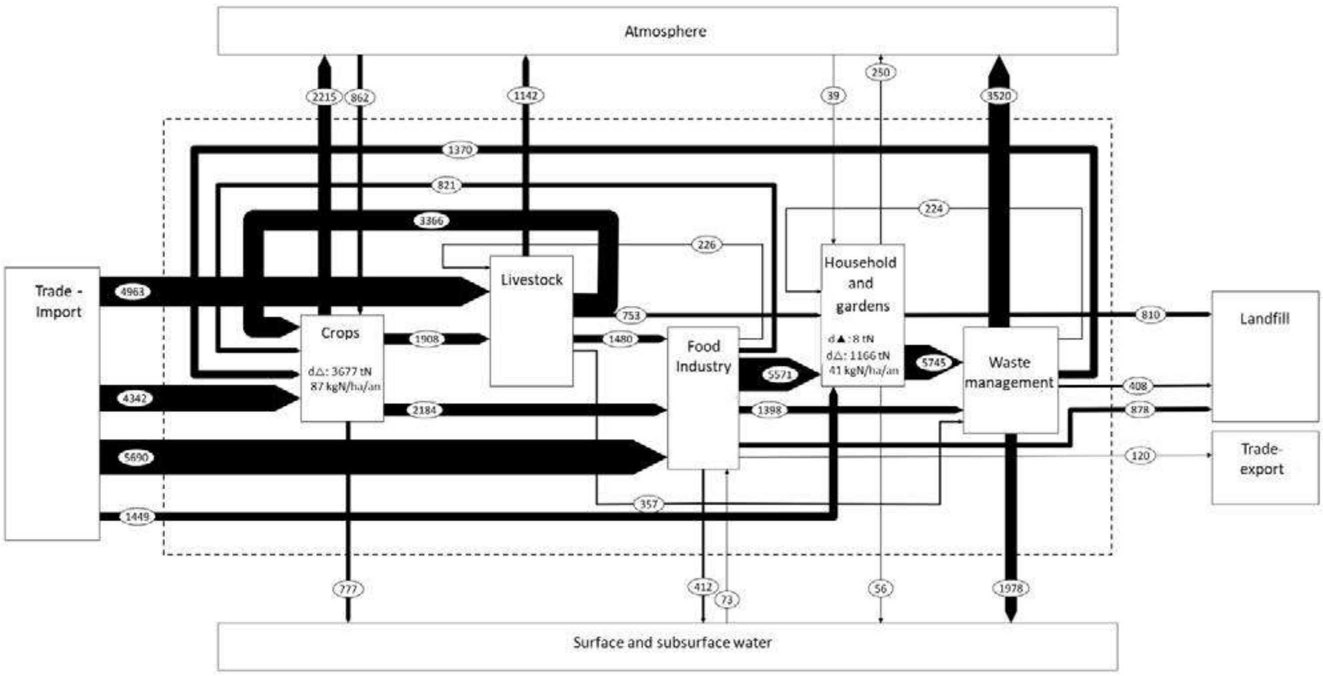

Figure 2. Nitrogen flows between 5 different sub-sectors across the agro-food system in the current system represented as tons of substance per year. The width of the arrows is proportional to the intensity of the fluxes involved in these processe. The substance analyzed here is nitrogen (N), but the same metabolism graph is available for biomass, phosphorus and carbon.

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Assessing the role of livestock within circular food systems

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1. INTRODUCTION

The competition for land in agriculture to produce food directly edible for humans or produce feed for livestock consumption is expected to increase as pressures on available land and rates of animal-source protein rise globally. One proposed solution to reduce this competition, known as the feed-food competition, is the use of circularity in the livestock sector. Livestock are able to utilize non-human edible products as feed, such as grass biomass, crop residues, co-products from food processing, and food waste. This process allows for livestock to upcycle resources that would otherwise be unused in the food system. However, in the need to transform our food systems to a more sustainable state, it is vital to understand how to best assess circularity in livestock systems (de Boer and Van Ittersum, 2018; van Hal, 2020; van Zanten et al., 2018).

2. METHODS

We first identify which types of indicators might be used for the purpose of assessing circularity in livestock systems: target-based indicators, practice-based indicators, result-based indicators, and outcome-based indicators (Schreefel et al., 2024). We compare how the current methods used to assess livestock could be applied to circularity through examples from the scientific literature.

3. RESULTS AND DISCUSSION

We situate the role of each assessment type in the context of assessing livestock and make recommendations for when to use which type of assessment. We found that nutrient use efficiency is best situated to practice- and result-based indicators (Gerber et al., 2014). If practice- and result-based indicators are measured without outcome indicators, then there is a risk of unintended rebound effects. In contrast, attributional and consequential life cycle assessments are best suited to outcome-based indicators. Consequential life cycle assessments can best show how changing the degree of circularity, for instance, by increasing or decreasing the level of non-human edible products, would impact environmental flows in and outside the product's production cycle (Figure 1). Holistic food systems models can demonstrate outcome-based indicators to the most detailed level, as the ability to track multiple production cycles at once solves issues with allocation present in LCA studies (van Zanten et al., 2019).

4. CONCLUSIONS

We demonstrate in our work that circularity in livestock systems can be measured with different indicators that each play an important role in monitoring the role that circular livestock play in our food systems. Policymakers and scientists should embrace the complexity of analyzing and designing circular livestock systems by choosing the correct methodological approach.

5. ACKNOWLEDGEMENTS

We would like to acknowledge Imke de Boer and Ollie van Hal for their guiding work in this field.

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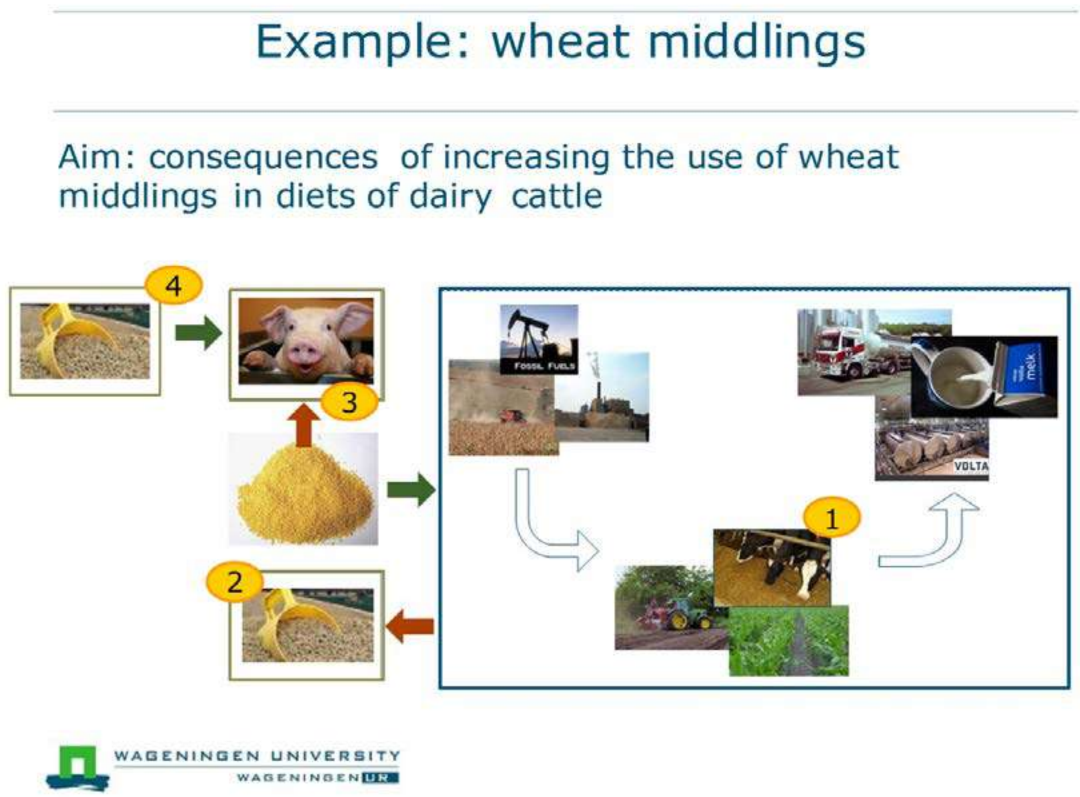

Figure 1 – An example of system expansion in the processing of wheat middlings to demonstrate how livestock fed on food processing by-products can change the environmental impact of the whole food system (Van Zanten et al., 2019).

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Methodological framework to evaluate circularity in livestock systems

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1. INTRODUCTION

Over the last decades, the specialization of modern agricultural and livestock systems has increased land productivity to meet the demand for food but has led to a greater dependence on external inputs based on fossil fuels (fertilizers, concentrates), as well as an externalization of environmental impacts. In addition, the disconnection between the components of the agri-food system has led to significant imbalances that end up as emissions, generating impacts on a local and global scale. The transition towards circular food systems is therefore imperative, and livestock can play an important role in it by i) promoting efficient use of biomass resources unsuitable for humans (grasslands, crop residues, food by-products), and ii) by implementing strategies and technologies that allow reducing inputs and recycling outputs within the system.

Jointly assessing circularity and environmental impact in such complex systems is not easy though. While life cycle assessment (LCA) methodology has been applied to this purpose, impact categories and process units of LCAs do not always capture the actual implications for resource flows in agri-food systems, and specific approaches to assess circularity are needed.

Through the CircAgricGHG project, we have adapted and tested a selection of LCA and circularity indicators to be applied in agri-food systems within a consistent methodological framework. The purpose of this work is i) to share the main concepts and advances proposed by this framework and ii) to discuss their strengths and challenges when tested on some case studies of livestock systems applying circular strategies.

2. METHODS

Evaluating whether agricultural strategies currently promoted for livestock sustainability involve circularity, depends on what is considered as circular. Considering the context and goal of the project, a definition of circularity especially adapted for livestock production systems was proposed, aligned with the general principles of circular economy (CE). Previous research initiatives, guidelines, and scientific literature were gathered and reviewed. The applicability of different metrics and approaches identified to assess circularity in agri-food systems (AFS) was explored. A specific framework was also developed to identify and categorise the resource flows involved in this type of system.

3. RESULTS AND DISCUSSION

As a result of the review and evaluation process, a selection of indicators and methods that can be applied when assessing the circularity of livestock systems was proposed (Table 1). They were organized according to their suitability considering the type of circular strategy explored and the main resources involved in every specific context.

A specific framework was also developed to identify and categorise the resource flows involved in AFS systems, which often have a strong link to natural or semi-natural ecosystems (Figure 1). The two types of cycles (biological and technical cycles) considered in the model of circular economy (Ellen MacArthur Foundation, 2019) are associated with the concepts of Ecosphere and Technosphere in LCA methodology, integrating both approaches for circularity and environmental impact assessment within the same framework. According to this view, systems in the Technosphere can produce either primary and/or secondary products, while resources extracted from natural systems (Ecosphere), can be categorized as renewable or non-renewable inputs (as parallelism between primary vs secondary products from systems in the Technosphere).

4. CONCLUSIONS

An approach is proposed integrating LCA methodology concepts and circularity indicators with the aim to be applied in agri-food systems within a consistent methodological framework. Next steps involve to explore their strengths and challenges when tested on some case studies of livestock systems applying circular strategies.

5. ACKNOWLEDGEMENTS

Financial support was provided by the Spanish Government through María de Maeztu excellence accreditation 2023-2026 (Ref. CEX2021-001201-M, funded by MCIN/AEI/10.13039/501100011033); by the Basque Government through the BERC 2022-2024 program; and by the CircAgric-GHG project (MCIN/AEI/10.13039/501100011033) and the European Union NextGenerationEU/PRTR (ref. num: PCI2021-122048-2A).

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Table 1. selection of indicators for assessing circularity of livestock systems

Resource	Circular Strategy	Indicator
Nutrients	Reduce losses	PNB - Partial Nutrient Balance
Nutrients	Reduce losses	NUE – Nutrient Use Efficiency
Nutrients	Increase recovery	NRI – Nutrient Recycling Index
Nutrients	Minimize resource use	ICirc – Circularity of input flows
Nutrients	Increase recovery	OCirc – Circularity of output flows
Biomass/Nutrients	Minimize resource use	ePCR – Edible Protein Conversion Ratio
Biomass/Nutrients	Minimize resource use	Secondary-to-total input (%)
Biomass/Nutrients,	Reduce losses	Losses (%)
Biomass/Nutrients,	Increase recovery	Finn's Cyling Index
Land	Minimize resource use	Land competition
Land	Minimize resource use	Land Use Ratio
Non-renewable Energy	Minimize resource use	CED – Cumulative Energy Demand
Water	Minimize resource use	Water footprint (Blue)
Water	Minimize resource use	AWARE / Water Scarcity
Non-renewable resources	Minimize resource use	Abiotic depletion
Non-renewable resources	Minimize resource use	Consumption of fossil-P fertilizers

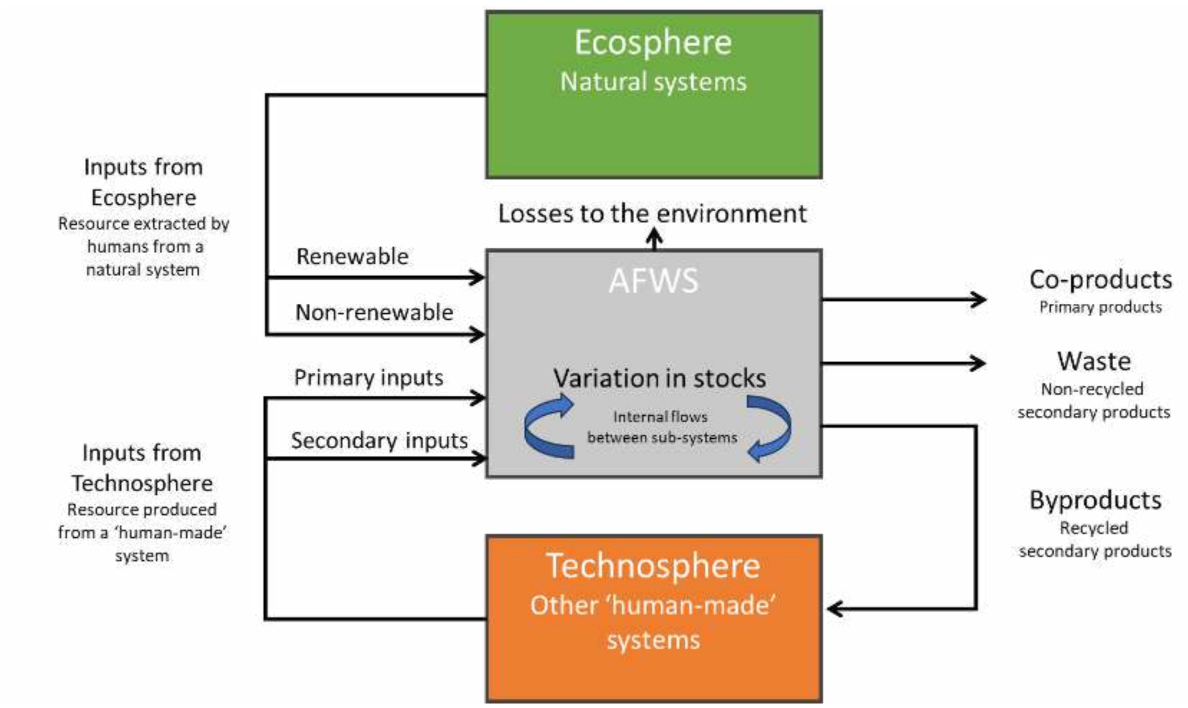

Figure 1. Resource flows to consider in circularity assessments of agri-food-waste systems (AFWS).

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Nature-positive harvest and processing of green tide sea lettuce into feed and food grade proteins

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1. INTRODUCTION

This study investigates the techno-economic and environmental sustainability of harvesting and processing Ulva sp., a green tide seaweed, for protein production. The research highlights the potential of Ulva as a sustainable non-animal protein source, addressing the high fiber and phenolic content that hinders protein digestibility. The study focuses on a case within the Danish scientific-industrial landscape, exploring water quality restoration and climate change mitigation through the harvesting of Ulva, further processed into food and feed-grade proteins.
At present in Denmark, 4.5k tonnes of sea lettuce is harvested annually, which correspond to a daily landing of 25 tonnes of VV (Bruhn et al. 2020). It consists of 16.7% dry matter and 18% crude protein content (Juul et al., 2022). This was selected as present scenario and an extensification of it with an annual landing of 11k ton for future scenario. Harvest data is produced under the auspices of the research and development project SeaSusProtein (GUDP) and landings of sea lettuce in 2019 and 2020.

2. METHODS

The study employed a life cycle assessment (LCA) and net present value (NPV) method to assess the environmental sustainability and economic viability of harvesting and processing Ulva. The LCA considered various scenarios, including the Danish electricity mix and a future windmill-based scenario, assessing impacts on global warming, eutrophication, and land use. The economic analysis evaluated the NPV of two habitat restoration scenarios, considering different scales of Ulva harvesting.

3. RESULTS AND DISCUSSION

The results indicated that Ulva harvesting could offer significant environmental benefits, including nutrient recovery and climate change mitigation through carbon and nitrogen capture. Economic analysis revealed positive NPVs for the scenarios, suggesting the financial viability of the Ulva-based biorefinery concept.

3.1 Scenario results

These results were also demonstrated for scalability and efficiency improvements in larger-scale scenarios. The total global warming footprint per kg food-grade protein ranges from 3.8 kg CO2 eq, whereas the net GW footprint varied from -0.3 to -0.8 kg CO2 eq for present and future scenarios. Similarly, the total freshwater eutrophication potential (FEW) ranges from 0.002 to 0.0015 kg P eq , and net FEW -0.0012 to -0.0013 kg P eq, total marine water eutrophication (MWE) 0.00018 to 0.0001 kg N eq and net MWE between -0.016 to -0.015 kg N eq, and the total Land use (LU) 0.3 to 0.1 m^3 and net LU -0.5 to -1 m^3, for present and future scenario respectively. Similar pattern of results was obtained for feed. Also, the economic analysis showed the net present value of this analysis varies from 25 Mio € to 60 Mio € from present to future scenarios which is 2.4 times higher in later scenario.

4. CONCLUSIONS

The study concludes that the gentle harvesting and processing of Ulva for protein production presents a viable pathway towards environmentally sustainable and economically feasible alternative protein sources. In this way the product system delivers not only financial products but also non-financial profits in terms of habitat restorations, water quality restoration, climate change mitigations and avoided land use. Our findings underscore the importance of integrating environmental and economic assessments in evaluating the potential of new bio-based product service systems.

5. ACKNOWLEDGEMENTS

The study was primarily funded by Green Development and Demonstration Programme (GUDP), Denmark, j. no 34009–19-1615

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Fertilisers from fish processing and aquaculture production waste: An ecofriendly alternative for crop production?

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1. INTRODUCTION

The production of mineral fertilisers causes several sustainability issues: while the manufacturing of nitrogen fertilisers requires high energy input, phosphorus fertilisers depend on the extraction of phosphate rock from finite deposits (Zhang, Akyol, and Meers 2023). In a circular economy, fertiliser production should thus be shifted towards the valorisation of so far unused biowaste streams from various sources (Chojnacka, Moustakas, and Witek-Krowiak 2020; Zhang, Akyol, and Meers 2023). An increasingly important waste stream originates from fish processing and aquaculture production. In this study, we analyse the environmental impacts of the production and application of bio-based fertilisers (BBFs) produced from fish processing and aquaculture waste and compare them to the production and use of mineral fertiliser.

2. METHODS

The goal of the life cycle assessment (LCA) was to compare 1) the environmental impacts of BBF production and 2) BBF application in crop production with those arising from mineral fertilisers. The scope of the LCA was cradle-to-farm gate assuming burden-free waste streams and applying economic allocation for co-products of the BBFs. As functional units, 1 kg of BBF and 1 kg of crop product (wheat grain, ryegrass and broccoli) were selected. Five impact categories were analysed in detail. Data on BBF production were obtained from industrial and pilot production facilities. Data of the latter was upscaled to industrial production, guided by the framework of van der Hulst et al. (2020). For the LCA of crop production, the Excel-based FarmLCA tool was used, that models field emissions, draws inventory data from ecoinvent and assesses impacts based on "IMPACT World+". The potential change in crop yield was determined from pot and field trials performed with the BBFs, calculating their agronomic mineral fertiliser equivalent (MFE). The reference inventories for mineral fertiliser were taken from ecoinvent and matched with the NPK content of the BBFs for the comparison.

3. RESULTS AND DISCUSSION

Results from the BBF production revealed a mixed picture (see Table 1): In comparison with their corresponding mineral fertiliser reference, BBF 4 and 5 showed generally lower environmental impacts while BBF 2 and 3 exhibited mostly higher impacts. BBF 1 performed better for some impact categories, but worse in others. Especially the transport of waste to the BBF production facility, energy intense dewatering or drying processes and packaging affected environmental performance of the BBF production negatively. Most of the BBFs exhibited a better agronomic performance when used as P fertilisers compared to the use as N fertiliser. However, BBF-related yields were generally low and resulted in higher environmental impacts.

4. CONCLUSIONS

The preliminary results of this study show that the environmental benefits of BBFs compared to mineral fertilisers depend strongly on the production process of fertilisers, but also on their agronomic performance. Therefore, BBFs can be part of the circular economy, but their environmental performance should be further optimized focussing on transport, water removal as well as agronomic performance.

5. ACKNOWLEDGEMENTS

The project SEA2LAND is funded by the European Union's Horizon 2020 Research and Innovation Programme (GA no. 101000402). We would like to thank Corinne Andreola, Marie Soone, Tommy C. Olsen, Laure Candy, Clement Chastrette, Christine Raynaud, Monica Gutierrez, Haizea Domínguez, Joaquin Romero, Iñaki Aramburu, Jingsi Zhang, Çağrı Akyol, Liina Edesi, Tiina Talve, Marta Aranguren and Sarah Symanczik for providing data, Nicolas Wittman for support in the modelling and Saioa Ramos for reviewing inventory data.

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Zhang J., Akyol Ç., and Meers E. 2023. Nutrient Recovery and Recycling from Fishery Waste and By-Products. Journal of Environmental Management 348.

Table 1. Environmental impacts of producing 1 kg of BBF relative to their corresponding mineral fertilizer reference with the same NPK concentration

No	Case study	BBF description	Climate change, short term	Freshwater eutrophication	Marine eutrophication	Mineral resources use	Terrestrial acidification
1	Estonia	BBF granules from bokashi fermentation	59%	159%	31%	249%	24%
2	Spain	NPK solution with amino acids from acid autolysis	567%	47%	232%	424%	122%
3	Italy	Hydrolysate from enzymatic hydrolysis	619%	676%	173%	617%	386%
4	Norway	Pelleted fish sludge	148%	1%	26%	82%	29%
5	France	Solid BBF from extrusion	84%	1%	25%	89%	24%

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Modelling and assessment of circular scenarios in local sheep supply chains: the MAX-SHEEP project

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1. INTRODUCTION

In recent decades, the progressive globalisation of supply chains produced relevant effects on the territories in which they were originally settled (Taddeo, 2022). In the Mediterranean region, sheep supply chains largely suffered such effects, despite their historical and crucial role in maintaining the ecosystems of the territories where they are located (Madau et al., 2022). MAX-SHEEP is a research project aimed at developing an eco-industrial model of the Italian sheep supply chain, capable of supporting the implementation of circular solutions in local contexts. Started at the end of 2023 and funded by the NextGenerationEU Plan, the project will test the potential circular and "bio-economic" transition of sheep supply chain in three Southern Italian regions: Abruzzo, Apulia and Sardinia, where sheep farming is typical (over 50% of the sheep reared in Italy). This article describes the project's strategy and methodological approach.

2. METHODS

The theoretical background of MAX-SHEEP is based on the s.c. *Place-based* approaches to Industrial Ecology (IE) that, inspired by the biological paradigm, are able to propose solutions aimed at increasing the level of sustainability and the inter-sectoral integration of the territory in which are implemented. The project is composed of three steps. In Step 1, desk activities will be focused on the analysis of the sheep supply chain features, the identification of potential closed-loop solutions and the selection of suitable modelling and assessment tools and indicators. In Step 2 the sheep supply chain will be modelled, to obtain a linear "baseline" and potential "closed loop" scenarios. Step 3 includes on-site activities of simulation and validation of the circular models developed in the involved regions. Methods and tools will range from those for mapping complex systems (e.g. Material Flow Analysis), to those for environmental assessment (e.g. Life Cycle Assessment), up to those for collaborative sharing (e.g. Industrial Symbiosis) and simulation (e.g. Agent-Based Modelling, System Dynamics).

3. RESULTS AND DISCUSSION

MAX-SHEEP will lead to the development of a dynamic IE-based model that contains: i) the main features of a linear sheep supply chain; ii) the potential circular solutions applicable; iii) an integrated set of modelling and assessment tools and indicators to be used; iv) three applicative scenarios, deriving from the potential development of the circular supply chains in the local contexts identified. In particular, from WP2a, currently underway, it is expect to obtain the definition of the structural elements (main actors, processes, and flows of products, by-products, waste) and of the functional relationships of the sheep supply chain and their representation, starting from breeding, up to the meat, leather, leather and wool branches.

4. CONCLUSIONS

The circular transition of local systems goes through the inter-sectoral integration of existing supply chains with other local production and consumption activities. MAX-SHEEP project intends to provide an example of how this can be achieved in the sheep supply chain. Overall outputs are expected to be *taxonomic* (systematization of knowledge on supply chain and contexts, applicable circular solutions, and most significant metrics), *exploratory* (testing approaches and tools for integrated analysis, mapping and assessing the circular solutions identified) and *applicative* (exploiting the potential of integrating circular supply chains in local contexts). Finally, the MAX-SHEEP approach is expected to be further replicated in similar contexts.

5. ACKNOWLEDGEMENTS

The present article is an outcomes of the project “MAX-SHEEP: Modelling and assessment of circular scenarios in local contexts. Applications in the sheep supply chain” funded by the NextGenerationEU Plan, within the PRIN 2022 PNRR program promoted by the Italian Ministry of University and Research (Project code P202238JP9).

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Environmental Perspectives on Wine Packaging: A Comparative Study of Single-Use and Reusable Options

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1. INTRODUCTION

Spain is the world's leading vineyard, accounting for 13% of the global total. In terms of production, Spain ranks third in the world. Wine packaging plays a crucial role in preservation and aging. EU Directive (EU) 2018/852 emphasizes reuse for resource efficiency and environmental impact reduction (EU, 2018). Spain aligns with this directive, focusing on promoting glass packaging reuse and the European Commission targets 70% glass recycling by 2025 and 75% by 2030 (BOE, 2022). In wine production, glass bottles have a significant climate impact due to high energy consumption in manufacturing. Therefore, reuse is key for mitigation. The main objective of this research is to analyse the environmental feasibility of implementing a reusable glass bottle system in the wine industry at the national level that can serve as a sectoral contribution to the Spanish Circular Economy Strategy as part of the GO REBO2VINO project.

2. METHODS

In this study, the life cycle assessment (LCA) method is used to compare the environmental impacts of two different wine packaging systems in Spain: single-use and reusable glass bottles. The functional unit considered is the volume of wine bottled by the winery during the pilot test, and a cradle-to-grave approach is adopted (Figure 1). The LCA was conducted using the latest version of GaBi software (Sphera, 2022) with integrated databases, employing the Environmental Footprint (EF) method (European Commission, 2021).

3. RESULTS AND DISCUSSION

An Excel tool is designed for wineries to compare the environmental impact of wine packaging options. Figure 2 displays a screenshot of this tool, featuring guidelines, boundaries, inventory data, calculation, and results. Key inputs in the inventory sheet include functional unit, the quantity of bottles, material composition (% of recycled content), volume and weight of bottles, and weight of boxes. Breakage rates and for reusable bottles, the number of cycles in the pool (the pool, the total amount of reusable bottles to guarantee the performance of the system, is estimated bearing in mind the input data) are crucial for impact assessment. Transportation data covers bottle transport from producer to consumer and, for reusable bottles, collection, washing, return, and disposal transport. The end-of-life stage for both options is also considered in this tool. The calculation sheet assesses environmental impacts using LCA for Experts software (results of GaBi are hidden in this tool). Data is sourced from database inventories or software-performed models (such as for glass bottle production and washing). The final sheet presents a comparative analysis of both packaging options.

4. CONCLUSIONS

This tool will be utilized to demonstrate which packaging option single-use, or reusable bottles is more environmentally efficient. Considering the diversity of business models and typologies of companies in the Spanish wine sector, LCA is very helpful in this context to determine under what circumstances the implementation of circular economy strategies remains environmentally beneficial, avoiding the transfer of impacts from one stage to another.

5. ACKNOWLEDGEMENTS

Thanks to the Circular Economy Operational Group for the Reuse of Glass Bottles in the Wine Sector: Impact Analysis and Feasibility, and Digital Strategy Design (GO REBO2VINO), funded by the 2022 Innovation Projects Call of the Ministry of Agriculture, Fisheries, and Food of the Government of Spain.

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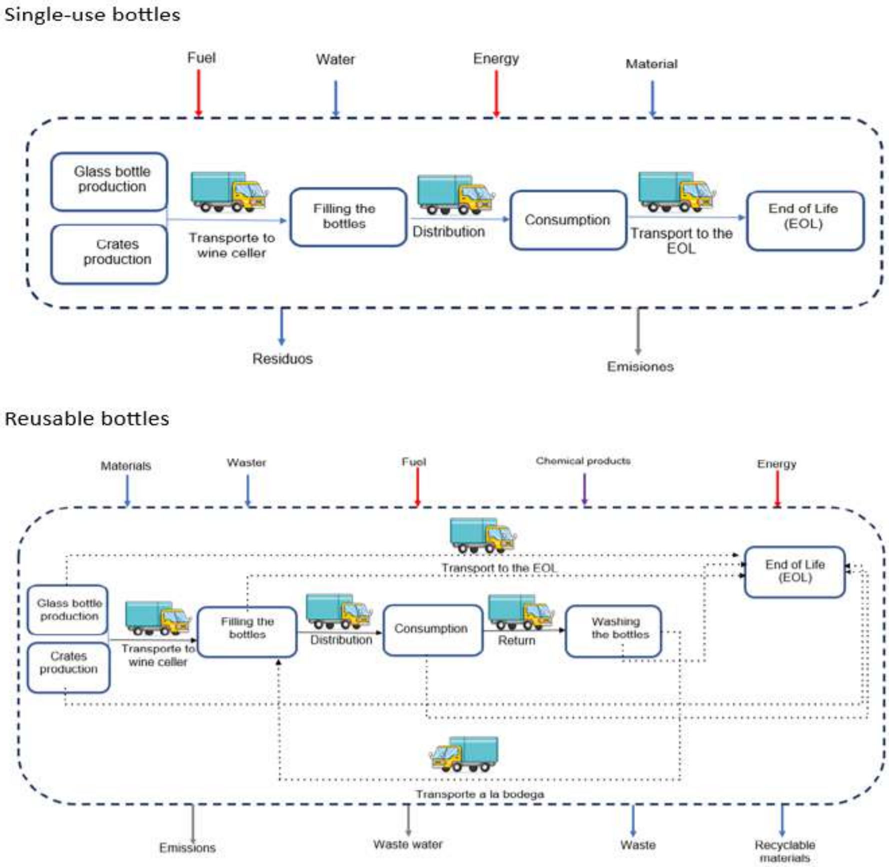

Figure 1. Boundaries of the study

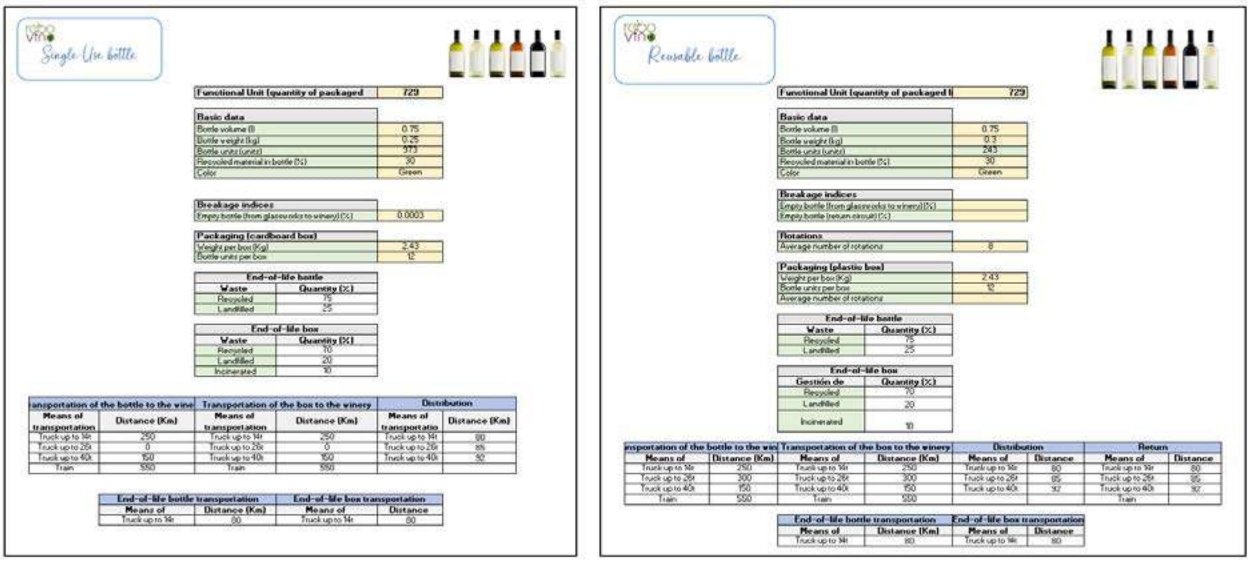

Figure 2: LCA Inventory Excel-based tool

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LCA of hazelnut by-products valorization through animal feed application

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1. INTRODUCTION

Hazelnuts are one of the world's leading nuts (Perez-Armada et al., 2019) and one of the main downsides associated are hazelnut waste (HW) originated from the confectionary sector, like the shell (HSh) and skin (HSk). The application of the principles of cascading biomass use in economic sectors such as food and feed production, allows to maximize resource efficiency, reduce carbon emissions and exploit biomass for high-added-value products (Keegan et al., 2013). On the other hand, feed is considered the highest environmental hotspot within the life of pets (Yavor et al., 2020). In this line, HSh and HSk can be used in feed for dogs. The HSk is used as an ingredient in the feed, which would improve the digestion and diet (Caccamo et al., 2019); and the HSh, is incorporated grounded in small pieces to clean the teeth by abrasion while eating it. To evaluate the sustainability of the hazelnut dog feed, an evaluation of the environmental impacts of the product will be carried out.

2. METHODS

The LCA methodology (Life Cycle Assessment) was utilized to achieve the proposed objective. This study was performed using the software SimaPro and the ReCiPe method for data interpretation. A cradle-to-gate approach was applied, considering the impacts from the cultivation of hazelnuts to the manufacture of dog feed. To deal with multifunctionality, mass allocation was performed between the coproducts. The functional unit established was 1 Kg of HW, which resulted in 0.048 Kg of HSk and 0.952 Kg of HSh. Table 1 shows the scenarios considered for the analysis. The replacement of corn by HW in a standard commercial dog feed, introduced in different proportions and compared to the current practice of using the waste for energy recovery, was considered.

3. RESULTS AND DISCUSSION

The LCA analysis tried to determine the environmental impacts of HW reutilized in dog feed compared to conventional animal feed. Table 2 shows the impact of HSh and HSk as raw material. The mass allocation led to a greater impact related to HSh, due to the higher content of HSh compared with HSk in the FU. Table 3 presents the impacts of the three scenarios considering different pathways for HW utilization. Scenario 2 had the largest impact, this is due to the high impact associated with the cultivation of the hazelnuts and the processing of the HSh. Scenario 3 showed the best relation between sustainability and hazelnut utilization. From the cascading approach it is interesting to valorize HW in high-added-value applications, but more scenarios should be contemplated to achieve a sustainable feed that uses the biggest quantity of residue.

4. CONCLUSIONS

The utilization of HW with a cascading approach in the feed and food sector aims to create high-added-value products that increase the efficiency of the resources and reduce the impacts to the environment. The results obtained with the LCA quantified these impacts and give the possibility of comparing the product with others on the market, introducing an alternative animal feed with good properties and more sustainable.

5. ACKNOWLEDGEMENTS

The authors would like to thank for the financial support provided by the research project entitled: “Cascade valorization of hazelnut industry by-products for industrial use and livestock feed”, financed by the Ministry of University and Research – Italian Government

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Table 1. Utilization of HSh and HSk in the three scenarios contemplated.

	HSh in feed	HSk in feed	HSh in energy	HSk in energy
Scenario 1	0% - 0kg	0% - 0kg	100% - 0.95 kg	100% - 0.048 kg
Scenario 2	10% - 0.0952 kg	100% - 0.048 kg	90% - 0.857 kg	0% - 0kg
Scenario 3	0% - 0kg	100% - 0.048 kg	100% - 0.95 kg	0% - 0kg

Table 2. Impacts of HSh and HSk as raw materials.

	Mass [kg]	Cultivation	Processing	Total
HSh [kg CO_2 eq]	0.952	0.710	0.086	0.796
HSk [kg CO_2 eq]	0.048	0.035	0.0043	0.039

Table 3. GWP impact of the three scenarios contemplated.

	Scenario 1	Scenario 2	Scenario 3
GWP (without energy recovery) [kg CO_2 eq]	0.603	0.664	0.584
GWP (with energy recovery) [kg CO_2 eq]	0.619	0.677	0.599

Cocoa and olive oil: sustainability assessments

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Olive pit: Transform a waste product into a valuable resource

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1. INTRODUCTION

Olive pit is a by-product of olive oil production, representing approximately 20% of olive production in mass [1] and is usually considered a waste. However, this waste could be converted into a new product, enhancing the concept of the circular economy. In this study, we proposed to use olive pits to produce biodegradable shoe shapers, instead of using traditional shoe forms without organic valorisation, and made with fossil resources. By achieving bio-compostability, we aim to close the shoe shapers' life cycle by using them as fertiliser in the SOVENA Group agriculture project. Simultaneously, a bio-compostable polymer reinforced with olive pits will be developed and functionalised to be compostable in existing composting facilities in Portugal.

2. METHODS

The methodology employed in this study involves a Life Cycle Assessment (LCA) based on ISO 14040-44 [2, 3]. The project's main goal is to assess and compare the environmental impacts of different types of shoe shapers, namely those developed as part of the project and two already available on the market. To delineate the project boundaries,

Figure 1 outlines the key stages of the cradle-to-cradle system. Starting with olive tree cultivation, collecting olive pits through an olive mill, followed by crushing and processing until it becomes a powder. This powder is then mixed with a recycled polymer matrix to develop a compound, which is injected to produce a shoe shaper. The ensuing stages include finishing and packaging, distribution, and end-of-life disposal at a biodegradability centre, followed by the reintroduction of the fertiliser produced into the SOVENA Group. This comprehensive approach ensures a thorough evaluation of the environmental impact across the entire life cycle of different shoe shapers. Although, as the project is still ongoing, this study evaluates preliminary formulations to produce the shoe shapers. The declared unit (DU) was defined as the production of one pair of shoe shapers, and this preliminary analysis included the production of the formulations tested for shoe shapers manufacturing. This study used mass allocation and an attributional approach. The impact assessment was performed using SimaPro software, with primary data provided by PIEP and Safiplás and secondary data from the Ecoinvent database. The ReCiPe Midpoint Hierarchist perspective (H) method was employed, and normalisation was applied to the results.

3. RESULTS AND DISCUSSION

As shown in

Figure 2, the recycled Polylactic acid (rPLA) shoe shapers showed a better environmental performance than those available on the market with Acrylonitrile Butadiene Styrene (ABS) and Polypropylene (PP). This can be explained by the fact that the products available on the market are made from virgin and fossil raw materials, whereas the project's options use a recycled material, namely rPLA. Additionally, the inclusion of olive pit in the production of novel shoe shapers seemed to be a better environmental option, which can be explained since this waste come with a burden-free impact. In the end, among the evaluated formulations, the 70% rPLA + 30% Olive Pit option demonstrated the best environmental performance.

4. CONCLUSIONS

The insights from this preliminary study suggested that the use of recycled materials and residues can promote environmental performance. This result advocates that producing shoe shapers from olive pits can be considered a practical application case of the circular economy concept, demonstrating the possibility of transforming a waste product into a valuable resource, reducing waste and the environmental impact, and creating economic and social value.

5. ACKNOWLEDGEMENTS

This research was supported by the NextGenerationEU program applied in Portugal, with the code number RE-CO5-i01.02 Sustainable Plastics, WP4, PPS14.

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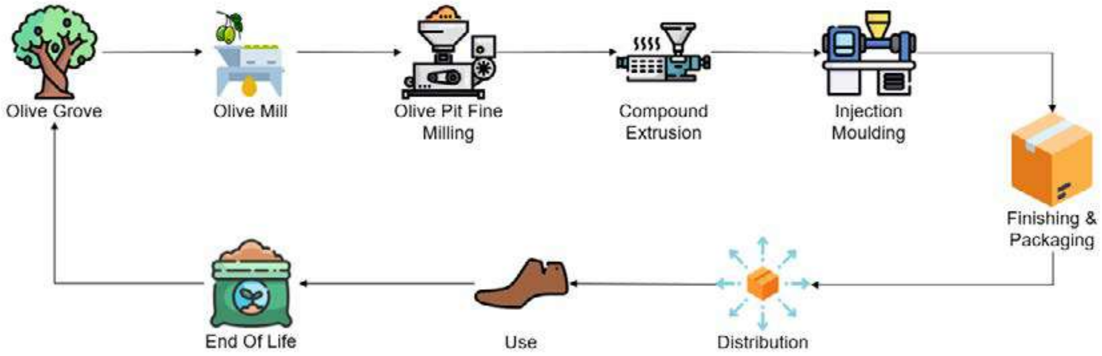

Figure 1. Project flowchart for the production of biodegradable shoe shapers incorporating olive pit, and thereafter the use of these shoe shapers as fertiliser in its end of life.

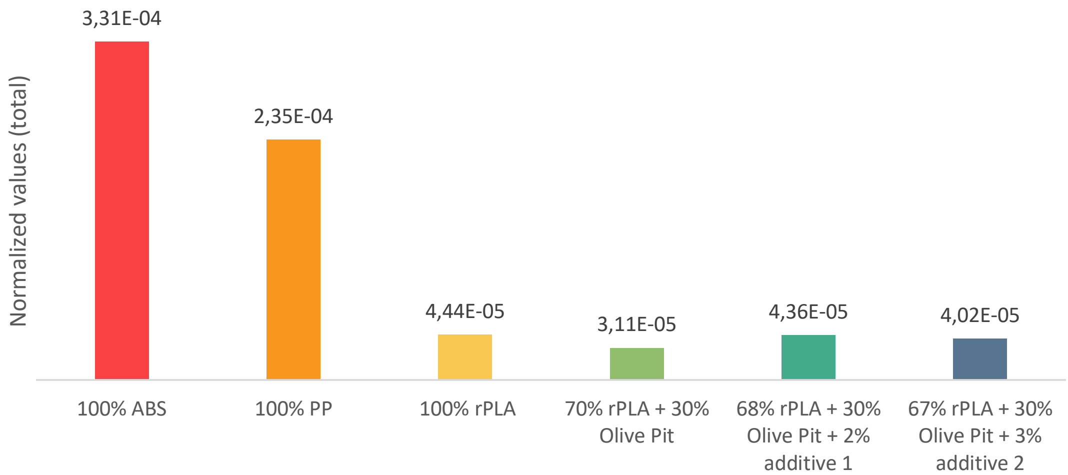

Figure 2. Total LCA normalised results by DU (production of a pair of shoe shapers).

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Life Cycle Assessment of organic chocolate products in Peru

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Keywords: agroforestry; cocoa; environmental footprint; LCA.

1. INTRODUCTION

Although there is increasing literature on reporting environmental profiles using Life Cycle Assessment (LCA) of agroforestry products, such as coffee, Brazil nut or cocoa (Avadí, 2023; Raschio et al., 2018; Recanati et al., 2018), studies are not as common as in other agri-food sectors. These agroforestry systems are of interest in many areas of Latin America as they are an important source of revenue for farmers, and have also shown to have lower environmental impacts, at least in terms of greenhouse gas (GHG) emissions, than other food producing systems, mainly due to the capacity of carbon sequestration in the sites they are cultivated (Parodi et al., 2022). The current project focuses on providing a full LCA of the production of organic chocolate in Peru, considering the cocoa cultivation practices of a group of 25 female producers located in central Peru, and the processing of cocoa beans into intermediate and final cocoa-based products for the chocolate industry.

2. METHODS

Data for modelling the agricultural stage was obtained from 21 female cocoa producers located in Satipo, region of *Junín*, who have recently transitioned from conventional to organic cocoa production practices. For the processing stage primary data from a chocolate producing plant in Pisco (coastal Peru) were gathered with the support of the plant technicians. The function of the system is the delivery of a certain amount of three different chocolate products: i) white organic chocolate drops (45%); ii) organic chocolate drops (55%); and iii) organic chocolate kibbles (55%), to the port for export. Hence, the functional unit selected was 1 kilogram of each of these products. It includes the environmental impacts linked to the intermediate products produced at the plant (i.e., cocoa powder, cocoa liquor, cocoa cake, and cocoa butter) which are inputs for obtaining the three final products. Carbon sequestration on field by cocoa and shading trees was modelled and included in the carbon balance, although not all farmers presented shading trees in their plots. Background data for the Life Cycle Inventory were modelled using the ecoinvent database. A total of 8 impact categories were selected for the Life Cycle Impact Assessment taking into consideration the recommendations of the product category rules for agroforestry products, including carbon and water footprint indicators. A sensitivity analysis was carried out mainly at the cultivation stage to understand impact variations related to husk management practices, and fertilizer emissions (mainly N_2O). Similarly, sugar production alternatives in South America were modelled under variable land use change assumptions.

3. RESULTS AND DISCUSSION

The results show that agricultural production of dry cocoa beans is the main driver of GHG emissions. Despite the organic conditions of the farms, which lowers the associated impacts of fertilizer and pesticide production as compared to conventional cocoa practices (i.e., synthetic fertilizers), the post-harvest management of the cocoa husk appears as a critical source of GHG emissions and derived uncertainty. In this sense, adequate composting conditions, which are only present for some of the farmers, maintain the emissions of methane at low levels, but direct return of the husks to the field can generate a two- or three-fold increase in GHG emissions. Total emissions of organic chocolate drops (55%) ranged from 3.52 to 16.6 kg CO_2eq per kilogram of final product, with the highest scenarios corresponding with lack of mismanagement of cocoa pod residues. Carbon sequestration from aboveground biomass, mainly from shading trees and, to a lesser extent, the cocoa trees, lowers the previously shown values by 1.76 kg CO_2eq per kg of chocolate drop. GHG emissions at the chocolate plant, while lower, should not be disregarded, as relevant emissions were found to be related to the use of natural gas and cooling agents. Sugar, which is currently imported from Brazil, is an important ingredient in the processing stage, representing a similar proportion in mass as cocoa-based intermediate products (i.e., cocoa liquor). For other impact categories (see Table 1), toxicity emissions at the cultivation site were low given the organic characteristics of the plots, which do not use conventional pesticides to combat pests. In contrast, eutrophication emissions are mainly linked to nitrogen and phosphorus-based fertilizer emissions. Similarly, ammonia emissions from fertilization, road freighting and the use of fossil fuels at the plant are important sources of particulate matter. Finally, water scarcity impacts are minor, as cocoa and sugarcane plantations rely entirely on rainfall, and water use at the processing plant is limited.

4. CONCLUSIONS

Organic practices by farmers guarantee reduced environmental impacts in cultivation practices as compared to conventional systems, but four key parameters prevail in determining the GHG emissions profile of organic chocolate products: i) carbon sequestration from shading; ii) N_2O emissions from applying of nitrogen-based fertilizers; iii) the way in which cocoa pod residues are treated and modelled in terms of emissions; and iv) impacts from the production of sugar.

5. ACKNOWLEDGEMENTS

We thank Prof. Ramzy Kahhat for valuable scientific exchange, as well as PromPerú and Ruta Peruana Exportadora, involved in the development of the CalCacao software.

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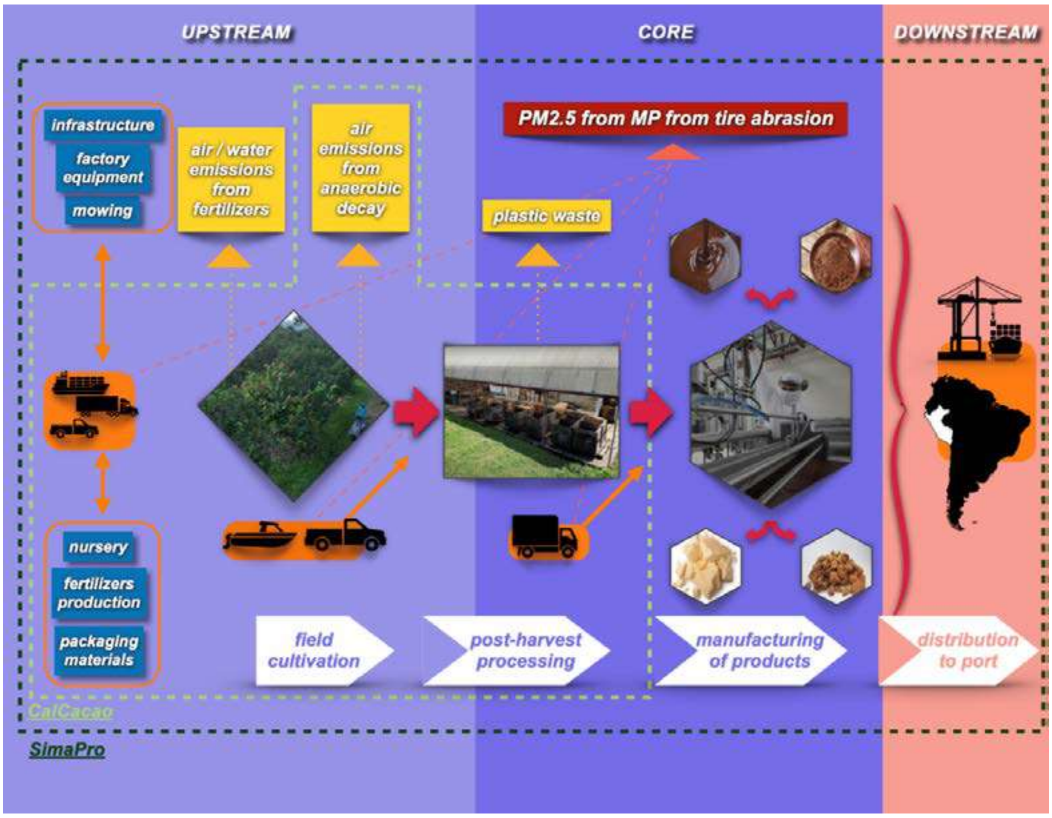

Figure 1. Cradle-to-gate system boundaries of the production of organic chocolate products in Peru (MP: microplastics).

Table 1. Environmental impact results for final chocolate products for 8 impact categories using SimaPro. Results reported per kilogram of final product, including the production of cocoa beans and the chocolate processing-plant in Pisco (Ica).

Impact category	Unit	Organic chocolate drops (55%)	Organic white chocolate drops (45%)	Organic chocolate kibbles (55%)
WS	m^3	4.68	4.54	4.74
TA	g SO_2eq	11.40	11.63	11.40
FET	PAF * m^3 * day	3.2E+03	2.0E+03	1.9E+03
Eu	g Peq	0.365	0.368	0.364
GW	kg CO_2eq	3.52	3.18	3.53
HT-C	CTUh	2.21E-08	3.01E-08	2.11E-08
HT-NC	CTUh	1.51E-07	1.21E-07	1.51E-07
FPMF	g PM2.5 eq	2.79	2.90	2.78

Life cycle inventory: modelling, databases, and tools

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Input-output based life cycle inventory for staple foods in Indonesia

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1. INTRODUCTION

Life cycle inventory (LCI) is a key issue in producing high quality LCA results. Two different approaches are commonly used when developing LCI for an LCA study: (1) process-based and (2) input-output (IO) based approaches, which are also referred to as bottom-up and top-down approaches respectively. While the former is superior in level of detail and is based on book-keeping, the latter might be preferred due to its completeness and is based on macroeconomic statistical data (Stadler et al., 2018). In fact, process-based modelling is more popular among LCA studies, although some also use hybrid models (using process- and IO-based approaches), which may produce detailed LCI with better completeness. The use of such hybrid approaches, however, could be challenging due to the scarcity of readily available IO-based LCIs in the literature, especially for the case of developing countries. Therefore, this study aims to develop IO-based LCI using cases from Indonesia, the largest emerging economy in Southeast Asia, focusing on the food sector which is among those contributing significantly to environmental issues.

2. METHODS

We developed life cycle inventories for staple foods in Indonesia using the 2016 Indonesian IO table provided by BPS-Statistics Indonesia (2021). The high resolution (185x185 matrix) of the applied IO table allows us to quantify the monetary value of all inputs required to satisfy 1 USD of final demand for selected staple foods, including meat products (processed meat), fishery products (processed fish), dairy products, rice products (milled and polished grain), and soybean products. Six categories of final demand considered in the IO table were included in our work, including household consumption, non-profit institutions serving households, government final consumption, gross fixed capital formation, inventory changes, and exports. We used the Leontief model (Lenzen, 2000), as given by Equation 1, to calculate the amount of input required for the defined functional unit, i.e., 1 USD for each selected staple food.

$$x = (I - A)^{-1} f \qquad \text{Equation 1}$$

Where x is the vector of total output, I is the identity matrix, A is the coefficients matrix, f is the final demand vector. The IO table does not include any environmental data, and thus the LCI table being developed only considers flow exchange within the technosphere.

3. RESULTS AND DISCUSSION

Our preliminary results are presented in Table 1 (all figures are expressed in monetary value). Of the 185 products considered in our LCI, only 28 are presented in Table 1 since they are among the top contributors (by monetary value) to the selected staple foods, while the rest are aggregated as *others (n=157)*. It should be noted that all of these staple products belong to the processed-food category, e.g., frozen, preserved, salted. Our analysis shows that the raw material itself is the one that contributes most to each product system considered, followed by transportation and energy. For example, fish and fresh milk are the major inputs of the LCI for fishery- and dairy-products, respectively. We believe this work can fill data gaps found in the literature, while contributing to the development of a global LCI database for food products.

4. CONCLUSIONS

Our work can serve as a proxy in cases of missing information in the process-based LCI modelling or can also be used for constructing hybrid LCI models for the product system being considered. However, further work, such as product disaggregation and unit conversion (to physical values), may be required for more relevant uses of this work.

5. ACKNOWLEDGEMENTS

We would like to thank Mohammad El Wali, postdoctoral researcher at the University of Helsinki, for his valuable input and suggestions to our work.

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Table 1. Input-output based life cycle inventory for selected staple foods in Indonesia*

No	Direct Input	Amount (USD/USD staple foods)				
		Meat Products	Fishery Products	Dairy Products	Rice Products	Soybean Products
1	Electricity	4.55E-04	4.31E-03	2.15E-03	3.43E-04	7.56E-04
2	Natural gas	1.84E-04	9.05E-03	9.35E-04	2.93E-07	6.84E-07
3	Water supply	4.03E-05	1.04E-04	2.25E-04	3.79E-06	1.40E-04
4	Land transport	1.48E-02	1.08E-02	6.13E-03	2.25E-03	1.18E-02
5	Sea transport	3.98E-03	1.95E-03	1.73E-03	5.43E-04	1.84E-03
6	River and lake transport	4.68E-04	2.93E-04	2.89E-04	7.47E-05	2.45E-04
7	Air transport	2.25E-03	3.29E-03	1.84E-03	3.35E-04	3.07E-03
8	Animal slaughter products	3.89E-01	4.82E-04	1.50E-07	0	5.01E-04
9	Livestock and its products, except fresh milk	6.52E-03	0	0	0	0
10	Poultry and its products	1.09E-02	0	3.08E-04	0	1.22E-02
11	Animal and vegetable oils	6.89E-03	1.09E-04	3.82E-02	0	1.10E-02
12	Wheat flour	1.69E-03	3.10E-04	4.51E-06	0	3.02E-02
13	Fish	0	3.37E-01	0	0	6.29E-03
14	Shrimp and other crustaceans	0	6.35E-02	0	0	1.41E-03
15	Other aquatic biota	0	1.35E-02	0	0	8.90E-06
16	Seaweed and seaweed-like	0	1.15E-01	0	0	9.31E-03
17	Basic chemistry, except fertilizer	1.24E-05	2.36E-03	1.86E-03	0	7.71E-03
18	Fresh milk	0	0	2.09E-01	0	1.83E-04
19	Chocolate and confectionery	0	0	6.25E-02	1.66E-07	1.20E-02
20	Fruits	2.56E-05	6.93E-06	2.26E-02	0	1.69E-02
21	Sugar	1.01E-04	5.48E-07	2.10E-02	7.83E-08	1.30E-02
22	Cocoa	0	0	1.19E-02	0	1.70E-02
23	Paddy	0	0	0	6.65E-01	0
24	Plastic	7.90E-05	1.84E-03	3.15E-07	3.40E-04	4.46E-03
25	Soy bean	0	0	0	0	6.42E-02
26	Coconut	3.74E-04	1.55E-07	3.55E-03	0	2.34E-02
27	Vegetables	1.66E-04	1.40E-05	0	0	2.14E-02
28	Cassava	0	0	0	0	1.57E-02
	Others (n=157)**	1.83E-01	1.28E-01	2.43E-01	3.46E-02	2.04E-01
	Total	6.21E-01	6.92E-01	6.27E-01	7.03E-01	4.88E-01

*This life cycle inventory was compiled based on the 2016 Indonesian IO table. The IO table covers all economic flows within the country during the referenced year with a total output value of 1.75 trillion USD. However, the IO table does not include any environmental data, and thus proceeding to the impact assessment stage using this solely LCI table is not feasible.
**Of the 185 products considered in our LCI, only 28 are presented here since they are among the top contributors (by monetary value), while the rest are aggregated as *others (n=157)*. In other words, the life cycle inventory being presented covers all processes that are actually linked, and thus reflects 100% completeness (i.e., 0% cut-off).

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Improved Life Cycle Inventory Data for Food Packaging in a Public Database for Eco-design and Food labelling

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1. INTRODUCTION

Even though packaging generally represents only a small part of the overall environmental impact of a food product/packaging combination (less than 15% for 2/3 of food products based on findings from the Mypack Horizon 2020 project [1]), consumers are sensitive to the related waste and packaging is an important area for eco-design for companies. Packaging appears as one of the first comparison points consumers would look into within a product category. Reliable packaging characterisation data and assessment methodologies are therefore a pre-requisite. In France, the reference public food LCA database is AGRIBALYSE® developed by ADEME, the French Agency for Ecological Transition. The French technical institutes from the agri-food sector together with ADEME and INRAE (National Research Institute for Agriculture, Food and the Environment) are strongly committed to the continuous improvement of the database. In the current version of the database [2], a highly simplified approach to packaging was implemented, restricting the impact assessment of the packaging to the one main element and assuming a single material. Environmental benefits from recycling were also not accounted for. In this context, a project has been initiated in fall 2022 in order to propose a harmonised set of LCIs for a large set of food packaging types. The project involved 5 technical institutes from the agri-food sector representing different large product categories (meat, fruit & vegetables, oil & fats, dairy, wine), a technical center for plastics and a supporting LCA consultant.

2. METHODS

The scope of the project was to cover all main packaging types for all the food products covered by the technical institutes involved and included in the AGRIBALYSE®. The first step consisted in the identification and selection of packaging solutions for modelling and assessment, followed by detailed characterisation of these solutions as illustrated on Figure 1. Packaging experts were called in to characterise precisely material composition and associated processes. Analyses were carried out in a specialised laboratory to get required data on some complex packaging composition, especially for multi-layer plastic packaging. A methodological framework aligned with recommendations from the LCA community (e.g. ADEME framework for comparative LCA of packaging solutions [3]) & the European PEF (Product Environment Footprint [4]) approach was developed. A global modelling architecture was then implemented taking into account the need to make the approach easily reproducible for additional packaging options to be added in the following versions of the database.

3. RESULTS AND DISCUSSION

The conducted work has led to 385 LCIs of packaging solutions modelled in a detailed and consistent way, covering the main current packaging alternatives for about 1000 food products. The correspondence between the packaging solutions and the associated food products is accessible through a catalogue whose principle is shown on Figure 2.

4. CONCLUSIONS

All detailed packaging LCIs and the associated LCA methodology will be freely accessible when the next AGRIBALYSE® version will be made available in the course of 2024. It is believed it will be valuable material to facilitate the implementation of packaging LCA at a time when companies are expected to rethink their packaging strategies in the light of the ecological transition and need to do so on the basis of objective data for sound decision-making.

5. ACKNOWLEDGEMENTS

The authors thank the ADEME for the financial support for the project.

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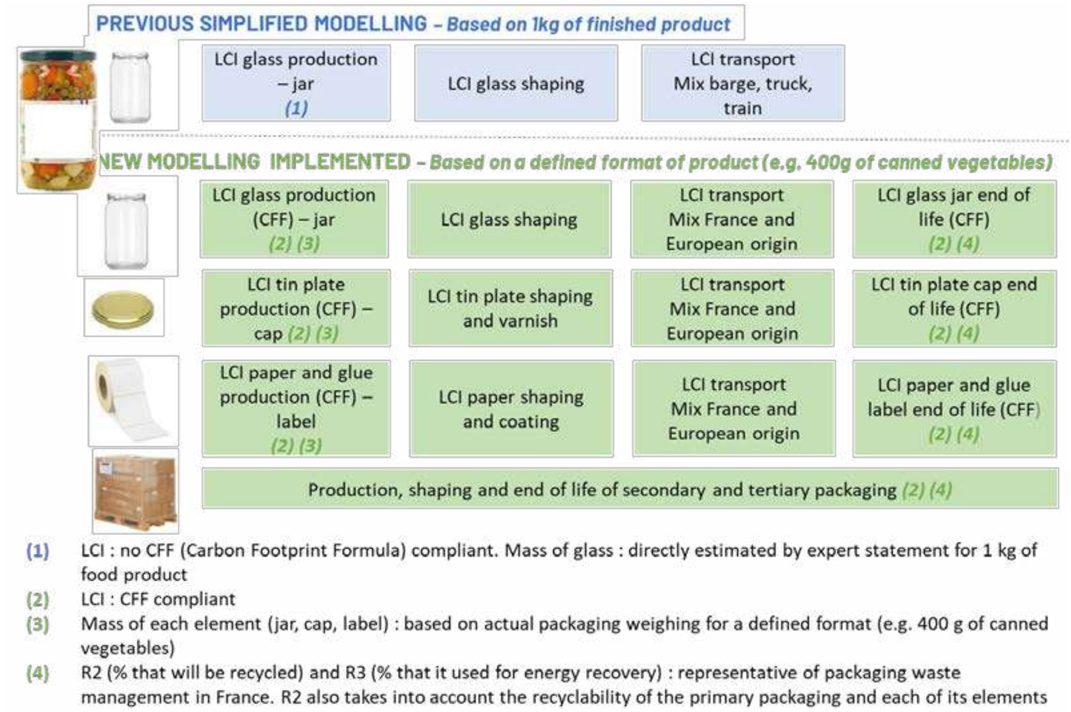

Figure 1: Illustration of the improved packaging modelling in the AGRIBALYSE® public database

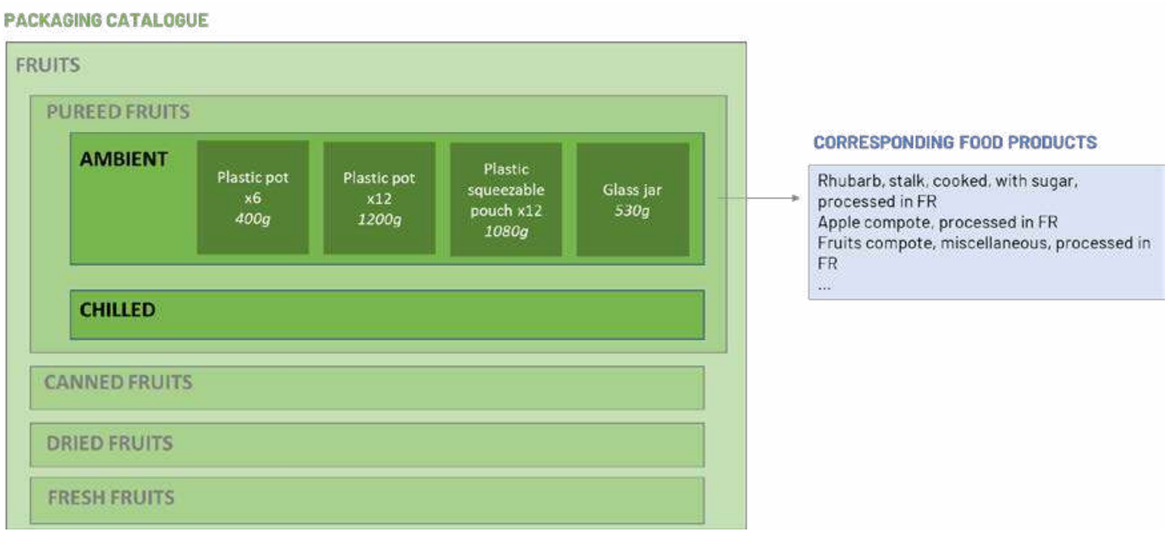

Figure 2: Illustration of the catalogue of packaging solutions and related products modelled for integration in AGRIBALYSE®

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Making a consistent environmental footprint database for the agri-food sector: Agri-footprint

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1. INTRODUCTION

Life cycle assessments (LCAs) heavily rely on data, and their conclusions and applicability strongly depend on data quality. Modelling Life Cycle Inventories (LCIs) of food products requires access to numerous datasets related to each item's supply chain. Access to primary data of supply chains is often limited, which makes compiling complete LCIs complex. Therefore, the use of environmental footprint background databases is key for food related LCAs (Cucurachi et al., 2019).

The Agri-footprint database provides consistent, comparable LCI data for agri-food products around the globe (Blonk et al., 2022). As the world's leading environmental footprint database in this sector, understanding how it is made is of great importance for the Food LCA community.

2. METHODS

To allow for comparability of the products in the Agri-footprint database, a consistent LCI modelling approach was conceived and implemented through various models developed by Blonk (Figure 1). This approach uses publicly available global statistics of agricultural and food production (e.g. FAOSTAT, IFASTAT), internationally recognized standards (e.g. ISO 14040 /44, PEF methodology, several PEFCRs, etc), background LCI data (e.g. electricity mixes, fertilizers) and in-house knowledge, (e.g. processing steps, approach to transportation, pesticide use). Key challenges in the making of Agri-footprint include limited access to data sources (e.g. update frequency, dealing with confidentiality and data sensitivity) and inconsistencies between standards (e.g. allocation), which place pressure on desk research and on in-house knowledge.

3. RESULTS AND DISCUSSION

Agri-footprint contains over 4800 LCI datasets that cover the production of agricultural commodities, their processing and the market mix of derived products for the feed and food production markets. The consistency of the Agri-footprint data allows LCA practitioners to use and compare it without the effect of significant modelling differences, a key aspect to decision making. The database thus prioritizes comparability over highly specific activity (input) data.

The external sources of activity data and the standards used to generate the Agri-footprint database are updated with different frequencies, and sometimes, in divergent directions. When updates are irregular or stopped, when inconsistencies arise, or when decisions are required to balance sector-specific methods with overall consistency, independent choices are made by Blonk to ensure high quality modelling and data based on the company's knowledge of the industry. Staying up to date with this knowledge and collaborating with external experts is key to maintaining the database quality throughout its different versions.

Once the LCI datasets in Agri-footprint are generated, they are used to obtain LCA information. To make that possible, the database is published in various formats and LCA software, whose implementation influences the assessment of environmental impacts based on the database.

The use of external background datasets in Agri-footprint adds a layer of complexity when interpreting the impacts of the datasets, as well as the sources of change between versions of the database. Understanding the magnitude, relevance, and source of such potential differences is a continuous process where efforts of different actors of the LCA community are needed.

4. CONCLUSIONS

The reliability of LCAs is tightly linked to the data they use. Practitioners should understand how the background data used is generated to recognize its limitations and applicability.

To overcome some of the challenges the LCA community experiences, Agri-footprint is designed as a consistent database that contains comparable datasets. To generate such datasets, large quantities of data, including activity data, standards and background datasets are required. Expert knowledge is key to deal with gaps and inconsistencies. Transparency is thus crucial when communicating environmental impacts, as many factors weight in when assessing the applicability of data to individual LCA studies.

Finally, close communication and collaboration between the different actors of the LCA community, both in the food sector and in other sectors connected to it through its supply chain, are key to make the best environmental impact data available.

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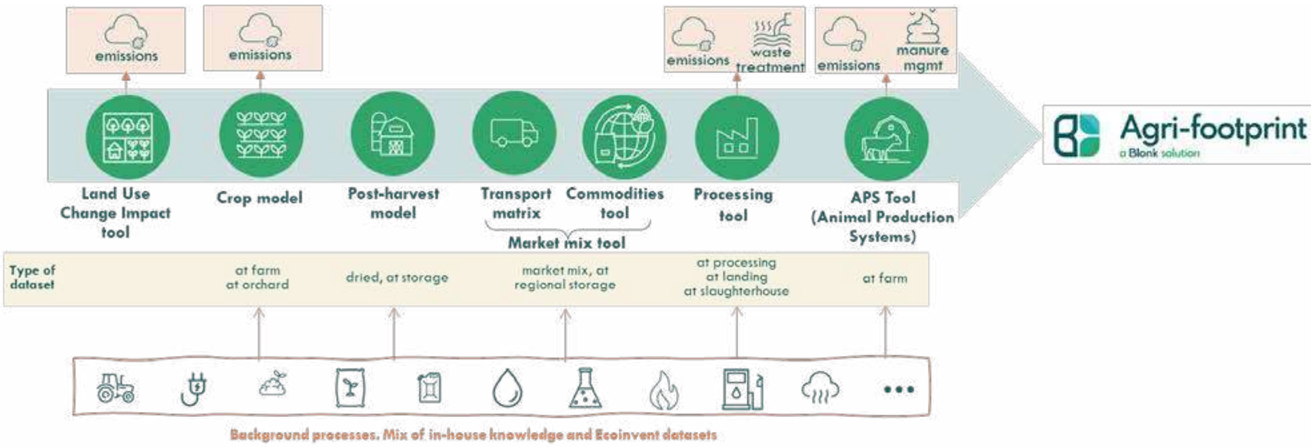

Figure 1. Models used in the making of Agri-footprint

Improving data availability for agricultural life cycle inventories through a common data standard

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1. INTRODUCTION

Although agricultural production is the major contributor to many environmental impacts of food items, the availability and data quality of life cycle inventories (LCIs) of food items is often poor. The large variability of production systems is often not reflected in most commonly used LCIs of food items, as they are based on data from only a limited number of farms, which have not been sampled to be representative. With a drastically increasing importance of LCAs, decision making in the industry and for policy, this must be seen as particularly critical.

At the same time, substantial efforts are being made to collect agricultural data for different purposes. Yet, this data is often not used for improving the availability and quality of data for LCIs. A major reason is that data is collected according to different classifications and nomenclatures, which hinders re-use of existing data for different purposes. Therefore, this paper aims to contribute to improving data availability and quality of agricultural LCIs by elaborating a generic and comprehensive ontology of data for agricultural sustainability assessments that can be applied to any dataset of an agricultural production system worldwide.

2. METHODS

To achieve this aim, we a) conducted 15 qualitative interviews with international experts in order to understand the expectations towards a common data standard, b) reviewed scientific literature and existing datasets, c) assessed the data requirements of different approaches that aim to assess different dimensions of sustainability (e.g. Schader et al. 2019), d) deducted common concepts while accounting for specificities of different disciplines and tools e) piloted the ontology by implementing it at the HESTIA platform (Poore 2021) and applying it to a farm survey in low-income countries and a field trial dataset in a high-income country via the HESTIA platform.

3. RESULTS AND DISCUSSION

The comparison of data needs for existing approaches for sustainability assessments showed synergies between all approaches at class level. This emphasizes the large potential of a common ontology for data. Synergies were particularly strong between the LCA approaches. The three approaches are of different complexity, with LCA_3 being the most comprehensive approach. We found also substantial synergies with multi-criteria assessments, especially the SMART-Farm Tool, which covers 80-90% of the classes of the LCA approaches. On the contrary, the benefit of using of using LCA data for multi-criteria assessments would be limited (27-40%), as usually MCAs beyond go the input-output data required in LCAs.

The ontology that we derived consists of the eight super-classes: Production system, Inputs, Outputs, Context and Impacts. Each super-class is divided into different classes. Classes are further divided into sub-classes until all instances of a sub-class can be described by the same properties. Properties are defined to be able to cover all potential data requirements of a sustainability assessment. The implementation at the HESTIA platform showed that the ontology can be practically applied and that HESTIA is able to represent the ontology.

4. CONCLUSIONS

Our study contributes to improving availability and quality of LCIs globally. It can be applied both to existing datasets and to new data collection activities. Ideally, it is already used in the planning phase before data is actually collected. The users of this classification will benefit from improved data exchangeability with other studies.

5. ACKNOWLEDGEMENTS

We thank the Swiss Federal Office of Agriculture (FOAG) and the Food and Agriculture Organization of the United Nations (FAO) for funding this Project.

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Table 1. Overview of data matches between different sustainability assessment approaches at data class level

Tool below... ... covers the classes matchted by the tools below by...

	LCA_1	LCA_2	LCA_3	TAPE_S_1	TAPE_S_2	SDG 2.4.1	SMART	Economic	Mean
LCA_1	**100%**	**70%**	**61%**	**33%**	**43%**	**41%**	**27%**	**45%**	53%
LCA_2	**95%**	**100%**	**75%**	**50%**	**57%**	**59%**	**39%**	**59%**	67%
LCA_3	**85%**	**78%**	**100%**	**42%**	**53%**	**50%**	**40%**	**62%**	64%
TAPE_S_1	**40%**	**44%**	**36%**	**100%**	**53%**	**68%**	**37%**	**24%**	50%
TAPE_S_2	**65%**	**63%**	**57%**	**67%**	**100%**	**64%**	**45%**	**55%**	65%
SDG 2.4.1	**45%**	**48%**	**39%**	**62%**	**47%**	**100%**	**34%**	**38%**	52%
SMART	**85%**	**89%**	**89%**	**96%**	**93%**	**95%**	**100%**	**90%**	92%
Economic	**65%**	**63%**	**64%**	**29%**	**53%**	**50%**	**42%**	**100%**	58%
Mean	73%	69%	65%	60%	62%	66%	46%	59%	

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Towards streamlined and transparent tools in the agri-food sector: a user-friendly benchmarking protocol to align tools with LCA standards

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1. INTRODUCTION

The increasing demand for companies to assess and report their environmental performance has led to a proliferation of tools designed for evaluating the environmental impact of agricultural and food products. However, the diversity of available tools has given rise to a significant challenge—stakeholders in the agri-food sector use a lot of different tools, hindering the comparability of results. Despite the presence of numerous general and sector specific Life Cycle Assessment (LCA) standards, the relationship between these standards and the diverse array of tools remains ambiguous. This challenge arises from the fact that it is difficult to filter and identify the specific requirements that are relevant for tools as the standards are built for LCA studies and not tools, and there is a lack of a clear transparent overview of the extent to which tools align with certain standards.
To address both challenges and enhance transparency and comparability in the assessment of agricultural/food product environmental performance, we present a benchmarking protocol. This aims to fulfill the need to guide tool providers on how LCA tools align with established LCA standards, and in doing so identifies gaps required to reach alignment.

2. METHODS

Three benchmarking protocols are developed for the floriculture, fruit and vegetables and marine fish sectors.
Five steps were taken to develop the protocols. First the relevant requirements for LCA tools were identified and extracted from the different general LCA standards and the sector specific LCA standards. The standards in this study are the ISO 14040 /14044, ISO 14067, Greenhouse Gass (GHG) protocol (WRI & WBCSD, 2004), Product Environmental Footprint (PEF) (Zampori & Pant, 2019) , Horti Footprint Category Rules (HFCR) (Helmes et al., n.d.), Flori Product Environmental Footprint Category Rules (PEFCR) (Broekema et al., 2023), feed PEFCR (FEFAC, 2018) and the marine fish PEFCR (PEFCR for Unprocessed Marine Fish Products, 2021). The second step was to align the requirements of the different standards, and afterwards a questionnaire was developed. The tool providers answer questions on methodological aspects of the underlying model in this questionnaire, and these answers are then cross-checked with the standards. It was then tested by different tool providers in the three sectors and the feedback derived from these tests was used to further improve the benchmarking protocol

3. RESULTS AND DISCUSSION

A highly detailed benchmarking protocol is developed of approximately 135 questions due to the high prescriptive sector specific methodologies (Fig 1). It is designed to be applied to tools in which an underlying LCA model is pre-defined, and the user interacts with the tool by entering company/product/supply-chain-specific information. The tool providers fill in the detailed questionnaire and it is then cross-checked for alignment with the different standards.

Some key limitations are transparently noted. For developing this protocol, requirements from the standards and guidance documents applicable to tools were selected. However, such a selection requires a certain level of interpretation, and it is possible that a slightly different selection would have been made by other protocol developers. Also, study-level conformance relies on user-provided data accuracy, outside this protocol's scope. It therefore isn't intended for fulfilling review or verification requirements; rather, it guides tool providers for user adherence to standards.

4. CONCLUSIONS

The developed protocol includes an easy-to-use questionnaire for tool providers to complete, coupled with a complete overview of the accompanying standard/guidance requirements for each methodological aspect, to see how LCA tools in the agri-food sector align with the different LCA standards. This intends to make it easier for the tool users to understand what is behind the calculations, and for tool providers to understand what features should be available in the tool to align more with the specific LCA standards.

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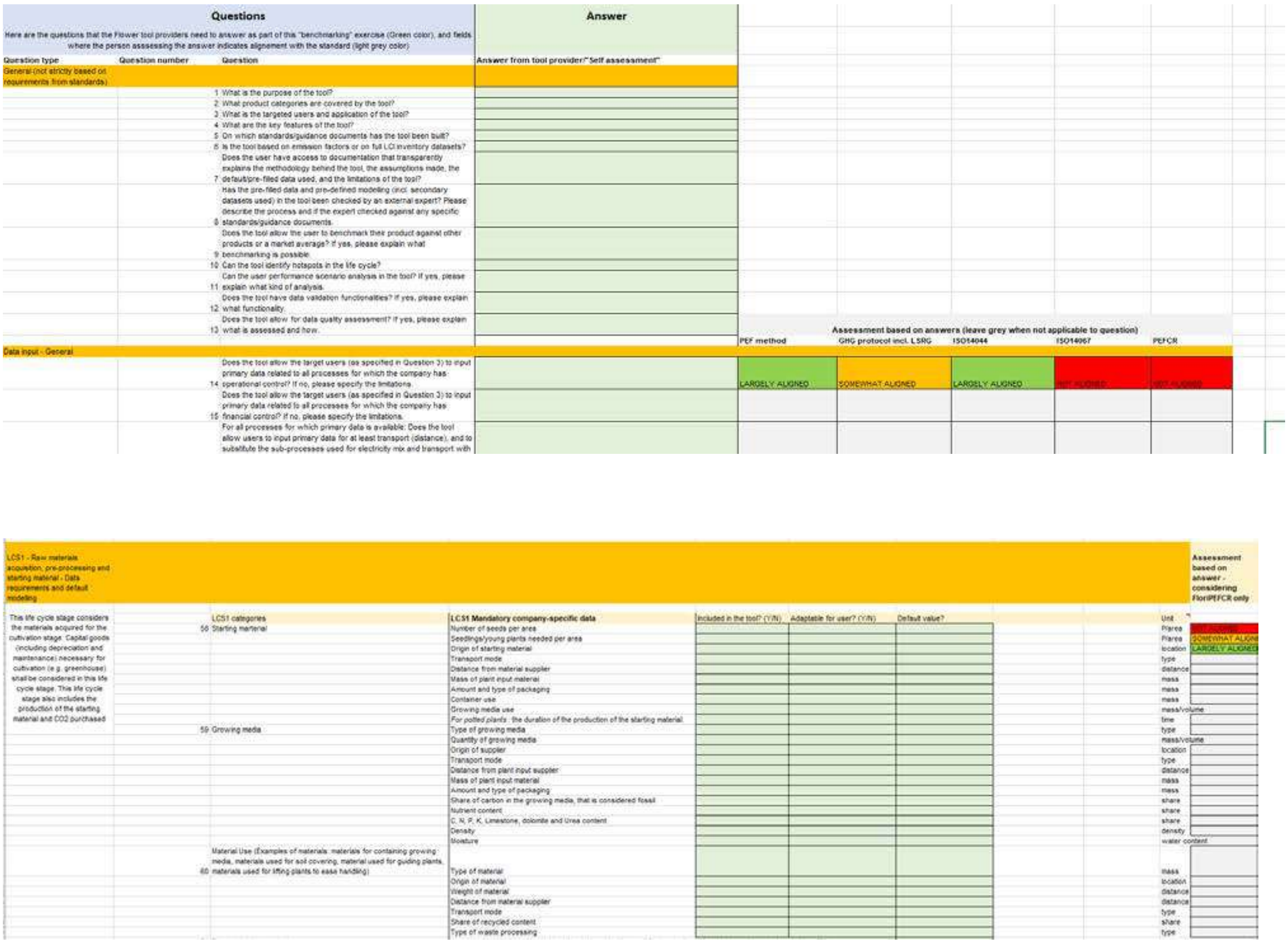

Questions			Answer					
Here are the questions that the Flower tool providers need to answer as part of this "benchmarking" exercise (Green color), and fields where the person assessing the answer indicates alignement with the standard (light grey color)								
Question type	Question number	Question	Answer from tool provider/"Self assessment"					
General (not strictly based on requirements from standards)								
	1	What is the purpose of the tool?						
	2	What product categories are covered by the tool?						
	3	What is the targeted users and application of the tool?						
	4	What are the key features of the tool?						
	5	On which standards/guidance documents has the tool been built?						
	6	Is the tool based on emission factors or on full LCI inventory datasets?						
	7	Does the user have access to documentation that transparently explains the methodology behind the tool, the assumptions made, the default/pre-filled data used, and the limitations of the tool?						
	8	Has the pre-filled data and pre-defined modeling (incl. secondary datasets used) in the tool been checked by an external expert? Please describe the process and if the expert checked against any specific standards/guidance documents.						
	9	Does the tool allow the user to benchmark their product against other products or a market average? If yes, please explain what benchmarking is possible.						
	10	Can the tool identify hotspots in the life cycle?						
	11	Can the user performance scenario analysis in the tool? If yes, please explain what kind of analysis.						
	12	Does the tool have data validation functionalities? If yes, please explain what functionality.						
	13	Does the tool allow for data quality assessment? If yes, please explain what is assessed and how.		Assessment based on answers (leave grey when not applicable to question)				
				PEF method	GHG protocol incl. LSRG	ISO14044	ISO14067	PEFCR
Data input - General								
	14	Does the tool allow the target users (as specified in Question 3) to input primary data related to all processes for which the company has operational control? If no, please specify the limitations.		LARGELY ALIGNED	SOMEWHAT ALIGNED	LARGELY ALIGNED	NOT ALIGNED	NOT ALIGNED
	15	Does the tool allow the target users (as specified in Question 3) to input primary data related to all processes for which the company has financial control? If no, please specify the limitations.						
		For all processes for which primary data is available: Does the tool allow users to input primary data for at least transport (distance), and to substitute the sub-processes used for electricity mix and transport with						

LCS1 - Raw materials acquisition, pre-processing and starting material - Data requirements and default modeling								Assessment based on answer - considering FloriPEFCR only
This life cycle stage considers the materials acquired for the cultivation stage. Capital goods (including depreciation and maintenance) necessary for cultivation (e.g. greenhouse) shall be considered in this life cycle stage. This life cycle stage also includes the production of the starting material and CO2 purchased		LCS1 categories	LCS1 Mandatory company-specific data	Included in the tool? (Y/N)	Adaptable for user? (Y/N)	Default value?	Unit	
	58	Starting marterial	Number of seeds per area				Pl/area	NOT ALIGNED
			Seedlings/young plants needed per area				Pl/area	SOMEWHAT ALIGNED
			Origin of starting material				location	LARGELY ALIGNED
			Transport mode				type	
			Distance from material supplier				distance	
			Mass of plant input material				mass	
			Amount and type of packaging				mass	
			Container use				mass	
			Growing media use				mass/volume	
			For potted plants : the duration of the production of the starting material				time	
	59	Growing media	Type of growing media				type	
			Quantity of growing media				mass/volume	
			Origin of supplier				location	
			Transport mode				type	
			Distance from plant input supplier				distance	
			Mass of plant input material				mass	
			Amount and type of packaging				mass	
			Share of carbon in the growing media, that is considered fossil				share	
			Nutrient content				share	
			C, N, P, K, Limestone, dolomite and Urea content				share	
			Density				density	
			Moisture				water content	
	60	Material Use (Examples of materials: materials for containing growing media, materials used for soil covering, material used for guiding plants, materials used for lifting plants to ease handling)	Type of material				mass	
			Origin of material				location	
			Weight of material				distance	
			Distance from material supplier				distance	
			Transport mode				type	
			Share of recycled content				share	
			Type of waste processing				type	

Figure 1. Examples of the benchmarking protocol for floricultural products.

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NewTools- social categories as a part of a food scoring system

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1. INTRODUCTION

Transforming the food system is an important part of building a sustainable, equitable, and resilient future for both people and the planet. It requires collaboration among various stakeholders. By bringing together actors from all parts of the food system, the Norwegian research project NewTools, serves as a bridge for dialogue and collaboration, ensuring that diverse perspectives and expertise contribute to the development of common goals. These common goals might include promoting sustainability, consumption of nutritious and healthy food, and creating a more resilient and equitable food system. The success and acceptance of a scoring system depend on the transparency of the framework, inclusivity in its development, and alignment with the values and priorities of diverse stakeholders. This paper describes the process of establishing weighting factors for the social impact categories.

2. METHODS

The starting point for weighting was 23 social categories, which were chosen based on hot spot analysis and stakeholder surveys, based on the UNEP Social LCA framework (Benoît Norris et al., 2020), but due to data availability, only 15 categories were included in the further analysis. For the categories, data was collected from countries linked to Norwegian food consumption, including both imported and domestic sources. The data sources were obtained from various data sources, e.g. ILO stat (International Labour Organization, n.d.) and Sustainable Development Report (Sachs et al., n.d.). A principal component-analysis (PCA) was performed to identify correlations between the social categories. This analysis provided the basis for reducing the number of categories and thus the need for data without significantly affecting the precision of the score. To be able to calculate a single score for the social categories, weighting factors were prepared based on the distance to the target. Distance-to-target weighting approaches can be developed for specific countries or regions, reflecting the perspective of the consumer regions, producer regions or the worst-case-region (Muhl et al., 2021). Here, a consumer region perspective were used, e.g. the targets applicable for Norway.

3. RESULTS AND DISCUSSION

The preliminary results for the PCA are shown in figure 1. Categories with arrows pointing in the same direction are positively correlated and arrows pointing in opposite directions are negatively correlated. A change in one of the highly correlated categories will correlate to a change in the other.

Figure 1 PCA Biplot of the social categories

According to the biplot, the following categories are highly correlated:

a) female income, access to agricultural input
b) sustainability and adaption, local supplier quality, disaster risk management, non-poverty headcount ratio, child labour index, food safety
c) corruption perception index, work load, average income
d) labour rights, global non slavery index

After grouping, a category was chosen for each group based on which has the best data access and data quality. For these categories, distance to target weighting factors were calculated, by calculating the distance between the target value, e.g. SDG targets or ideal values, and actual values achieved.

4. CONCLUSIONS

The PCA documented correlations between categories and thus the number of categories could be reduced and correspondingly also the data requirement in a scoring system. Weighting factors for social categories are needed for a scoring system. If weighting is not used, different categories will appear to be equally important (equal weighting) and in reality, this is often not the case.

5. ACKNOWLEDGEMENTS

This work was supported by the NewTools project - Developing tools for food system transformation, including food summary scores for nutrition and sustainability" funded by the Research Council of Norway (grant no. 326888). In the project, 28 project partners also contribute to a varying degree through self-financing of own activities.

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Harvesting Precision: Developing an Uncertainty Strategy for an Agricultural Carbon Footprint Calculator

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1. INTRODUCTION

The Embrapa-designed Footprint Pro Carbon calculator, integrated into the Bayer Pro Carbon Connect platform, plays a pivotal role in quantifying carbon emissions across agricultural processes. It encompasses both foreground (agricultural processes) and background (agricultural input production) aspects within the Life Cycle Assessment (LCA) framework.

Quantifying carbon emissions within a calculator is challenging due to uncertainties and varied accountability methods. Nonetheless, addressing these uncertainties enhances the reliability, comparability, and precision of results (GHG Protocol, 2022).

While LCA identifies four uncertainty types (Rosenbaum et al., 2018 - parameter, model, scenario, and relevance), we prioritize parameter uncertainty in this study. This choice is driven by the wealth of accountability methods (like GHG Protocol, 2022) and the more practical implementation within a calculator's scope.

This study aims to develop a strategy for implementing uncertainty calculations specifically focusing on parameter uncertainty within the Footprint Pro Carbon calculator for agriculture.

2. METHODS

In essence, parameter uncertainty involves characterizing input parameters and employing an error propagation method to extend this uncertainty through calculations to the final aggregated carbon footprint results. Within the agricultural sector, this involved conducting a comprehensive study to harness uncertainty information pertaining to all agricultural input data and associated emission methodologies. The latter encompasses nitrogen emissions (both direct and indirect), fuel emissions, emissions associated with input production, and land-use change (carbon sequestration was not included in the calculator). The process necessitates methodological decisions on how to characterize uncertainty and choose an error propagation method, with these choices mutually influencing each other.

Table 1 shows the considerations for the choice of error propagation method. Among the considered ones - Taylor Series, Analytical, and Monte Carlo - the Monte Carlo method was primarily selected for the calculator due to its scalability and rich output information.

Table 2 outlines key questions and challenges related to the uncertainty of the parameters. Notably, the uncertainty information was available in plenty of references, allowing for comprehensive consideration for all parameters (making sensitivity or contribution analyses not required) even with harder requirements due to the Monte Carlo error propagation method. Additionally, the Pedigree Matrix (Weidema et al. 2013) was incorporated to account for uncertainty related to representativeness and quality.

3. RESULTS AND DISCUSSION

The final uncertainty strategy was as follow:

- Uncertainty information was gathered for all inputs and parameters using available data from references, databases and data collection processes of the agricultural inputs. No sensibility or contribution analysis was made;
- Pedigree Matrix coefficients used as additional uncertainty;
- Monte Carlo simulation will be used to propagate the uncertainty to the final results. Additional tests shall be done to assess independence among parameters;
- Final aggregated result will have rich uncertainty information, making it possible to perform further analysis such as uncertainty contribution and key point analysis.

4. CONCLUSIONS

Navigating uncertainty provides crucial insights for decision-making and agricultural development, especially in carbon emission accountability. This work reveals the decisions and methodologies in addressing uncertainty within the Footprint Pro Carbon calculation, presenting a comprehensive overview of the applied strategy.

5. ACKNOWLEDGEMENTS

The authors thank Finep (Project 01.22.0591.00) for financial support and Anna L. M. T. Pighinelli, Nilza P. Ramos, Renan M. L. Novaes, Ricardo A. A. Pazianotto, Rafael P. Albuquerque, Màri L. Shiosawa, Débora Camilo, Thais E. Hiramoto, Renata P. Ferreira, Adriano Anselmi for technical support.

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Table 1. Error propagation methods and further characteristics (Igos et al., 2018).

Method	Information requirement	Output	Chosen?
Taylor Series (1st order linear assumption)	Variance	Variance	Not chosen as the calculator has enough complexity to require not only first degree series. Only variance as result.
Analytical (variance formulas)	Variance	Variance	Not chosen as it does not scale well with further demands of the calculator. Only variance as result.
Monte Carlo (random sampling)	Distribution	Distribution	Chosen. Has rich information output and is scalable. Tests are required for the independence of data.

Table 2. Questions, challenges and decisions on uncertainty distribution of parameters.

To which data should I apply uncertainty?	After an initial examination of the uncertainty data within the method references, databases, and data collection, the decision was made to assign uncertainty to all parameters because there was sufficient available data well described. In cases where this proves challenging, one could perform a sensitivity or contribution analysis to identify and prioritize the most crucial variables for which uncertainty information should be obtained as we perceived this step to be the most time and resource intensive.
What types of uncertainty will be considered for each parameter?	We opted for the ecoinvent methodology (Weidema et al., 2013) because it aligns with the utilization of the ecoinvent database as background information for the calculator. This methodology incorporates both measurement uncertainty and variability-induced uncertainty as 'base uncertainty.' Subsequently, this 'base uncertainty' is augmented with the uncertainty arising from insufficient quality and representativeness, a factor accounted for through the application of Pedigree Matrix coefficients.
What metrics will be used to characterize uncertainty for the parameters?	The Monte Carlo method requires a comprehensive parameter description in the form of a distribution. Consequently, each parameter must have a parameterization of its uncertainty distribution, with the required information collected from the corresponding data references.
What will be the output for uncertainty?	The Monte Carlo method allows for the uncertainty to be given by means of a standard deviation or a confidence interval, as the uncertainty result is in the form of a distribution.
Is there any requirement for the data?	To execute a Monte Carlo simulation, it is crucial for the data to exhibit independence (lack of correlations among parameters). To evaluate this independence, statistical correlation tests will be applied. In the event of high correlation among parameters, the Monte Carlo sampling method will be adjusted by incorporating copulas to account for the variable correlations.

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FarmLCA: a LCA tool for capturing the complexity of agro-ecological farm systems

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1. INTRODUCTION

While producing sufficient food is vital for an increasing world population, our current food systems contribute substantially to environmental problems, such as climate change, pollution and eutrophication. Agro-ecological innovations are seen as potential solutions to achieve more sustainable food systems. At farm scale, agro-ecological practices include recycling of nutrients and biomass, reduced external inputs, enhanced soil health, improved animal welfare and increasing biodiversity through the use of synergies (e.g. between animals, crops, trees, soil and water) and economic diversification (Wezel et al. 2020). While agro-ecological systems typically show lower environmental impacts on a field or farm scale, they tend to produce less food per hectare. To analyse such trade-offs, models are needed that can capture the complex on-farm environmental interactions of crops, livestock, trees and soils as well as environmental impacts related to off-farm activities. Here, we present such a model, the FarmLCA, which comprises two parts: 1) a farm system model for interactions of crops, livestock, trees and soils and 2) a coupled LCA of on- and off-farm environmental impacts. To demonstrate the model we assess a typical mixed farm in Scotland, UK, producing arable crops and beef, and show the effect of agro-ecological innovations introduced on that farm.

2. METHODS

The farm system model enables assessment of impacts for crop management as well as animal husbandry (Figure 1). Emissions from fields, changes to soil organic carbon, as well as emissions from manure management and enteric fermentation of livestock are calculated in different submodels (Table 1). Interlinkages between crops and livestock can be assessed by specifying the share of crops or straw sold or used internally for feed, grazing or bedding, as well as the share of crop residues not harvested and integrate into soils. The nutrient content of on-farm manure used for crop fertilization is calculated based on the herd structure and feeding of the herd. Plausibility checks on available manure and on-farm feed, rationing requirements of the herd as well as fertilization requirements of crops are implemented. The second part of the model links the on-farm impacts to impacts of imported feed, fuel, fertilizer as well as standard life cycle inventory databases to assess impacts of machinery, irrigation etc. Impacts are finally assessed through IMPACT WORLD+ (Bulle, et al. 2019).

3. RESULTS AND DISCUSSION

Applying the model to a mixed farm in Scotland (530 ha of arable crops, temporary and permanent grassland, 220 cows and 211 calves) showed hotspots regarding climate impacts of beef (enteric methane) as well as crop production (field emissions from fertilization). Introducing innovations (no-till, cover crops) on the crop side affected both impacts of crops as well as of beef. Trade-offs and synergies with other environmental impacts will be shown.

4. CONCLUSIONS

The FarmLCA model is an operational tool to overcome the shortcomings of typical LCA software when dealing with complex interactions at farm-scale to assess the environmental performance of agro-ecological innovations. It has been widely applied in many case studies on mixed farms, agro-forestry systems, but also both conventional and organically managed specialised arable or livestock farms. Future developments should focus on implementing more detailed indicators for example to capture potential impacts of agro-ecological practices on biodiversity. The FarmLCA provides pragmatic and time-efficient solutions to assess the environmental impacts of farms, farming practices or food products and can be combined with an economic assessment to support farmers decision-making.

5. ACKNOWLEDGEMENTS

This work has received funding from the EU Horizon 2020 research and innovation programme under following projects: MIXED (grant agreement No. 862357), PATHWAYS (grant agreement No 101000395), SEA2LAND (grant agreement No. 101000402), Re-Livestock (grant agreement No. 101059609).

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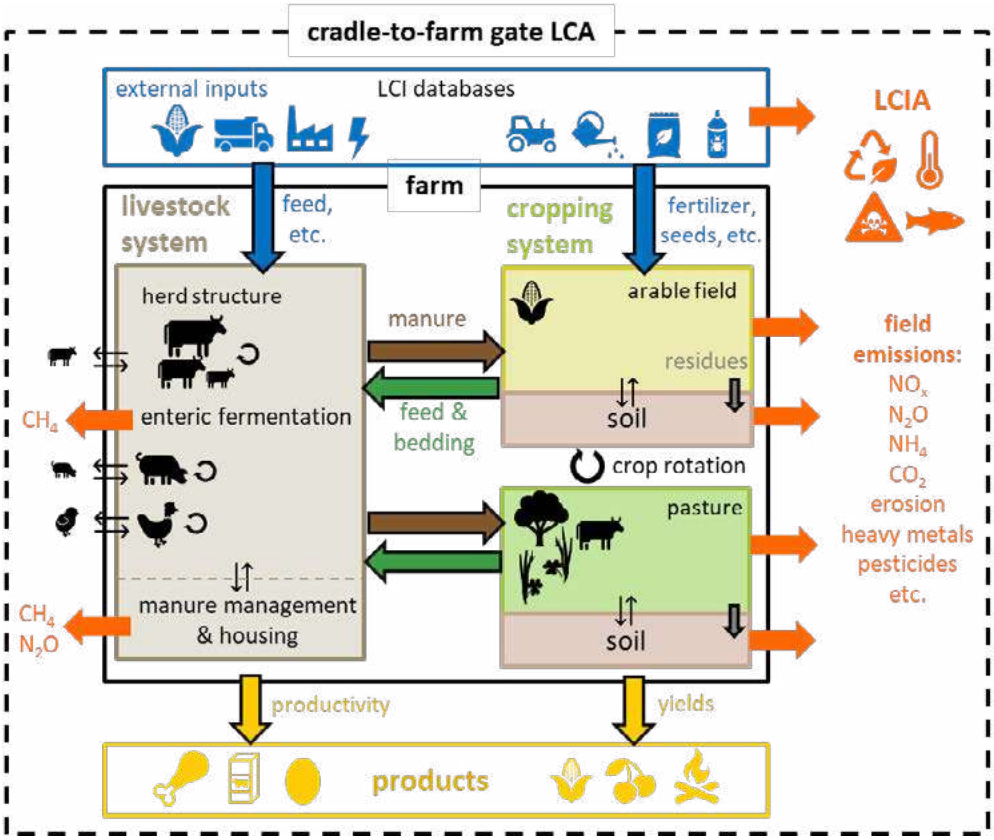

Figure 1. Elements of the FarmLCA model. For arrows with black contours, plausibility checks are conducted regarding nutrient in- and outputs.

Table 1. Submodels implemented to calculate emissions of livestock and crops

Production	Emission	Method
Crop field emissions	N_2O	IPCC 2019 (Tier 1 & 2)
	CO_2	IPCC 2019 (Tier 2)
	NO_x	EMEP/EEA 2023 (Tier 1)
	NH_3	EMEP/EEA 2023 (Tier 2)
	NO_3	SQCB-NO3
	PO_4, P	SALCA-Phosphorus
Manure management	CH_4	IPCC 2019 (Tier 2 & 3)
	N_2O, direct & indirect	IPCC 2019 (Tier 3)
	NH_3	EMEP/EEA 2023 (Tier 2)
Enteric fermentation	CH_4	IPCC 2019 (Tier 2 & 3)

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Recommendations for ISO-compliant allocation in agri-food scenarios

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Keywords: *allocation, co-product, waste, crops, livestock*

1. INTRODUCTION

The food sector is essential to provide nutrition to the growing global population, but also contributes significantly to a variety of environmental impacts such as greenhouse gas emissions, acidification, eutrophication, and land use [1]. Life cycle assessment (LCA) is commonly used to assess such impacts. One of the most controversial issues in LCA is allocation, which is used to partition these life cycle impacts when processes produce multiple co-products, such as different parts of a field crop, or multiple animal products produced from a single livestock species. The choice of allocation methods can have a large impact on the results of an LCA. However, there is a lack of transparency and consistent application of the ISO 14044 guidelines [2] in published LCA studies. Therefore, the goals of this work were 1) to assess current food sector allocation methods against the ISO guidelines, and 2) to provide recommendations for allocation methods that align with ISO guidelines for field crop and livestock LCAs. This information can be used to consistently model co-products and wastes associated with field crop and livestock production systems. Such consistency is imperative when making comparisons between different food products, in order to ensure the provision of adequate nutrition within the planetary boundaries for environmental impacts.

2. METHODS

First we performed a review of the literature to determine the current state of affairs in allocation and other multi-functionality modelling in field crop and livestock LCAs. These results were then compared against the ISO standards which recommend to first avoid allocation of impacts by subdividing the process into multiple processes that only produce one product, or by system expansion. If this is not possible, ISO recommends to allocate impacts between co-products based on a biophysical, or causal, relationship between flows. The last option is to allocate impacts based on another kind of relationship, such as the economic value of the co-products [2]. Finally, we provided recommendation tables for common multi-functionality scenarios in crop and livestock supply chains, based on the ISO guidelines.

3. RESULTS AND DISCUSSION

Despite its place at the bottom of the hierarchy, economic allocation was performed the most frequently, often justified because it represents the motivation behind producing each co-product. However, the ISO guidelines indicate a preference for natural science-based approaches, therefore we provided recommendations in line with biophysical causal pathways. Drawing from published methods, we recommend biophysical allocation for the co-products of crop and livestock production, either based on internal causality (such as metabolic partitioning of energy within an animal) when possible, or external causality (such as the protein or energy content of the products). We provide detailed recommendations for common multi-functionality scenarios in crop and livestock product systems (Table 1). These include recommendations for manure, either as a waste product (consistent with internal causality since it is a metabolic waste), or as a co-product (consistent with external causality if it is used as an input to another process).

4. CONCLUSIONS

Based on the results of the literature review, it is clear that additional guidance is necessary for consistency and adherence to ISO guidelines for allocation in agri-food systems. Therefore we provided recommendations in line with the ISO guidelines, and a natural-science based perspective. These recommendations can be used to enable consistent comparisons of the environmental impacts of different food production pathways, and to inform the optimization of a climate-friendly food system. This will also serve as an opportunity for discussion and collaboration in this important methodological space.

5. ACKNOWLEDGEMENTS

Funding came from the Natural Sciences and Engineering Research Council of Canada.

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Multi-functionality scenario	Recommendation
Inclusion of management practices, inputs, and outputs that can be mainly attributed to a single crop, in an LCA of a single crop from a cropping system	Subdivision to avoid allocation (i.e., attributing all field operations, inputs and, outputs directly related to single crop to only that crop in the rotation)
Inclusion of management practices, inputs, and outputs that can be allocated using causal pathways to a single crop, in an LCA of a single crop from a cropping system	Allocation based on causal pathways, e.g., allocating N inputs to the cropping system to each crop in the system based on N contents of crops
Inclusion of management practices, inputs, and outputs that cannot be attributed or allocated using causal pathways to a single crop, in an LCA of a single crop from a cropping system	Allocation based on generic biophysical criteria, such as mass, energy, cereal units (based on nutritional value to livestock), time in rotation
LCA of individual product from multiple co-products from single crop	Allocation based on internal causality of plant growth
LCA of all products co-products from a single crop	System expansion to include all products
Inclusion of N fixation from legumes in LCA of legume product	System expansion plus substitution to include credit for displaced N fertilizer
Multiple dairy products produced from milk	Subdivision when possible, then allocate based on milk solids content
Co-products at slaughterhouse, processing co-products, co-products produced by the animal (e.g., eggs/milk/wool and meat), multiple livestock species farmed in the same place	Subdivision when possible, then allocation based on metabolic partitioning when possible, then allocate based on relevant external causality (e.g., energy, N content)
Manure, mortalities	If waste (based on internal causality, or external causality if disposed of): allocate waste treatment impacts to co-products based on metabolic partitioning when possible, then allocate based on relevant external causality (e.g., energy, N content) If co-product (based on external causality if used as an input to another process): Subdivision when possible, then allocate based on relevant external causality (e.g., energy, N content)
Consequential LCA of change in supply or demand	System expansion plus substitution

Table 1. Recommendations for common multi-functionality scenarios in crop and livestock LCAs, in line with the ISO guidelines and biophysical causality principles.

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An overall system perspective on food (processing) residues in life cycle inventories

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Keywords: food residues, allocation, cut-off, polluter-pays, biomass, bioproducts

1. INTRODUCTION

Food waste and food residues have been identified by LCA as a relevant possibility for reducing the environmental impacts of food consumption. Thus, they became an important issue in the political debate. Several initiatives and ideas have developed how to reduce the amount of food residues or make best use of them. Most of them still assume that using waste is free from environmental burdens of the upstream life cycle. Approaches just focusing on the food system miss the interlinks to many other sectors like energy or material provision. Increasing competition in turn changes the LCA results due to economic allocation.

2. METHODS

In this presentation we summarize several results from LCA studies for different issues in the context of disposal, use, and valorisation for food processing residues. Therefore, we also discuss the implication of cut-off approaches and the polluter-pays-principle in the allocation of residues used to provide new products outside the food system. An important example addressed will be the market for used cooking oil and the several types of substrates used in biogas plants (Jungbluth 2023).

3. RESULTS AND DISCUSSION

We will show a systematic overview to address different sectors and pathways for the usage of food processing residues. Some process routes are e.g.:

- Food (maybe upgraded)
- Fodder for animals and insects
- Fertilizer (compost)
- Biomaterials (e.g. leather from apple peels)
- Biochemicals (glycerine, oils, ethanol)
- Processed materials (bioplastics)
- Energy carrier (biodiesel, biogas, ethanol)
- Energy (heat, electricity)
- Waste management with energy and substance recovery (municipal waste incineration (MSWI) or wastewater treatment plant (WWTP) with sludge digestion, direct incineration, partly recovery e.g. of phosphorus)

The analysis shows that ideas for the use of food processing residues are not always environmentally friendly if considering the markets and price developments for certain substrates classified as waste (Jungbluth 2023).

The following example should illustrate such a problem setting (Kopf-Bolanz et al. 2015a, b). We investigated the use of whey as pig feed and assumed that milk powder is used for human consumption in the base case. This is compared with two alternative scenarios for upgrading the food processing waste:

A: Production of whey protein powder (WPC 35) and whey powder, import cereals for pigs

B: Production of whey protein powder (WPC 65), import cereals for pigs.

The comparison shows that the first scenario results in a more ecologically favourable situation. The second scenario involves a higher level of processing into WPC 65, but due to increased energy consumption and large amounts of whey serum to be disposed of, it performs ecologically worse than the current use in pig fattening.

4. CONCLUSIONS

Doing LCA for the assessment of environmental impacts due to food residues and its use often involve allocation questions. We propose and conclude to strictly apply the polluter-pays-principle to all types of food processing residues (EPD 2021; European Committee for Standardisation (CEN) 2022). It should be applied consistently on the side of the process where the residue is provided and the process where it is used or treated further. Applying cut-off approaches on one or the other side as e.g. prescribed by mono-sectorial product category rules might lead to incomplete assessments of environmental impacts and thus wrong incentives. We highlight that it is always relevant to see both sides of the coin.

Furthermore, the efforts (and impacts) of upgrading and valorisation need to be considered. Not every idea proves to be suitable if these impacts are included. For the functional unit it is important to clearly define the scenarios which are compared with each other. This often limits the possibilities for generalization as not all possible pathways are considered.

Furthermore, it should be noted that LCA results influence the market. Then e.g. increasing prices (due to good environmental performance of the product) of used substrates lead to higher impacts. This leads to less attractive pathways from an environmental point of view.

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Completeness issues in LCA data results in underestimated results

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1. INTRODUCTION

A large number of academic agri-food LCA studies have been carried out in the last decade to identify more sustainable food production practices, and hundreds of dietary comparisons have drawn conclusions from these[1]. However, environmental impacts related to food products are underestimated if system boundaries exclude important processes and their emissions, or if characterisation factors are missing for certain environmental emissions.

On the HESTIA platform (hestia.earth), an online open-access repository for agri-food LCA data, we therefore require completeness criteria to be specified for each data upload. These completeness criteria detail whether a study specifies inventory flows, such as amounts of electricity and fuel used, seed use, or pesticides applied. In the current study, we explore how LCAs of different agri-food sectors have dealt with these issues.

2. METHODS

About 47 thousand agri-food processes from over 700 sources have been uploaded to HESTIA. Based on these data, we evaluated to which extent agri-food LCA studies align with the 19 data completeness criteria defined in the HESTIA schema. We also screened for uploads that presented freshwater ecotoxicity impacts, but where the active ingredients of pesticides lacked characterisation factors in USEtox v.2.12. This to exemplify how results can be underestimated in the impact assessment stage.

3. RESULTS AND DISCUSSION

Completeness differed among different criteria and agri-food sectors. This can in part be explained by irrelevance of some criteria for certain food systems (e.g. animal feed in horticulture), but also highlights incomplete inclusions of some inputs and products, such as soil amendments and crop residues. In the case of pesticides and freshwater ecotoxicity potentials, inventory data were often aggregated into generic categories (e.g. herbicides), and 321 active ingredients lacked corresponding characterisation factors in USEtox 2.12 (Table 1). This resulted in some studies neglecting up to 90% of their total freshwater ecotoxicity impacts compared LCIA data using complete sets of characterisation factors[2]. In order to address this, we believe that developers of LCA software need to provide better safeguards and cautions regarding lacking characterisation factors for potential impacts. This, however, also requires that LCIA methodologies start classifying inventory flows towards impacts categories, even if characterisation factors cannot be established.

In HESTIA, we partially solve this issue for agri-food LCAs by organising products and emissions in our glossary of terms. For example, all pesticides are identified as potentially toxic, and if any characterisation factor is missing, we do not present toxicity impacts. We are also working on gap-filling functions that will make sure that proxy data are used when data are incomplete.

4. CONCLUSIONS

As LCA results are increasingly being used to guide dietary choices, while LCA models are becoming increasingly complex, we need to work towards better validation methods. This, however, requires LCA studies to transparently report underlying data and methodological choices. HESTIA offers a free open-access academic platform that promotes this purpose, but we also believe that reviewers and academic journals need to increase their requirements regarding validation and reproducibility of LCA results.

5. ACKNOWLEDGEMENTS

HESTIA is financed by Login5 Foundation, WWF UK, Defra, the Ardevora Charitable Trust, and the Oxford Martin School. PJGH is funded by the FORMAS Inequality and the Biosphere Project (2020-00454), IKEA Foundation, Gordon and Betty Moore Foundation (GBMF11613), and Walton Family Foundation (00104857), and the David and Lucile Packard Foundation (2022-73546).

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Category	Count
Pesticide unspecified (AI)	95
Urease inhibitor, unspecified	2
Herbicide unspecified (AI)	65
Insecticide unspecified (AI)	64
Fungicide unspecified (AI)	62
Nematicide unspecified (AI)	1
Rodenticide unspecified (AI)	1
321 other potentially toxic chemicals	853

Table 1. Generic pesticide groups and number of potentially toxic chemicals in 700 uploaded studies uploaded to HESTIA that were lacking characterisation factors in USEtox 2.12.

Novel Emissions Database for Enhanced SBTi FLAG and Land-Related Emissions Accounting at Scale

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1. INTRODUCTION

Agriculture is a significant contributor to greenhouse gas (GHG) emissions globally, accounting for 13-21% of the total anthropogenic GHG emissions from 2010-2019 (UNCC, 2021). Despite its importance, measuring agricultural emissions is a complex task due to the diversity of sources and activities involved. These can be influenced by various factors, including weather, soil type, crop and animal species, and management practices.

As a first focus, this model looks at GHG emissions given their immediate urgency and demand from companies. The model offers country-level emissions data for each crop made available by the Food and Agriculture Organisation Corporate Statistical Database (FAOSTAT), providing extensive global coverage with country-specific information, as well as semi-automated updates as and when FAOSTAT updates their data annually. The outputs have been added to Altruistiq's AQ Commodities LCIA database, used in Altruistiq's customers' emissions calculations and will feed into other research projects undertaken by Altruistiq. This enables companies to understand the differences in the emissions of crops they are buying when purchased from different countries. To help facilitate more informed decision-making, Altruistiq's AQ Commodities LCIA database allows businesses with global supply chains and who cannot get primary data across this global supply chain, gain an informative, directional understanding of the on-farm emissions of their products.

2. METHODS

Figure 1 shows the calculation logic for agricultural input data, characterised by land attributes like the use of nitrogen fertiliser for crop cultivation or fertilised grassland. Emission factors are assigned to inventory data before an economic allocation is conducted. Co-products are handled and total emissions per product are normalised to 1 kg.

Energy-related parameters consider the total market value of agricultural products per country when creating allocation factors for a product. For other parameters like fertilisers, pesticides, and land management activities, we assume these are associated only with crop cultivation.

The AQ Commodities LCIA database covers all activities and emissions from cradle-to-purchase gate, excluding livestock products, capital goods, and maintenance of farm equipment. It covers 195 countries for five years from 2016 to 2020. When allocation is required, an economic allocation is applied. Co-products of cereal grains are incorporated in the AQ Commodities LCIA database. The resulting allocation factors, adapted from Poore & Nemecek (2018) are assigned to relevant crops and total emissions for each parameter are distributed according to the crop's economic value. Pendrill et al. (2020) is used as the main data source for land use change emissions. The study establishes a connection between deforestation risk and agricultural and forestry production, trade, and consumption, and links the associated emissions to particular crop types.

3. RESULTS AND DISCUSSION

The AQ Commodities LCIA database provides a comprehensive breakdown of 12,994 unique environmental footprints associated with various crops in a total of 195 different countries across the globe. This extensive coverage, however, varies significantly among countries. On average, each of these countries has 48 different types of crops represented in the data. The map below (Figure 2), indicates the geographic coverage of the AQ Commodities LCIA database. It also provides an overview of the number of individual crops that are represented in each country, shown by the number in each country on the map. This map offers a quick and easy way to understand the spread and range of crops across different regions.

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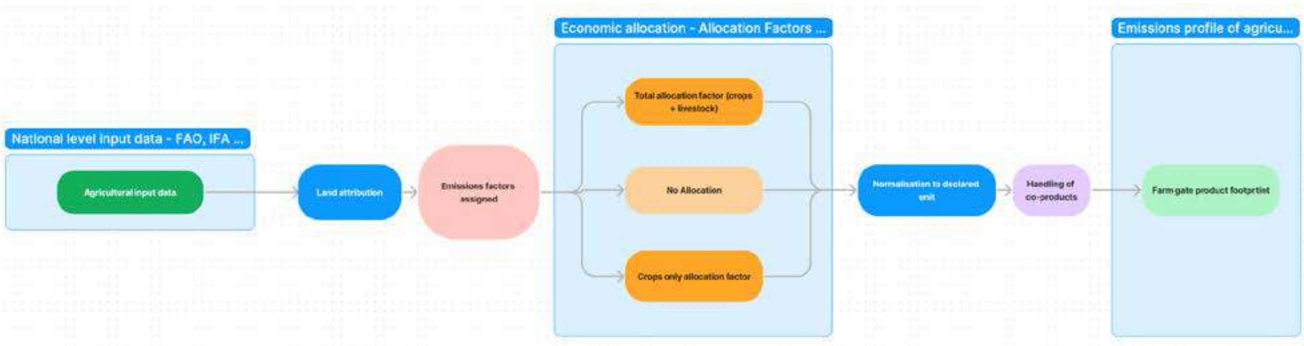

Figure 1. AQ Commodities LCIA database calculation flow

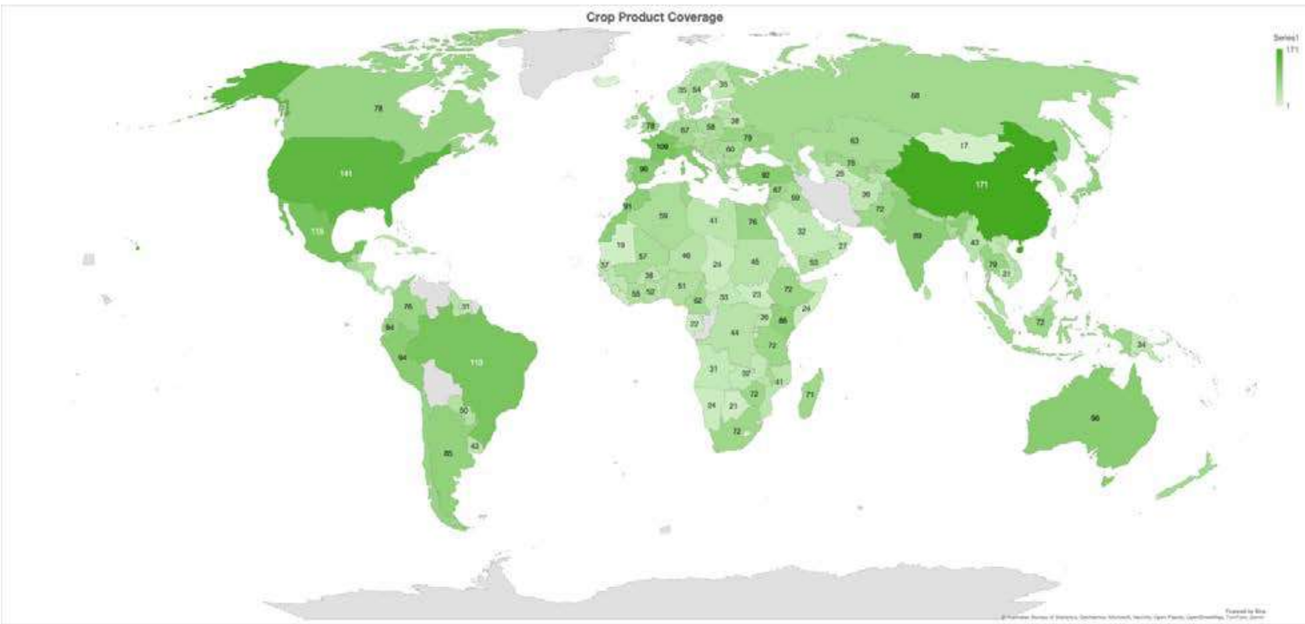

Figure 2. Map showing geographic coverage of the AQ Commodities LCIA database

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AGRIBALYSE, the French LCI database: a reference tool for the transition of food systems

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1. INTRODUCTION

In France, a growing number of users and tools for assessing the environmental impact of foodstuffs rely on the Agribalyse database which provides since 2013 accessible, reliable, transparent life cycle inventory (LCI) data, aligned with international and European standards (PEF notably), and covering the main agricultural commodities produced and the main food products consumed in France [1]. Behind the data lie 15 years of innovative partnership bringing together a wide range of expertise and skills within the REVALIM scientific interest group (SIG), bringing together ADEME (French Agency for ecological transition), INRAE (France's National Research Institute for Agriculture, Food and Environment) and technical institutes for agriculture and food (ACTA and ACTIA) with the support of ANSES (French Agency for Food, Environmental and Occupational Health & Safety).

2. METHODS

The AGRIBALYSE database relies on a robust and homogeneous architecture, using proxies to fill data gaps and to enable continuous improvement over time. Given the extent of the database, priority has been given to transparency, a systematic methodological approach, and concentration on hot spots (the agricultural phase in particular). REVALIM group is ensuring continuous improvement in data quality, regularly updating data and proposing improvements to methods, all in close collaboration with international work (GLAM, PEF), complementary databases (ecoinvent, World Food Database) and software that makes Agribalyse data freely available as open data (Simapro, OpenLCA, Brightway). Regarding data, new products are regularly added, recently meat substitutes (such as vegetarian sausages); existing ones are regularly updated (a major update of agricultural inventories is under progress). Regarding the methodology, we are currently working on several issues, notably the modelling of packaging, the water footprint, the impact of farming practices on biodiversity, and the carbon storage/removal in soils (figure 1). Agribalyse is mainly an LCI database, but also provides impact indicators for each agricultural product and for each of the 2,500 food products, which are calculated according to the EF methods.

3. RESULTS AND DISCUSSION

Covering hundreds of agricultural, aquaculture and fishing products, and 2500 food products, Agribalyse is, to the best of our knowledge, the largest publicly available agriculture and food LCI database. In the context of growing interest by consumers around environmental impact of food products, linked with massive development of ecolabelling tools, and with recent legislation on environmental labelling in European counties, France in the first place, the Agribalyse database is a seen as a reference database. Many countries would like to draw inspiration from it to build their own national databases, even outside Europe. Retailers (such as Colruyt), major catering companies (such as Elior) and digital applications designed to enlighten consumers (Yuka, Open Food Facts), already use Agribalyse data. At the same time, companies in the agricultural and agri-industrial sectors are making massive commitments to decarbonisation strategies, to meet national, European and international targets for drastically reducing GHG emissions by 2050. This is leading more and more companies to use Agribalyse data as a reference tool for eco-design initiatives. The Agribalyse methods also serve as a reference for low-carbon certification schemes, such as the low-carbon label.

4. CONCLUSIONS

Agribalyse faces today major challenges related to the large increase in the number of expert and more especially non-expert users, since open data facilitates the widespread use of product impact indicators, but at the same time limits the possibility of getting to know users. To overcome this difficulty, Agribalyse is structuring its relationship with users, by setting up a service to answer users' questions, organising events to present the results, and collecting suggestions for improvements and the integration of new data.

5. ACKNOWLEDGEMENTS

The authors thank all the members of the REVALIM group.

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Table 1. A broad scope to cover the French diet (including imported products)

Product category	Number of products	Example
Fruits and vegetables	431	*Carrot, cooked; Apricot, pitted, dried; Strawberry, raw*
Meat	400	*Beef, minced steak, 5% fat, cooked; Chicken, leg, meat and skin, roasted/baked*
Cereals and starchy products	377	*Dried pasta, cooked, unsalted; Breakfast cereals, rich in fibre, with or without fruits, Biscuit (cookie), with chocolate, prepacked*
Egg, Milk and dairy products	286	*Yogurt, Greek-style, on a bed of fruits; Abondance cheese, from cow's milk*
Processes meals	241	*Soup, leek and potato, dehydrated and reconstituted; Lasagna or cannelloni with meat (bolognese sauce); Pizza, vegetables*
Fish	220	*Salmon, raw, farmed; Sushi or maki with seafood products ; European pilchard or sardine, fillets without fishbone, in olive oil*
Drinks	219	*Mineral still water; Beer, regular (4-5° alcohol); Apple juice, pure juice*
Sauces and condiments	169	*Bearnaise sauce, prepacked; Curry, powder; Salt, white, for human consumption*
Sweets, desserts and ice creams	80	*Mousse, chocolate, refrigerated ; Ice cream, luxury, in box*
Fats and oils	57	*Sunflower oil; Olive oil, extra virgin*
Baby food	33	*Baby milk, second age, powder; Baby food jar with vegetables and starch*

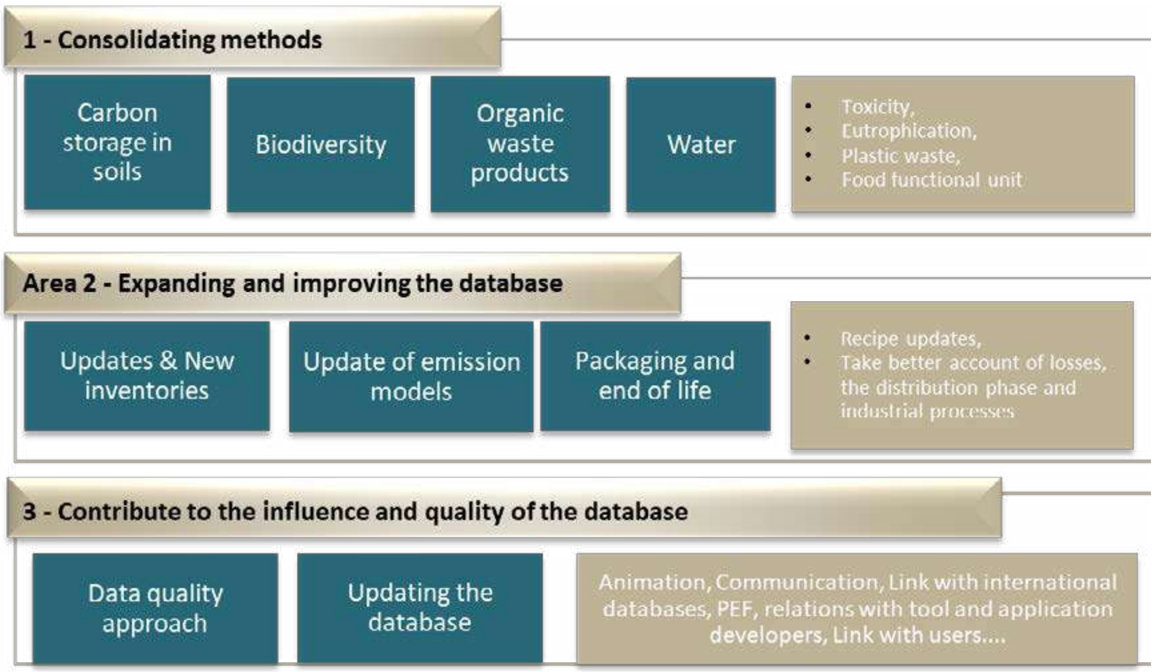

Figure 1. REVALIM Roadmap [2022-2026]

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Enhancing Accessibility and Reliability of LCA-Based Tools: A Case Study of a Climate Scan for Dairy Farms in Flanders

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1. INTRODUCTION

An LCA-based climate scan for dairy farms (Klimrek) has proven to be an effective instrument to offer Flemish farmers insight into the environmental impact of milk production at farm level and support them in the selection and implementation of cost-effective climate measures. The results of the climate scan facilitate reporting on greenhouse gas emissions from primary production and can therefore also inform the development of sustainability programs. This has generated interest across the dairy supply chain's stakeholders (from feed producers to policy makers). However, the data-intensive nature of the LCA approach has hindered the widespread implementation of the tool. Completion of the full climate scan takes on average 2 days of work, which is too time-consuming and thus too costly. Additionally, some data points are often unknown or poorly documented, reducing the reliability of the results. Besides this, questions are raised on how the correctness of input data can be ensured. To respond to these challenges, a co-creative approach was followed to develop a simplified version of the scan, that allows for a more user friendly, quicker and more reliable analysis of the farms' climate impact.

2. METHODS

Development of the simplified scan started with the consultation of different stakeholders (farmers, climate consults, dairy producers) to identify the most time-consuming aspects, pinpoint unknown or undocumented data points, and determine the desired output of the scan. This showed that the scan will be used for 2 purposes: 1) calculating the carbon footprint of the farm for integration into sustainability programmes of dairy producers, 2) providing farm-specific advise to interested farmers. The first purpose will be the predominant use of the scan and for this purpose no additional impact categories should be considered, and supplementary information on potential climate measures is unnecessary. For the second purpose, however, additional information and impact categories are needed. To address this, a modular format is proposed, with a core module to calculate carbon footprint, while add-on modules facilitate the collection of information necessary to provide advice. In the future, other add-on modules will be added to calculate carbon sequestration, the farm's water balance etc.

In the second phase of the development, analyses were conducted on the benchmark dataset, comprising 289 scans from 224 Flemish dairy farms between 2020 and 2023, to assess the effect of replacing particular farm-specific data with defaults on the calculated carbon footprint. This analysis focussed on 1) data-points that are time-consuming to fill in and are not well documented or known by the farmer, and 2) data points with minimal variation between farms. In parallel, the potential for automated data input via the Flemish Agrifood data sharing platform (DjustConnect) was investigated.

3. RESULTS AND DISCUSSION

3.1 Analyse the potential for simplification

Analysis of the benchmark dataset showed that substantial simplifications can be implemented without significantly affecting the calculated carbon footprint. Rations of all animal categories (except lactating cows and heifers), for example, can be replaced by defaults as well as the pregnancy rate, and the classification into different parity classes of lactating cows. Also, detailed age categories for young cattle under 1 year of age, as well as information regarding manure types and grazing regimes for young cattle, can be substituted with default values. The coming months the revised tool will be tested to assess the time saved through these simplifications.

3.2 Investigate the potential for automatic data-input

Through a data-sharing platform, farmers can provide consent for automated data input into the climate scan. Data points accessible from validated digital sources were identified. For instance, connections with billing software and tools for calculating the environmental impact of compound feeds are investigated. These connections would enable automatic and detailed calculation of the environmental impact of purchased feed on the farm.

4. CONCLUSIONS

The development of a simplified version of the LCA-based climate scan for dairy farms addresses the challenges of time-consuming data collection and reliability of input data. Through stakeholder consultation and analysis of the benchmark dataset, it was determined that simplifications can be made without significantly affecting the accuracy of carbon footprint calculations, facilitating a more efficient and practical tool for farm-level assessment. Furthermore, automated data input presents opportunities to further streamline data collection and increase correctness of input data.

Flexible, efficient and consistent agricultural inventory modelling with SALCA

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1. INTRODUCTION

Agricultural production dominates the environmental impacts of the food sector. Agricultural systems strongly rely on the use of natural resources, their impacts are highly variable and the production units (farms) are numerous. A specific framework, versatile methods and efficient tools are thus needed to adequately assess the environmental impacts of agricultural systems in an LCA context and to capture their variability. The models should be sufficiently detailed to answer specific questions related to agricultural management and food production, yet at the same time deal with limited data availability. Here, we present the completely revised Swiss Agricultural Life Cycle Assessment (SALCA) concept and method.

2. METHODS

The SALCA concept comprises rules for the definition of system boundaries, functional unit and allocation, emission models for gaseous N, nitrate leaching, P emissions to water, soil erosion, pesticides, heavy metals, emissions from animal production, a life cycle inventory (LCI) database, calculation tools, impact assessment methods for soil quality and biodiversity and concepts for analysis, interpretation and communication (Nemecek *et al*. 2023). Here, we focus on the inventory modelling, interlinkage of models and show the potentials for various applications. The models are calculated at the crop, field, animal group and farm levels (Figure 1) and are integrated in a consistent and harmonised framework. This offers a great flexibility and the potential to be applied in many different contexts.

SALCA has a modular structure (Figure 2), which allows to manage its complexity and to exchange models, if needed for an application in a different context. By exchanging intermediate calculation results between the models, the consistency of the results is ensured. For example, changes in feed conversion efficiency will have effects on the nutrient, heavy metal and organic substance contents in manure and affect N and P emissions, heavy metal balances and soil quality. Since the models partly share the same input data, this alleviates the burden of data collection. SALCA takes specific characteristics of agriculture into account, which allows a detailed comparison of different production methods or systems.

3. RESULTS AND DISCUSSION

The same model system can be used at different levels to answer various questions: crops and their products (e.g. comparing crop management at different intensity levels), cropping systems (e.g. evaluating different weed management strategies), animal husbandry and animal products (e.g. comparing several dairy production systems), food and feed products (e.g. comparing domestic production to imports), farms and product groups, agrifood sector and food systems (e.g. evaluating different extensification strategies). The SALCA methodology has also been a backbone of the LCI databases ecoinvent, AGRIBALYSE and the World Food LCA database.

The strengths of SALCA lie in its comprehensiveness, specificity to agriculture, harmonisation, broad applicability, consistency, comparability, flexibility and modularity. Using a standardised tool offers opportunities for testing and ensures the comparability of the results across studies. The extensive data demand and the high complexity, however, limit the application of SALCA to experts. The geographical scope is limited to Central and Western Europe, with a special focus on Switzerland. However, due to the modular and flexible design, an adaptation to other contexts is feasible with reasonable effort.

4. CONCLUSIONS

SALCA enables answering a wide range of research questions related to environmental assessment and is applicable in different contexts. A further development would be the inclusion of the social and economic dimensions to perform a full sustainability analysis in the SALCAsustain framework.

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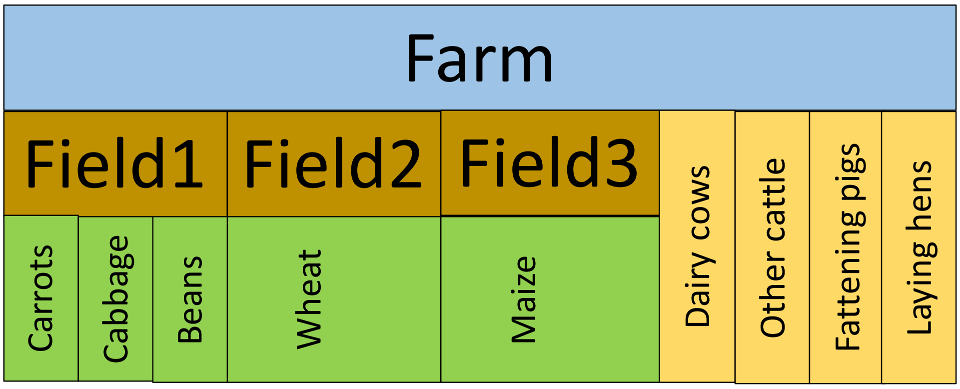

Figure 1. Schematic representation of the four levels of organisation of SALCA (illustrative example). Green = crops; yellow = animal group.

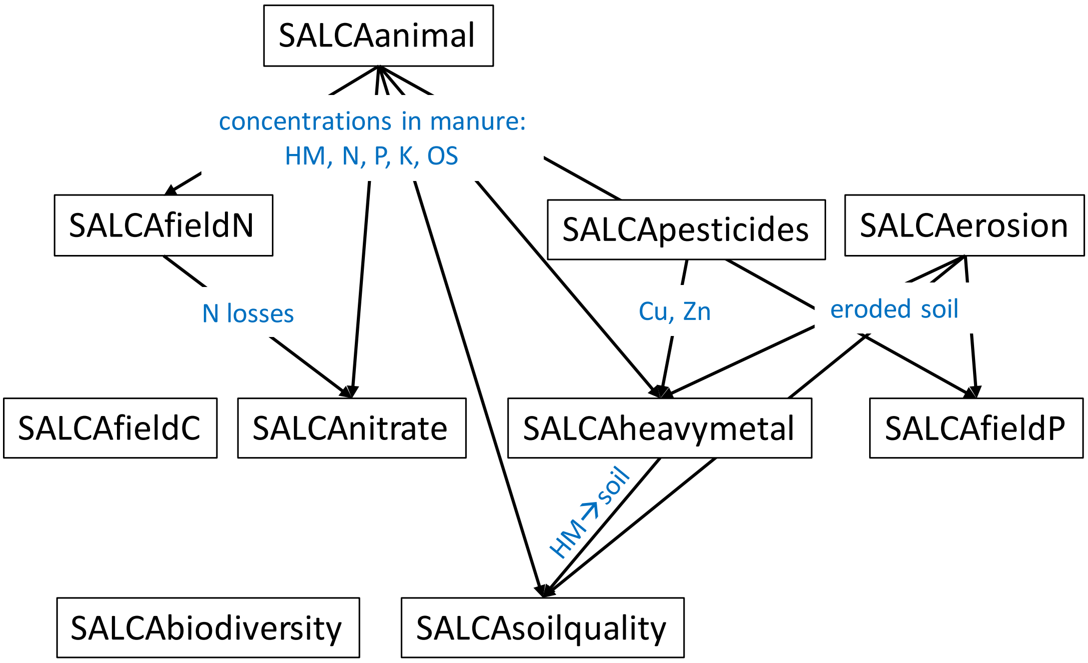

Figure 2. Data flow among the SALCA models. HM = heavy metals, OS = organic substance.

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Revealing persistent trends in LCA: a study of vineyard supply chain dynamics

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1. INTRODUCTION

LCA is recognized as one of the most widely used tools for environmental impact assessment of products, especially those in the agri-food sector. The utilization of simplified LCA approaches is highly valued, especially within corporate and enterprise contexts. (Arzoumanidis, 2017). The foundation behind this procedure is optimizing both the big data-demand and time-consuming processes while maintaining methodological rigor and the results' reliability.

The aim of this work is to set up a procedure for simplified LCA for the wine supply chain. It is based on an iterative algorithm for question selection, i.e. focused on identification of an optimal subset of inventoried inputs (i.e. hotspots). The algorithm built on relevance criteria offers flexibility to select the desired percentage of retained information during optimization.

2. METHODS

The algorithm is implemented on a robust and representative dataset of Italian wines. These differ for i) type (red, white and sparkling), ii) farm size (small, medium and large), and iii) cultivation practice (conventional, organic, …). Full LCA analyses were initially conducted for each wine using mainly primary data directly provided by the farmers. All the analyses are realized with the same approach: functional unit (i.e. 1 wine bottle of 0.75 L), system boundaries (from cradle to farm gate, including bottling), assumptions, software (SimaPro), database (Ecoinvent) and impact category (CML-IA baseline). Therefore, all wine environmental profiles elaborated are perfectly comparable. Five major impact categories were included: climate change, acidification, ozone depletion, eutrophication, and water use.

3. RESULTS AND DISCUSSION

The full LCA results have been organized in two kinds of matrices: i) “product vs. impacts” specific for each wine that describe the entire impact assessment, and ii) “impact vs. products” specific for each impact category that describe the differences among wines for a single impact category. The iterative algorithm, implemented through the double kind matrixes of just eight wines, identified a subset of five major hotspots (chemicals and fertilizers, diesel, energy consumption, glass, and cardboard), documenting a very representative portion of the total impacts of wine chain supply. As first round, the percentage of retained information was set at 90%. Once set, the algorithm was then tested on a wider sample (around thirty wines) by reassessing the impacts of the entire wine sample. Results from the "climate change vs. wines" matrix, when questions were reduced according to the algorithm, revealed a deviation of approximately 10% compared to the true values obtained with the full LCA calculation. The most significant deviation was observed for "sparkling wine".

4. CONCLUSIONS

The preliminary results of the simplified experimental LCA approach focused on the wine industry are quite comforting and push us to deepen the topic, both using a statistically even more significant sample and adapting it to other agricultural production chains. The main advantage of using a simplified approach like the one proposed lies above all in giving the enterprises an easy to use, flexible and smart tool so that they can monitor the improvements made in the company and translate them into avoided impacts.

5. ACKNOWLEDGEMENTS

This study was carried out within the Agritech National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1032 17/06/2022, CN00000022). This manuscript reflects only the authors’ views and opinions, neither the European Union nor the European Commission can be considered responsible for them.

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Climate impact dataset to promote sustainability of food service operators in Finland – learnings from dataset creation

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1. INTRODUCTION

The food service and restaurant industry play a pivotal role in promoting sustainable food consumption through offering sustainable meal options and shaping consumers' preferences. This study aims to contribute to these efforts by generating generic, ingredient-level carbon footprint data tailored to the needs of the food service sector, supporting the industry's long-term carbon neutrality objectives. Furthermore, our project aims to facilitate the integration of this carbon footprint data into production control systems used by restaurants, while making it compatible with the Finnish food composition database Fineli[1], which improves the usability of the data and thus supports food service operators in making sustainable choices in their day-to-day operations.

2. METHODS

The creation of the dataset included five main steps: i) reviewing the existing LCA data on domestic food production, ii) assessing the production of products with no available data and updating the assessments of major food crops, iii) identifying relevant data for the production of imported products from LCA-databases, iv) modelling the processing of agricultural products into ingredients based on the Agribalyse database[2] by altering raw materials and other inputs in the database, and v) deriving the final climate impacts for ingredients by calculating the weighted averages based on the degree of domestic origin. A general overview of the creation of the dataset is also presented in Figure 1. To evaluate the accuracy of processing information in the Agribalyse database in a Finnish context, we compared the results with the ones existing in previous research for processed food products.

The first version of the dataset was then refined in an iterative process, where the dataset was tested by food services and data gaps on ingredients identified by the users were then filled.

3. RESULTS AND DISCUSSION

The final dataset covers around 500 most important ingredients used in food services, covering the impacts of the entire production chain of ingredients from primary production to the point of service. The altering of existing database processes with information on Finnish agricultural production and other inputs (e.g., emissions of energy consumed in Finland) proved to be a feasible method for creating the post-farm life cycle for a large set of food products. The benefit of such approach is that it enables turning a relatively narrow set of agricultural products into several different processed food products. The lack of processing data often limits the assessment of food products, and thus impacts covering only the agricultural stage without the post-farm stages are sometimes used, for example in diet-level models. Tailoring the existing databases with context-specific information also holds the potential for more accurate modelling, than directly using existing information from databases.

4. CONCLUSIONS

Creating openly available datasets for food services and ensuring their compatibility with production control systems can support the development of more sustainable operations. This can also promote sustainable food consumption by facilitating more sustainable food selection in restaurants. Efficient utilization of existing databases can reduce the resource intensity in creating such datasets. Also, involving the end users in the development process can enhance the usability of the dataset while serving as an effective platform for dissemination.

5. ACKNOWLEDGEMENTS

The *Climate impact dataset for the food service sector* project has been funded by the Ministry of Agriculture and Forestry of Finland.

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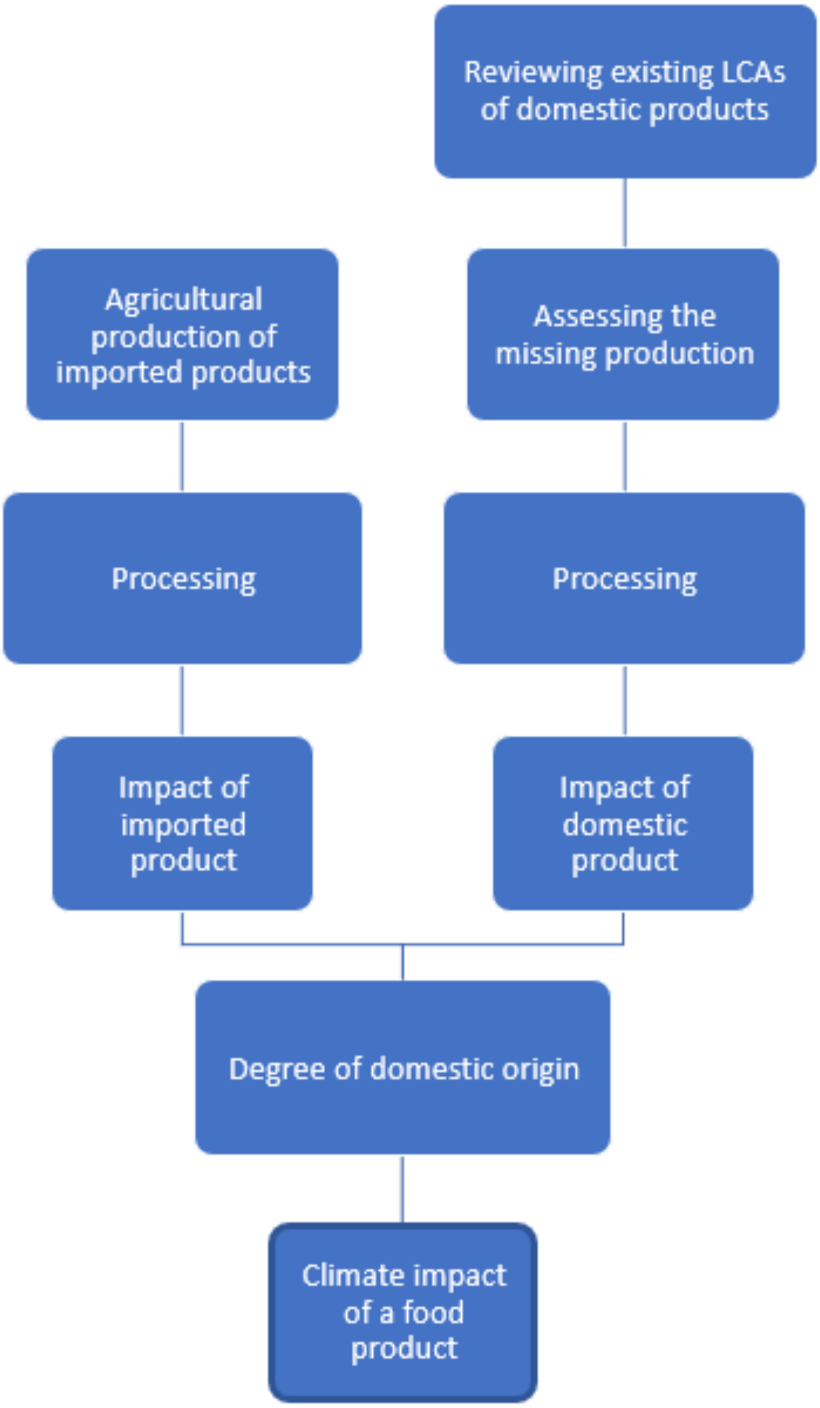

Figure 1. Overview on the structure of the dataset.

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Optimizing agroecosystem biodiversity: a review and framework for food system modelling

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1. INTRODUCTION

Food systems have been identified as the primary driver of biodiversity loss globally [1]. Food systems modelling (defined here as a model including two or more food systems aspects outlined by the FAO) is an important part of food policy cycle, able to make prediction and optimizations in a vastly complex context. Taking biodiversity loss into account in these models is however not a simple task and as a result, it is often neglected particularity in models that deal with dietary recommendations. For food systems models that do include biodiversity, many different indicators and approaches to capturing biodiversity loss are used. Life cycle analysis (LCA) and life cycle impact assessment (LCIA) are the most common methods of assessing biodiversity loss for more diet-oriented outputs [2]. Previous research has shown many benefits but also weaknesses in current methodology, particularly in including multiple dimensions of biodiversity, incomplete drivers of biodiversity loss and issues with spatial coverage [3]. Ecological models such as land use models have similar weaknesses with a major difference being spatial coverage. Land use models tend to focus on spatially explicit characteristics [4], species measures on certain regions, connectivity and habitat suitability, or hotspots. These two major approaches to food system modelling each have their own strengths and pitfalls. No research to date, has assessed the extent of biodiversity coverage of food systems more generally merging together the analysis of models addressing different aspects of the food system such as land use and diet (LCA/LCIA driven). Furthermore, no comprehensive framework exists to guide best practices and assess weak spots of models fitting into this category. The proposed research will build on the work of developing biodiversity loss frameworks currently in the literature[5], tailoring the metric framework to food systems. This research focuses around three questions: 1. What is the current coverage of popular approaches to assessing biodiversity in food systems models? 2. What are important factors being considered/what additional factors should be considered? and 3. How do current approaches address these factors?

2. METHODS

The methodology consists of three parts. In the first part of this ongoing research, we conducted a systematic review to identify current methods of accounting for biodiversity loss in food systems modelling. Search terms along with inclusion/exclusion criteria can be found in table 1. The results from the literature review will be analysed to identify areas of biodiversity coverage of the metrics being employed. In the second part of this research, we will carry out an expert working group session where gaps and deficiencies will be identified, and areas of importance highlighted. This work will serve as the basis of a framework for assessing biodiversity coverage in food system models. In the third part of this paper, we will use the developed framework to assess models included in the literature review for biodiversity coverage.

3. RESULTS AND DISCUSSION

Preliminary literature review results can be found in table 2. The working group session is to be held at the end of March and therefore there are no results as of yet.

4. CONCLUSIONS

NA

5. ACKNOWLEDGEMENTS

We would like to thank the participants in our working group, thus far: Rob Alkemade, Liesje Mommer, Jeanne Nel, Marleen Riemens, Dirk cn Appeldoorn, Jorad de Vries, Raimon Ripoll, Mieke de Wit, Erik Poelman, Ciska Veen, Oscar Goyeneche, Ignas Heitkoning, Arnold van Villet, Patrick Jansen, Peter van de Sleen and Merel Hofmeijer.

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Table 1. Search engines query terms and inclusion/exclusion criteria used for literature review of food systems models that account for biodiversity.

Inclusion criteria	Exclusion criteria	Search engine	Query
(I1) quantify biodiversity loss/gain (I2) Biodiversity is assessed at one of the 3 scales of the CBD (genetic, species, landscape) (I3) Must include production and or consumption and if it does not include both production and consumption must include one of the 5 explicit food systems elements as defined by FAO (aggregation, processing, distribution, disposal) (I4) Reproducible, established models that can be used by different stakeholders openly (I5) English	(E1) Farm level (E2) Non-peer review (E3) land type (arable, grassland, natural) as a proxy for ecosystem level biodiversity assessment	Web of science	TS=("food" AND "system*" AND "biodiversity" AND "model*" AND ("diet" OR "production" OR "consumption" OR "processing" OR "aggregation" OR "distribution" OR "waste") AND ("land*" OR "region*" OR "global" OR "chain"))
		Scopus	TITLE-ABS-KEY("food" AND "system*" AND "biodiversity" AND "model*" AND ("diet" OR "production" OR "consumption" OR "processing" OR "aggregation" OR "distribution" OR "waste") AND ("land*" OR "region*" OR "global" OR "chain"))

Table 2. Preliminary results of assortment of collected models for literature review of food system models that account for biodiversity. Displayed are extracted data from 8 models found in literature search.

Existing models	Scale	MEASURE	VARIABLE IN THE MODEL (Input)	Indicator
GLOBIO	Landscape - grid based	Terrestrial biodiversity intactness	Land use intensity	MSA
MaxEnt	Landscape - grid based	Species distributions probability	Environmental conditions of the grid	Richness/distribution and potential niches
BIOMOD	Landscape - R package	Species distribution	Variables - depends on package use	Species distribution range
ReCiPe	Country, global	Community composition	Land use and land use change, climate change, environmental pollution, water use	PDF/ year
LC-impact	Country, ecoregion, global	Community composition	Land use and land use change, climate change, environmental pollution, water use	PDF/year
Impact wordl+	Country, ecoregion global	Community composition	Land use and land use change, climate change, environmental pollution, water use	PDF/year
Stepwise	Global	Community composition	Land use and land use change, climate change, environmental pollution	BAHY
Ecoscarcity	Country, global	Community composition	Land use and land use change, land use intensity, climate change, environmental pollution	Eco-points (UBP)

Ecolabelling

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Reliable and meaningful environmental footprint communication to consumers – harmonization in Finland

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1. INTRODUCTION

Current communication on the environmental impacts of products is not helping consumers to make sustainable choices. Several studies show that around half of environmental claims are either misleading, unclear, vague, or unsubstantiated (Heinonen&Nissinen, 2022, European Commission 2021). This happens, even though in Europe there is already regulation in place for green claims. The Environmental Footprint Initiative (European Commission, 2024) has provided an assessment methodology for footprints, which hopefully will harmonize the assessment of environmental footprints in the future, and thus, provide a reliable background for communication. However, the Environmental Footprint Initiative has not yet any communication guidance. Thus, the need to improve and harmonize current communication on environmental footprints is urgent, as their communication is likely increasing, but general guidance on green claims do not cover them sufficiently.

2. METHODS

To draft the communication guideline, we reviewed the UCPD (2019/2161) = Unfair Commercial Practices Directive and its coming update, EU's Green claims directive proposal, ISO 14000 –standard series, scientific evidence, EC's Product Environmental Footprint (PEF) –initiative, and communication guideline of Voluntary Carmon Markets Initiative (VCMI). The guidelines have been discussed with the Finnish food industry and its stakeholders, holding one dedicated workshop for especially marketing and communication specialists and one more general to sustainability and LCA specialists.

3. RESULTS AND DISCUSSION

The guideline on footprint communication is divided into three sections: the actual footprint claim, mandatory additional information, and a report (See details in Figure 1.). The target is to engage the food sector so that in the future we will see more harmonized communication on environmental footprints which would be also more understandable for consumers. While developing the guidance with the food industry, it became clear that some companies are more willing to harmonize and move together than others, and some would like to have stricter rules while others more freedom to adjust communication to their brands. Nonetheless, they believe that the developed guideline is useful and will likely harmonize communication in Finland.

Currently, communication regarding environmental footprints is very focused on the carbon footprint. In the future, the pressure is growing to assess quantitatively also other environmental footprints, or even to communicate environmental impacts in relation to nutritional values of food products. There is an urgent need for consumer research to keep up with the developments of LCA methodology and study what information consumers need to make sustainable choices, and whether communication is an effective way to reduce the environmental impacts.

4. CONCLUSIONS

There are several guidelines on communication of green claims, but they are not found at all or not found adequate by the food industry. We hope that pulling together one document for best practice above the requirements of law and discussing the guidance with the food industry will attract the communication and sustainability specialists in the food sector to develop more meaningful communication on environmental footprints.

5. ACKNOWLEDGEMENTS

The project is funded by the Ministry of Agriculture and Forestry Finland, together with food industry and its stakeholders: Hankkija, Raisio, Oatly, Satarehu, Potwell, HKScan, Saarioinen, Atria. Meira, Olvi, Valio, Apetit, Fazer, Juustoportti, Paulig, Nestle Finland, Lantmännen Agro, Leijona Catering, S-group, SOK, Kesko, Heinon Tukku, Ruohonjuuri, Arla Finland, Yara Finland, Finnish Glasshouse Growers' Association, Finnish Food and Drink Industry, Finnish Grocery Trade Association, Finnish Hospitality Association, Union of Agricultural Producers and Forest Owners, Gaia Consulting, Biocode, Envitecpolis.

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Absolute **quantified value of the footprint** (not e.g. only as percentages or described graphically or by words)
The **unit of the footprint** (e.g. *CO_2-eqvivalent tai CO_2 eq.*)
The **functional or declared unit** (100 g or 100 ml)
Source: recommendations of the research group

Clear definition regarding the **environmental impact categories the claim covers.**
The main **system boundaries** of the assessment.
Source: EU Directive proposal EU COM/2023/166

Clarifying text, which includes concisely the most important additional information related to the claim **to make the claim understandable** or clear reference to such information (e.g. a link to website or and QR-code to such).
Source: ISO 14026:2018

Mandatory additional information, which includes e.g.
- Life Cycle Stages
- Used methodology and data
- Used LCA standard and guidance
- If consumption phase is major source of environmental impacts, a description how to consume the product with least environmental impacts

Source: EU Directive Proposal COM/2023/166

Imaginary example of recommended footprint claim and clarifying text:

Carbon footprint: 100 g CO_2-equivalents/100 grams ready-to-eat product
Eutrophying emissions: 100 g P-equivalents/100 g ready-to-eat product

The assessment covers the whole life cycle of the product, and it has been assessed with LCA aligned with the PEF (2021) guidance. Further information: www.productexample.fi/environmentalfootprint
**If the methodology and data requirements are aligned with PEF or Finnish national guidelines for food products, reference to the method is enough. Otherwise, short description of them shall be included.*

LCA report

Figure 1. Examples of the requirements for the footprint claim, and an example

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The status of ecolabels considering climate change for food products in Europe

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1. INTRODUCTION

Food systems contribute approximately 30% of the global anthropogenic GHG emissions (Poore and Nemecek, 2018; Rosenzweig et al., 2020; Vermeulen et al., 2012). Ecolabels which consider climate change from a life cycle perspective (hereafter ecolabels) provide transparent environmental information that can affect consumers' behavioural by encouraging them to buy more environmentally friendly products (Dietz et al., 2009), which in turn can incentivize producers to have more environmentally friendly practices. Currently, life cycle assessment has been applied to ecolabels (Dorea et al., 2022; Minkov et al., 2015), but using various label formats and environmental footprint assessment methods. Therefore, it is essential to compare the current ecolabels' format and LCA methodologies used to calculate the carbon footprint of food products.

2. METHODS

We selected the European Union member countries together with the UK, Switzerland, and Norway (EU27+3) as our study area. The currently available ecolabels were collected and screened through various approaches, including searching from literature, online searching engines, contact networks, etc. The information and data on ecolabels were collected through a semi-structured questionnaire through Google Forms [1], methodology documents and labels' websites.

3. RESULTS AND DISCUSSION

In Europe, the development of climate and environmental labels has primarily taken place in the Western European countries. Most of the ecolabels found were from Western European (20 out of 30 identified ecolabels). The European Commission (EC) recommended the Product Environmental Footprint (PEF) as a guideline for LCA to build a single green market (EC, 2021). However, multiple ecolabel formats are seen across the presented European labelling initiatives. In terms of the LCA methodologies, various aims, functional units, impact categories, system boundaries, and products are considered, and initiatives refer to various standards and guidelines.

4. CONCLUSIONS

There are plenty of ecolabels which considering climate change for food products from a life cycle perspective in European countries, especially in Western Europe. However, no consensus exists on the label format and methodologies. This study can help promote methodological harmonization and share frontier and empirical knowledge with the stakeholders of eco-labelling.

5. ACKNOWLEDGEMENTS

This research was funded by the Ministry of Food, Agriculture & Fisheries of Denmark, Climate and Environmental Label of Foods (41932 LBST NIFA MATK).

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Identification of most important environmental impacts of food

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1. INTRODUCTION

Despite the significant environmental impacts of food production (e.g. Willett et al., 2019), for consumers it is difficult to know about those impacts when purchasing food. Meanwhile, consumer research shows that information has to be provided in an easily understandable way. Consequently, a balance needs to be struck so that consumers are provided with sufficient information on food's environmental performance without being overwhelmed by the amount or presentation of such information. Against this background, the aim of this paper is to identify the most important environmental impacts of food.

2. METHODS

This was done by using a Delphi approach, a common method to find consensus among different stakeholders (Dalkey & Helmer, 1963; Hsu & Sandford, 2007). The study was conducted in three steps (Figure 1), starting with workshops in the four countries involved in the 'CLIF'[1] project and a workshop with international LCA experts. The second and third steps were two online surveys in which stakeholders from several countries, including the four CLIF countries, participated. In the survey, participants rated the various environmental impacts on a scale of 0-100.

3. RESULTS AND DISCUSSION

Across all participants with a global perspective, the most important environmental impact of food identified was climate change (91.3), directly followed by terrestrial biodiversity (90.0) and soil health (82.5). Water scarcity (55.4), novel entities (54.8), and marine biodiversity (51.7) followed on ranks 4 to 6. The ranking of most important environmental impact of food differed among the four analysed countries and the global stakeholders. On average and for three of the five groups surveyed, climate change, terrestrial biodiversity and soil health are the three most relevant environmental impacts of food. However, there is a significant difference to the stakeholder ranking in Paraguay, where climate change is in sixth place out of nine environmental impacts (Table 1).

[1] The publicly funded project "Climate Impacts of Food" (CLIF) belongs to the *International Climate Initiative* (IKI), which forms a part of the German government's international climate finance commitment. More Information is available via the official website at https://www.international-climate-initiative.com/en/. The involved countries are Germany,

4. CONCLUSIONS

In conclusion, it must be stated that the results are not representative, and thus should be interpreted carefully. Nevertheless, they provide an indication of the significance of the respective environmental impacts and the results can also be used as a basis for weighting environmental impacts.

5. ACKNOWLEDGEMENTS

We would like to thank the Federal Ministry for the Environment and Consumer Protection for funding the project 'CLIF – Climate Impacts of Food' as part of the International Climate Initiative (IKI).

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Category	Thailand (N=9)	South Africa (N=4)	Paraguay (N=5)	Germany (N=7)	Global (N=26)
Climate change	92,2	85,0	63,7	90,0	91,3
Terrestrial biodiversity	88,1	83,1	69,9	83,4	90,0
Soil health	85,5	89,0	84,5	81,8	82,5
Novel entities	83,9	88,6	51,5	81,4	54,8
Water scarcity	60,4	86,1	72,0	57,6	55,4
Marine biodiversity	81,4	62,2	71,7	47,1	51,7
Eutrophication	53,6	64,8	68,6	66,7	49,2
Atmospheric aerosol loading	80,3	65,2	63,0	44,8	46,9
Ocean acidification	50,9	53,4	61,0	43,9	46,4

Table 1. Results of the first Delphi survey on most important environmental impacts of food (N: number of participants from the second online survey)

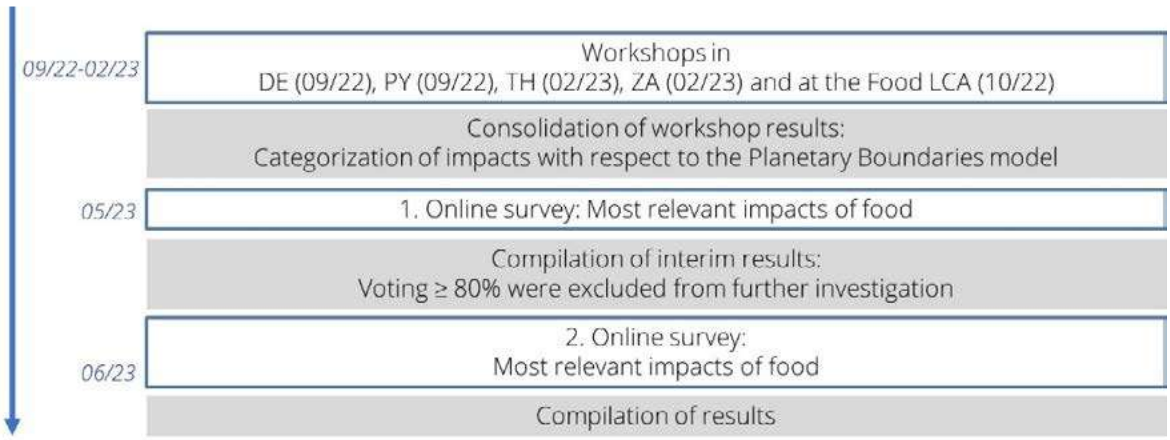

Figure 1. Process of the Delphi study

Communication of LCA results

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LCA FOOD 2024

HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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The carbon footprint of Irish seafood

Benen Dallaghan. bord iascaigh mhara

A practitioner's role against eco-amplification- a case study with California cotton

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1. INTRODUCTION

When it comes to regenerative agricultural production, a practitioner has to face challenges associated with limited prescription on how to model, the necessity of value based choices and the inability to capture the environmental benefits of nuanced practices using the state-of-the-art methodology. Complexities are heightened when extrapolating beyond the pilot farm to derive conclusions on a region-level, reporting on carbon sequestration and supporting downstream companies aiming to substantiate comparative assertions across different agricultural systems through LCA results. In a Californian cotton case study, the environmental impacts under regenerative, conventional, and organic farming are compared. The cotton produced regeneratively presents a net-negative footprint, while the net carbon footprint is the highest for the organic field, followed by the conventional field. The main differentiator across the results is the soil organic carbon (SOC) stock in the regenerative field, without which the conventional and regenerative fields would achieve similar footprints. While promising for supporting the wider adoption of sustainable practices by farmers, accounting for SOC changes is complex, and subject to rapid losses due to land management or extreme weather events. Therefore, the imminent possibility of the negative footprint becoming null is a significant risk and the communication of results externally comes with great responsibility. This research explores the role of LCA practitioners in a post-study communication strategy that can foster the transparent and accurate communication of results externally.

2. METHODS

In this case, we took on the challenge not only to transparently report on results but also to:

(a) actively provide guidance on preparing concluding statements for external use by downstream companies
(b) capture the additional environmental benefits (i.e., increased climate resilience, ecosystem quality, aggregate stability etc.) of regenerative agricultural practices that can go unnoticed in traditional LCAs
(c) encourage beneficial partnerships between farmers and corporations to support sustainable agriculture.
Towards that purpose, and given the flexibility of the content in ISO reporting, we incorporated a “science communication” package as part of the final deliverable (Table 1).

3. RESULTS AND DISCUSSION

The incorporation of the "science communication" package elicited positive feedback from our client, who appreciated the inclusion of all relevant considerations in the analysis. Based on our experience in the context of this case study, we foresee that this approach will encourage open discussions and assist in setting expectations for comparative claims post-LCA, emphasizing multilayered rather than rigid conclusions. In addition, we aspire for it to contribute to the minimization of post-processing efforts required for the extrapolation of definitive statements from non-LCA experts within corporations.

4. CONCLUSIONS

Ultimately, as LCA practitioners, our influence on how the results are communicated externally is limited. However, the opportunity to advise and guide our clients towards sharing conclusions that are well-supported, transparent and uphold integrity should not go unexploited. Embracing the risk of transitioning from conventional consulting, which is primarily based on fact-based quantitative assessments, to a holistic approach that captures non-traditional LCA insights is warranted, especially in the light of the ongoing climate emergency. Our responsibility transcends beyond the LCA community, and commands that science is simply explained and communicated broadly. Therefore, we see incorporating "science communication" packages in traditional reporting as the first step towards that direction.

5. ACKNOWLEDGEMENTS

Thanks to Rebecca Burgess from Fibershed.

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Table 1. Overview of additional report sections comprising the "science communication" package

Name of section	Content	Purpose
Interpretation	Graphs and visuals	Showcase SOC as a determining factor for carbon footprint (results incl. and excl. SOC)
Additional environmental information	Aggregate stability (i.e., climate resilience, enhanced water management, optimised nutrient retention, improved soil structure), Soil health (i.e., microbial activity, soil fertility) Water consumption	Offer a holistic picture of the environmental footprint by qualitatively or quantitively discussing a range of ecosystem services
Environmental benefits beyond the scope of LCA	Conclusions on ecosystem services on regenerative fields, showcasing contribution to the resilience of ecosystems	Viewpoint on sustainability beyond traditional LCA and external communication
Influence of limitations on drawing conclusions	List of core limitations and their influence on conclusions	Transparency and deeper understanding
Recommendations for downstream companies	Barriers that can be surpassed with financial support, technical expertise and valuable resources. Importance of monitoring schemes for claiming and maintaining removals.	Incentive to transition from simply claiming removals to long-term partnerships between downstream companies and farmers.
Concluding statement	Final conclusion of the study	External communication

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Calculating pre-crop effects from legume production in Norway by using system expansion

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1. INTRODUCTION

Growing of legumes require the use of crop rotations, which has shown to have the beneficial effect of increased yields compared to cereal monocultures which are still common in Norway (REF). The yield increase is caused by several factors, including reduced pest pressure because cycles of pests are broken but also the pre-crop effect of the legume crop. Pre-crop effects from legume production is normally included in LCAs of the crop receiving the benefit, but not the one that caused it. One reason for this is that the spatial system boundary of the production is commonly one year or one growing season. Hence, possible positive effects are “credited” to the following crop production whereas the actual reason for the increased yield lies in the legume production the year before. The aim of this study was to calculate the environmental impact of legume production (faba bean) in Norway including pre-crop effects using system expansion with substitution and the ICBM method. and the ICBM method.

METHODS

The functional unit was one kg of faba beans harvested and dried to 15 % moisture level. The temporal scope was two growing seasons, the faba beans season and the subsequent cereal season. To calculate the impacts of faba beans separately, system expansion with substitution was used, using average Norwegian spring wheat production to calculate avoided impact. The avoided impact was calculated in two ways, firstly by assuming Norwegian average production, secondly by comparison between neighbouring fields. In each pair, the same crop grown in the same local area with monoculture and crop rotation were compared. IPCC method Tier 1 was used for the calculation of N2O emissions. Impacts on soil carbon was calculated using the ICBM method.

2. RESULTS AND DISCUSSION

The precrop effect was very similar when using national average (15,0 % increased yield the next crop) and comparison between neighbouring farms (14 %). The results of the LCA show that the GWP of faba beans was 0,185 kg CO2-eq/kg faba bean. This is a significantly (70 %) lower impact than the number found in a previous study (Svanes et al. (2022), 0,62 kg CO2-eq/kg dried bean) using the same background data. The main reasons for the lower result were that SOC loss was much lower (0,195 kg CO2-eq/kg less) than in the previous study, and substitution gave a reduction of 0,14 kg CO2-eq/kg. The impact on other categories was also reduced, e.g. eutrophication by 13 %, acidification by 81 % and energy use (as CED) by 18 %. The climate impact is close to that found (0,16 kg CO2-eq/kg dried beans) in a previous Swedish study (Tidåker et al. (2021)) but much lower than what has been found in other studies.

3. CONCLUSIONS

Using attributional LCA, combined with system expansion with substitution, and the ICBM method for calculating the global warming impact of soil organic carbon change, the GHG emissions was shown to be 70 % lower than a previous study using the same background data. The calculation of precrop effects was made possible by using system expansion and substitution, a method normally associated with consequential LCA.

4. ACKNOWLEDGEMENTS

The research was made possible by the funding of the GreenPlantFood project.

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Navigating the Path of Climate Transparency: Oatly's Product Climate Footprint Declarations

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1. INTRODUCTION

The food sector, accounting for approximately one-third of total greenhouse gas emissions (Crippa et al., 2021), also faces adverse effects of them (Mirzabaev et al., 2023). Acting to reduce emissions in this sector is of utmost importance. Oatly believes that similar to nutritional information, consumers have the right to know the climate impact of their food in order to make more environmentally sustainable decisions (Oatly, n.d). Its commitment to promoting climate transparency in the food sector is exemplified through its five-year journey of declaring product climate footprints. This paper will analyze how Oatly has managed to make climate declarations for most of its products and describe lessons learned.

2. METHODS

This article will outline the insights gained from Oatly's journey in climate change declarations, focusing on lessons learned. The analysis will include, among other aspects, data management, legal considerations, and communication strategies.

3. RESULTS AND DISCUSSION

As of the end of 2023, 98% of Oatly's sales volume in EMEA and 88% in North America featured climate declarations. Below are some of the lessons learned during this journey.

Need for standardization: Early in the process, the absence of food-specific climate footprint standards was a burden. Even though Oatly follows well-known guidelines such as ISO 14067, these guidelines do not always address the specifics of the food sector. Oatly had to make methodological decisions by collaborating with experts in the food LCA sector to enable the climate impact of their products to be comparable and fair. Oatly also ensured adaptability to business changes by establishing a standardized calculation process and reproducibility of results and data documentation system.

Data Complexity: Another hurdle encountered was the high volume of internal data required for the calculations. To streamline this process, Oatly implemented automation through product lifecycle data management systems and integrated suppliers into the data collection process via contractual clauses in supplier agreements.

Communication of results: on-pack climate information played a significant role in the ability of consumers to make direct comparisons in the store without the need for additional tools, similar to nutrition or price labels. However, customers' understanding of these climate declarations and the lack of participation by other food companies represented major setbacks. Oatly overcame them with direct consumer communications and campaigns such as "Hey, Food Industry, Show Us Your Numbers", the “Dairy Climate Footprint Challenge”, bringing public attention to the need for climate declarations in the food industry, together with political participation including coalitions for a common methodology for climate labeling and advocacy for making climate labeling a law.

This journey of climate transparency has brought several benefits for Oatly. First and foremost, internal climate literacy has significantly increased, and stakeholders from teams such as logistics, production, innovation, and procurement, among others, actively engage with sustainability initiatives, fostering a sense of ownership towards the footprints, and a commitment to reducing Oatly's overall environmental impact. Additionally, the success of climate-footprint-focused campaigns, together with political engagement has positioned Oatly as a sustainability leader in this space.

4. CONCLUSIONS

Climate labeling is still not the norm for most global food companies, hindering consumers' ability to compare and make more environmentally sustainable decisions. Oatly's ongoing commitment to climate transparency demonstrates that, despite challenges, the calculation and publication of climate footprints of products not only empowers consumers to make more informed decisions regarding their climate impact, but also serve as a valuable tool for internal decision-making, supply chain optimization, stakeholder engagement, and establishes a model for climate leadership, reinforcing transparency and trust within the industry.

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Advancing and Automating LCA for Sustainable Agrifood Production with Opteinics™

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1. INTRODUCTION

The increasing demand for food which comes from global population growth is causing environmental degradation[1]. In order to steer food production towards environmental sustainability, food companies need transparency about their products' environmental impacts. To create this transparency, the framework Life Cycle Assessment (LCA) is used. Opteinics™ is a Software-as-a-Service (SaaS) platform that provides LCAs for the animal protein producing sector[2]. The use of Opteinics™ and other LCA software is currently limited to experts in the field and is not yet widely adopted by non-experts and Small and Medium Companies (SMEs) in the agrifood industry. This article explores the needs and pain points to improve the adoption of LCA software.

2. METHODS

Based on customer feedback and interviews with 30 companies in the food value chain, we identified the main pain points of the non-expert community and SMEs that prevent the adoption of LCA software.

3. RESULTS AND DISCUSSION

We identified the following pain points:

1. Management of confidential data used in LCAs is very sensitive to the industry and companies do not want to share the data with external consultants.
2. Complexity and difficulty in conducting LCAs for businesses in the food market, taking between 4-6 months with an external company if they want to do an LCA.
3. The need for businesses to stay ahead in environmental sustainability initiatives.
4. Lack of access to advanced, credible, and affordable LCA tools in the industry.
5. Challenges in navigating and deriving meaningful insights from LCAs.
6. Limited accessibility of LCA processes for businesses in the food market.

As a result of these findings, Opteinics™ aims at addressing all these pain points by:

1. Creating a SaaS solution that can be used in-house.
2. Eliminating the complexity of LCA, providing businesses with a streamlined approach with product LCA templates (e.g. chicken meat, pork meat, milk, etc.).
3. Future-proofing sustainability initiatives by evolving alongside industry standards.
4. Using a scientific approach and a certified methodology, while making it affordable.
5. Delivering a user-friendly experience.
6. Simplifying the process making it accessible to all businesses.

4. CONCLUSIONS

Opteinics™ simplifies the LCA process, ensuring that non-experts and SMEs in the food industry can measure and reduce the environmental impact of their products. The innovation of Opteinics™ lies in the automation, harmonization, and integration of scientific standards[3-11]. It calculates the environmental impact using 16 indicators from the Product Environmental Footprint (PEF[12]), helping businesses make informed decisions for sustainability in the agrifood system. Opteinics™ has successfully helped customers take steps towards sustainability. Science-based environmental footprinting is an ever-evolving field, and staying up to date with the latest research and methods is crucial to ensure accurate results.

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Towards more harmonized PEF wise food LCAs in Finnish context

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1. INTRODUCTION, BACKGROUND AND MOTIVATION

It is practically impossible to compare reliably the carbon and other footprints of food products in the public domain and discussion, since there are numerous ways, approaches, methods and practices for assessing carbon footprints of food products (eg. Pedersen et al. 2021, Joensuu et al. 2021; Katajajuurí et al. 2012). Numerous individual choices take different aspects into account and thus affect the LCA results many ways, even strongly. Therefore, the results of two different food LCAs from different sources are not directly comparable as such.

The food producers and companies, and their value chains, are still, served by all kind of LCAs. They enable companies to make better informed decisions eg. on the direction and success of emission reductions. Still these carbon and environmental footprints by companies are not comparable to the assessment by other companies or countries.

PEF development is a good and broad attempt to harmonise LCAs (European Commission 2017, 2021, PEFCRs 2018). However, there are still some challenges, whether the different food product categories are assessed in similar principles, eg. regarding allocations and how to include LULUC emissions in uniform way to all food product LCAs. Since European PEF process has been relatively slow, carbon and other environmental footprint assessments for foodstuffs need to be harmonised at national level faster, eg. Denmark has make their attempt already on that.

Different types of environmental footprint data are used as background information for both policy making and legislative work. Informed consumers compare products and make purchasing decisions based on carbon footprint labelling. Also companies might have environmental claims, where they might even compare values against global averages or even other products It is very clear, that first to a science based and harmonized approach for LCA is needed to have for these purposes.

2. CHALLENGES AND DISCUSSION

We are producing large and detailed PEF wise methodology for food products in Finnish markets. PEFCR documents and requirement for PEFCRs are the backbone of our work, in addition to past ISO (14040, 14044, 14067) and other key documents. The final PEFCR 'prototype' recommendation document in Finnish context paper will be published in the late 2024. To summarizing the work so far, Hietala et al. 2024 summarizes the key differences within 'current official' but expired actual food PEFCRs and some draft versions of PEFCRs and also with the overall PEFCR (2021). The PEF and PEFCR guidelines were observed in parallel and the comparability of the life cycle assessment results thus defined was also assessed between product groups. Due to the generic PEF guidelines, most PEFCR guidelines follow largely the same methods and requirements, but some critical differences also exist to challenge the actual comparability of food product LCA methodologies. In addition to the functional unit, the most significant differences were observed in allocation, system boundaries, especially in the definition of the use phase, and in the hierarchy levels of the modelling and regarding LULUC. Our comparison was challenged by the fact that PEFCRs vary in quality and documentation. This paper focus on those specific issues we have seen unsimilarities between current not-officially-existing PEFCRs and/or challenging issues in the current PEFCR guideline. The first obvious challenge is that all previous PEFCRs have expired. Partly the material from those has been integrated in the new version of PEF (2021, Commission).

LULUC emissions and especially soil carbon stock changes have been taken into account in only a few PEFCR guidelines, which is one of the most crucial 'newer' challenges in food LCAs. Mostly soil carbon changes have been discarded in previous individual food LCAs, or carried out with large methodological variation (e.g. Joensuu et al. 2021, Hietala et al. 2024). It should be noted that according to the general guidelines of PAS2050: 2011, changes in soil carbon stocks should not be taken into account when they are not due to direct land use changes (BSI 2011). As a result, for example, the effects of cultivation measures on carbon stocks should be disregarded according to the PAS2050 guideline, they could be only reported as a additional information, not under actual global warming category.

PEF is ambitious, as it should be, in many ways, such as number of relevant impact categories, on data quality requirements and reporting requirements. In the end from practical point of view, some of these requirements are even too extensive, and we try to balance with these in the Finnish guideline, trying to be as PEF wise as possible. Requirement to use NIR methods for GWP calculations is not directly harmonizing LCAs from different countries, which is over drawback as well.

Regarding individual impact categories, we will mainly focus on climate impact, eutrophication and water footprint with water scarcity. In addition, some national calculation rules will be developed for regionalized eutrophication impact category, but also having PEF wise eutrohication onboard as well.

3. CONCLUSIONS

Based on our analysis, it is clear that current PEFCRs does not aim to make LCAs of different food product categories comparable at all as stated in the PEF documentation as well, and from that reason it would be important to have one "food PEF" covering all the food products with uniform requirements. The more detailed and clear guidelines are needed and methodological issues should be treated in a similar manner between food product groups as well. As an example, we should have similar basic principles regarding all allocations, eg. in food industry, so when the emissions from supply chains are allocated to either whey, milk or cheese, or different parts of fish, they should be based on same main approaches, and we recommend here to use economic allocation in all cases.

How the LULUC emissions and removals should be included need to be much more clearly stated in forthcoming PEFRs, and this is one of issue what Finnis guidelines will cover in detail. We will furthermore include emissions also regarding land use whether the plants are cultivated in mineral or organic soils. In the end, there will be plenty of details to show later, and while we are doing some individual differences with respect to offial PEF (2021), we tend to be as PEF wise as possible. We also look for the possibilities to affect future versions of PEF, which in under preparation at the moment.

4. ACKNOWLEDGEMENTS

We would like to acknowledge all the financiers and collaboration partners of the Finnish FoodPrint project (2021-2024): Hankkija, Raisio ,Oatly, Satarehu, Potwell, HKScan, Saarioinen, Atria, Meira, Olvi, Valio, Apetit, Fazer, Juustoportti, Paulig, Nestle Finland, Lantmännen Agro, Leijona Catering, S-group/SOK, Kesko, Heinon Tukku, Ruohonjuuri, Arla Finland, Yara Finland, Finnish Glasshouse Growers' Association, Finnish Food and Drink Industry, Finnish Grocery Trade Association, Finnish Hospitality Association, Union of Agricultural Producers and Forest Owners, Gaia Consulting, Biocode, Envitecpolis. Finnish Environmental Institute, Lappeenranta University of Technology LUT, VTT Technical Research Centre of Finland, University of Helsinki, Ministry of Environment, WWF Finland and especially our main funder Ministry of Agriculture and Forestry.

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Ecolabelling of food products – exploring interactions between methodological challenges and stakeholder interests

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1. INTRODUCTION

The role of food production as an important driver of anthropogenic environmental impacts has been well established. Agricultural production alone is responsible for more than 40 % of global land use; furthermore, it is the principal driver of land system change, accounting for 80 % of deforestation. It is also responsible for around 70 % of global freshwater withdrawals. These and further impacts cause biodiversity loss at an alarming rate (Campbell et al., 2017). Despite their significance, information on these environmental burdens is seldom provided to consumers, especially at the product level. This is even though dietary choices play an important role in reducing impacts as environmental intensities of foods differ greatly. In recent years, there has thus been a surge of public and private initiatives aiming to establish ecolabelling schemes for food products. The current landscape is evolving fast.

Despite their different methodological approaches, one common denominator across initiatives is the central role that life cycle assessment (LCA) plays in determining products' environmental impacts. While the use of LCA for food labelling enables a robust quantitative assessment and comparison of products, it also entails a unique set of challenges. These challenges stem from different places; they include the method's (current) methodological limitations, necessary normative decisions that are fraught with conflict, the availability of data, as well as cost of implementation. This paper explores these challenges in detail and shows how they interact with the needs and expectations of different stakeholders. It illustrates both the scientific and the political dimension of design choices, seeking to provide a holistic overview of the landscape that a successful labelling scheme must navigate.

2. METHODS

The basis is an overview of the relevant features and limitations of LCA, e.g. methodological decisions that need to be made in connection with food labelling (e.g. regarding the functional unit, the data sources and quality requirements, the impact categories included, the weighting factors or the presentation of the results) as well as the approaches of prominent labelling initiatives. Furthermore, the stakeholders involved in the respective labelling schemes as well as their interests and needs are identified (cf. e.g. ISO 21502:2020). Stakeholders' preferences are then connected to the application of LCA, shedding a light on how they might influence labelling schemes. To do this, each stakeholder's (likely) position towards each methodological choice is described. This information is complemented with a rating of the stakeholders' influence on the respective choice. Lastly, findings are summarised to show to what extent individual design choices are driven by LCA's possibilities and limitations and to what extent they are driven by stakeholder preferences.

3. RESULTS AND DISCUSSION

The first results show that both LCA's characteristics and stakeholder preferences are important determinants of designs aspects. While some of these aspects are shaped by complex interactions between method characteristics and stakeholder interests (e.g. which impact categories and impact assessment methods to include, which functional unit to choose, scalability and reduction of costs), others are predominantly shaped by either the method's characteristics (e.g. requirements on data quality and consistency) or stakeholder interests (e.g. provisioning of data).

4. CONCLUSIONS

Establishing an effective, broadly applicable labelling scheme is a challenging task currently undertaken by a variety of actors. Lasting success depends on both the continued advancement of LCA methods, as well as efforts to increase stakeholder support, not least by reconciling stakeholders' conflicting interests. This paper aids in distinguishing between technical and political obstacles, providing a starting point for designing effective, context-aware measures towards successful ecolabelling of food products.

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LCA: value for businesses, beyond compliance

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1. INTRODUCTION

In today's rapidly evolving business landscape, Life Cycle Assessment (LCA) has emerged as an indispensable tool for companies aiming to understand and mitigate their environmental impacts. Beyond its essential role in regulatory compliance, LCA offers a wealth of strategic benefits. We will explore the diverse advantages of LCA, illustrating how it can be harnessed for strategic decision-making, fostering innovation, enhancing brand reputation, and driving competitive advantage. By showcasing these broader applications, we aim to highlight the critical importance of LCA in sustainable business practices and its transformative potential for future business strategies.

2. METHODS

We will present several case studies from our projects, analysing examples of businesses that have successfully utilized LCA beyond compliance. These practical insights will illustrate theoretical concepts in a more concrete manner, providing a deeper understanding of LCA's strategic benefits.

3. RESULTS AND DISCUSSION

3.1 Use case 1: Tactical One-Off Decision on Individual Materials

A chocolate manufacturer aimed to switch from plastic packaging to an eco-friendlier paper-based wrapping for its flagship product. A single LCA study was conducted with multifaceted objectives: (i) investigating the environmental impact of switching to paper-based wrapping, (ii) providing key input for a multi-million EUR CAPEX investment, and (iii) enhancing brand image through certifiable eco-claims. The study revealed a trade-off between fossil resource use and land use. Switching to paper packaging resulted in a 48% reduction in the use of fossil resources but caused a significant increase in land use by 1,569%. Despite this trade-off, the company decided to proceed with the switch to paper-based wrappers and made the necessary CAPEX investment. Concurrently, they began redesigning their primary and secondary packaging to focus on material reduction. (Supporting graphs on page 3)

3.2 Use case 2: Hotspot Analysis Throughout the Full Product Value Chain

A medium-sized furniture manufacturer was developing a comprehensive sustainability strategy. To identify hotspots throughout their value chain and set appropriate priorities, they performed an LCA for their best-selling product. The insights from the LCA shifted their focus from transport optimization, which accounted for roughly 2% of their total emissions, to researching alternative raw materials. These raw materials were responsible for over 70% of their impact across multiple dimensions, including Global Warming Potential (GWP), water use, and land use. (Supporting graphs on page 3)

3.3 Use case 3: Organizational, Multi-Product, Strategic Decision Making

A global player in the feed industry embarked on an ambitious project to build LCAs for their entire product portfolio. The initiative had multiple objectives: (i) establishing robust LCA capabilities internally, (ii) mitigating risks across the value chain, and (iii) leveraging generated data in sales discussions. By consolidating individual product LCAs into a comprehensive organizational LCA, they identified critical upstream risks such as resource depletion and price sensitivities. Additionally, the results were instrumental in downstream communications with clients regarding environmental impacts and avoided emissions. The LCA program also supported the roll-out of supplier engagement programs, focusing on improving primary data and ensuring business continuity in critical areas of the value chain. (Supporting graphs on page 3)

4. CONCLUSIONS

In conclusion, our exploration of real-life case studies demonstrates that the value of Life Cycle Assessment (LCA) extends far beyond compliance. Integrating LCA insights into strategic decision-making and daily business processes enhances environmental performance, drives innovation, improves business outcomes, and unlocks new opportunities. This underscores LCA's integral role in shaping sustainable business practices and strategies.

5. ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to all our colleagues at BrightWolves and Digit Mint for their invaluable work and expertise. We also thank our clients who have allowed us to share these insights with you at LCA Food 2024.

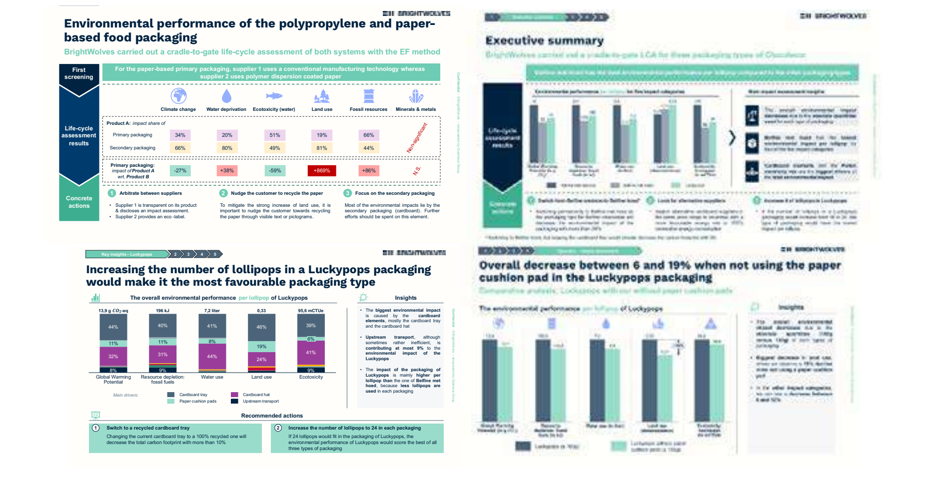
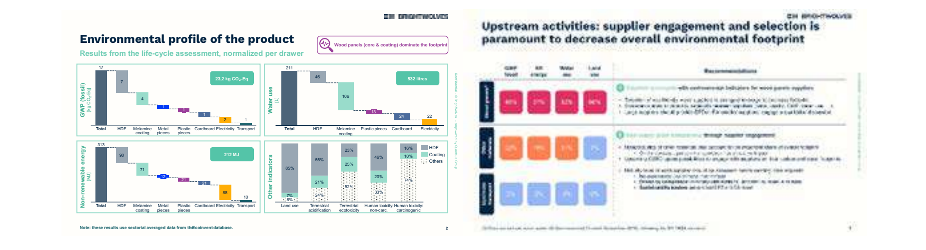
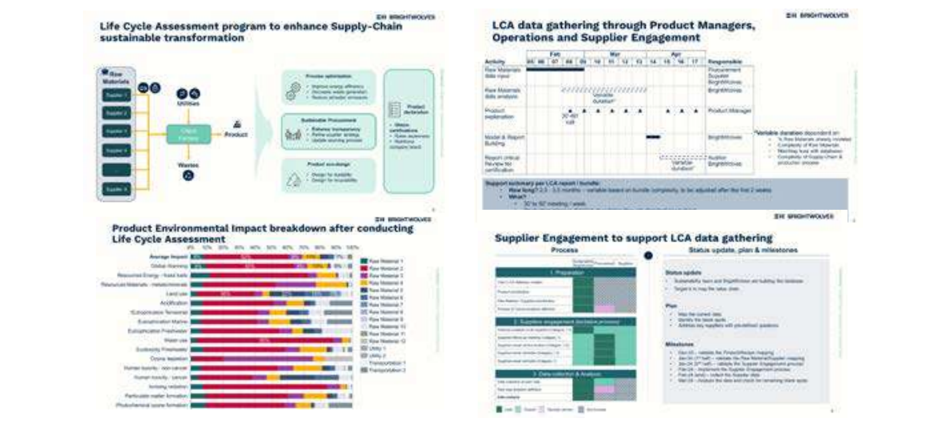
Use Case 1 supporting graphs	
Use Case 2 supporting graphs	
Use Case 3 supporting graphs	

Table 1. Description of table 1

Figure 1. Description of figure 1

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Defining benchmarks for the downstream supply chain stages for LCA-based voluntary sustainability standards: case study of the NZ avocado sector

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1. INTRODUCTION

Voluntary Sustainability Standards (VSS) are a widely acknowledged form of private sustainability governance (UNFSS Steering Committee, 2016). While some agri-food VSS use life cycle-based greenhouse gas (GHG) calculators for the farm stage, none incorporate quantified life cycle-based performance benchmarks across the whole value chain. Following on from a recent orchard-level study (Majumdar & McLaren, 2023), this work considers the packaging and distribution stages of the New Zealand (NZ) avocado sector and examines the potential for defining LCA-based post-harvest benchmarks – in the context of a potential VSS for an agri-food sector at the national level.

2. METHODS

A functional unit (FU) of 1 kg avocados was used for this study, and the system boundary was defined as ex-orchard gate to first point-of-sale in selected export and domestic markets. Input data for all relevant packhouse, transport, and coolstore stages were obtained from two packhouses in the Bay of Plenty, the largest avocado producing region of NZ. The majority of NZ-grown avocados are shipped to Australia, packed into single layer (cardboard) trays (SLTs) with additional cardboard pocket packs (PPs). Therefore, 'SLT' and 'shipping to Australia' were modelled as the baseline scenarios for packaging and distribution respectively. Alternative international distribution scenarios were modelled for shipping to South Korea, and air freighting to Australia and South Korea. In addition, scenarios were modelled for domestic transport to the North and South Islands of NZ; for domestic markets, the packaging is either bulk (i.e. loose-filled) cardboard boxes (BLF) without PPs, or multi-use plastic crates (PCs).

3. RESULTS AND DISCUSSION

The orchard stage impacts are higher than all three packaging alternatives and most distribution scenarios across all the impact categories. Within the packaging stage, SLT has the largest impact, followed by the BLF and PC packaging respectively. Both air freighting distribution scenarios have significantly higher climate change impacts than the orchard stage; air freighting to South Korea also has higher eutrophication and terrestrial ecotoxicity impacts compared to the orchard stage. Transport to the North Island has the lowest results for all the distribution scenarios; however, distribution to the South Island has significantly higher impacts across all impact categories (up to 400%) compared to the baseline distribution scenario (shipping to Australia). If the purpose of a VSS scheme is to drive environmental improvement, choice of benchmark should be related to the supply chain under consideration. As different packaging types are generally used for export and domestic markets, two different benchmarks are appropriate: SLTs for export supply chains, and the weighted average value for BLTs and PCs for domestic supply chains based on the industry average/median (Cossu et al., 2023). Since trade destinations and transport modes are highly variable and market dependent, an alternative benchmark such as 'impact/tonne kilometre' may be more appropriate for the distribution stage.

4. CONCLUSIONS

This study investigated factors to consider when developing LCA-based benchmarks for the downstream stages in a case study of the NZ avocado sector. The results of this study can be used to develop LCA-centric criteria in a future VSS-based scheme to support continuous improvement across a majority of the NZ avocado value chain.

5. ACKNOWLEDGEMENTS

The authors acknowledge NZ Avocado for their financial and administrative support for this study, as well as AVOCO for primary industry data and related information.

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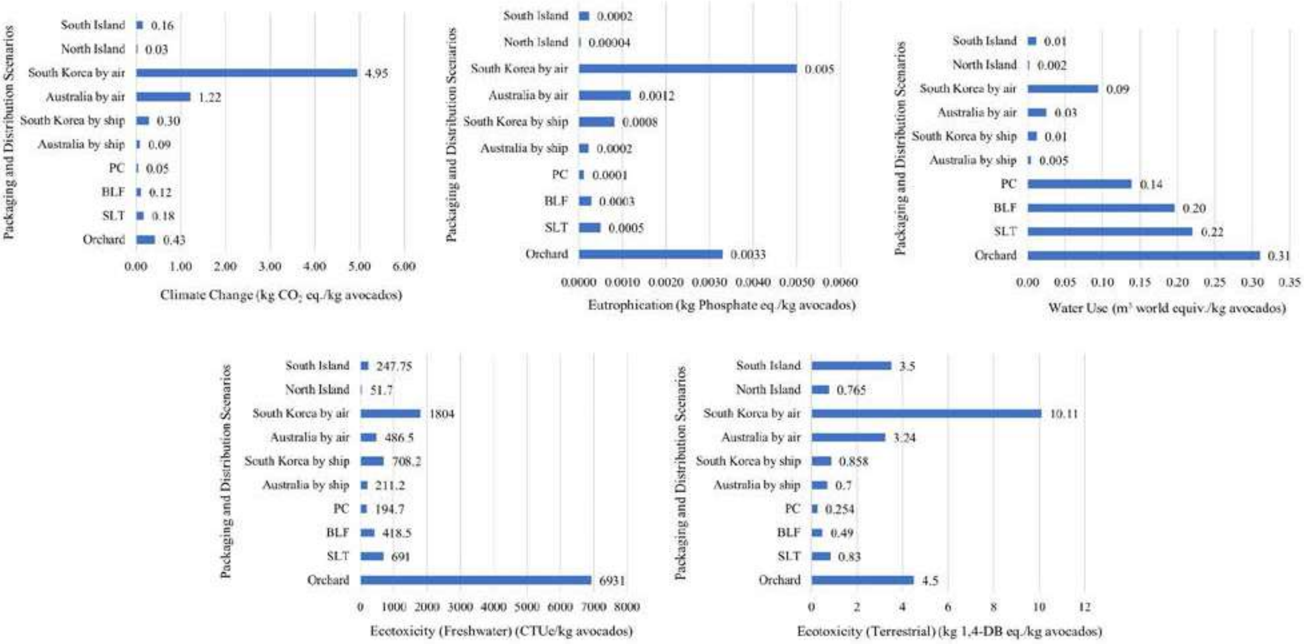

Figure 1. Environmental impacts of the studied packaging and distribution scenarios across five impact categories compared with the orchard stage impact scored determined in Majumdar and McLaren (2023).

Integration of Environmental, Social, and Governance criteria (ESG) into business strategies

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

Combining environmental and social LCA in brewing industry

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1. INTRODUCTION

The issue of sustainability is widely addressed in the literature, specifically in the agri-food sector. This study focuses on analysing the sustainability performance of the brewing industry. Several studies deal with the environmental impact of the brewing industry (Cordella et al. 2008; De Marco et al. 2016), which is an essential but insufficient subject for a sustainability analysis that respects the triple bottom line (people, planet, profit). The aim of this study is to combine Life Cycle Assessment (LCA) and Social Life Cycle Assessment (S-LCA), the former providing an analysis of the industry's environmental performance (Jolliet et al., 2017) and the latter characterizing and quantifying its social and socio-economic value (Feschet et al. 2014). Since both tools take a systemic approach, combining them allows for a robust analysis of the brewing industry's sustainability.

2. METHODS

As LCA is a standardized tool, this section followed the framework and principles described in ISO standards 14040 and 14044. Primary data were collected from breweries, malting plants and container producers, other data were also used from studies already carried out on the subject, as well as from databases available on Simapro (the software with which the study was conducted). The analysis of environmental performance enabled us to highlight the sector's hotspots and identify levers for reducing these impacts.

For S-LCA, the research methodology adopted is a qualitative longitudinal study based on five breweries. Primary data came from semi-structured interviews conducted in 2019 and 2020 with the breweries' entrepreneurs. The interviews explored the breweries' history, current situation, intentions and future goals, using a Social Life Cycle Assessment (S-LCA) grid as a guide.

We take an original approach by integrating these two tools to analyze the brewing industry as a unified system.

3. RESULTS AND DISCUSSION

The LCA enabled a complete environmental analysis of the industry "from cradle to grave", taking into account 18 midpoints indicators (problem-oriented) and 3 endpoints indicators (damage-oriented). These analyses highlighted the study's hotspots, such as the container, the brewing stage and transport, and enabled us to study viable solutions for reducing their impact, such as deposit refunds, environmental economies of scale and reterritorialization of the industry.

The S-LCA demonstrated the social and socio-economic impact of the 5 breweries studied. Using 16 indicators, the study showed that all the breweries are interdependent with their region, promoting local and regional development and creating beers from local ingredients in short food supply chains.

The combination of these studies provides a global analysis of the sustainable performance of the entire value chain. However, this work has its limitations, such as the constraints of temporality and system limits for indicators, the quality of the necessary input data, and the concordance of social aspects with other dimensions of sustainability.

4. CONCLUSIONS

The joint use of life cycle assessment and social life cycle assessment has enabled us to obtain an overview of the brewing industry's sustainable performance. By taking into account 18 environmental indicators and 16 social/socio-economic indicators, we were able to draw up a management dashboard assessing the industry's performance, which can be used to make organizational decisions.

5. ACKNOWLEDGEMENTS

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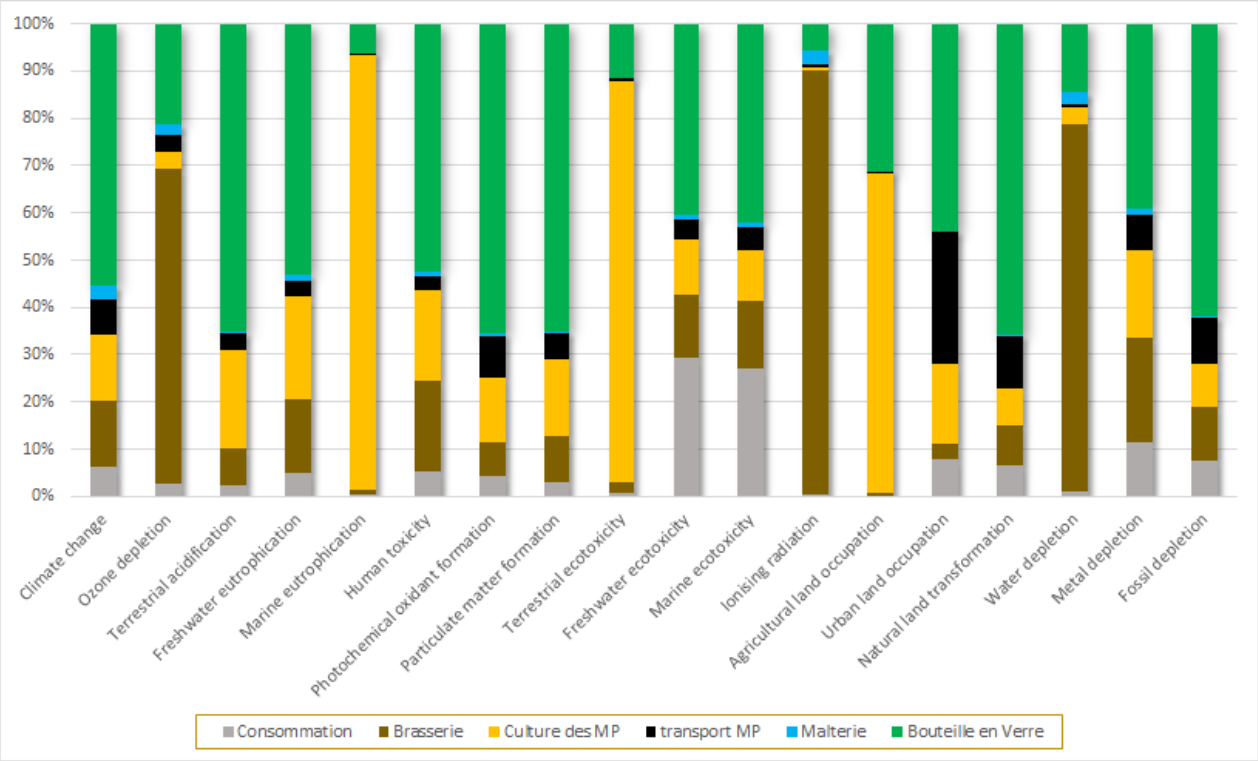

Table 1. Analysis of a litre of conventional beer consumed. ReCiPe Midpoint (H) V1.10 / Europe Recipe H / Caractérisation

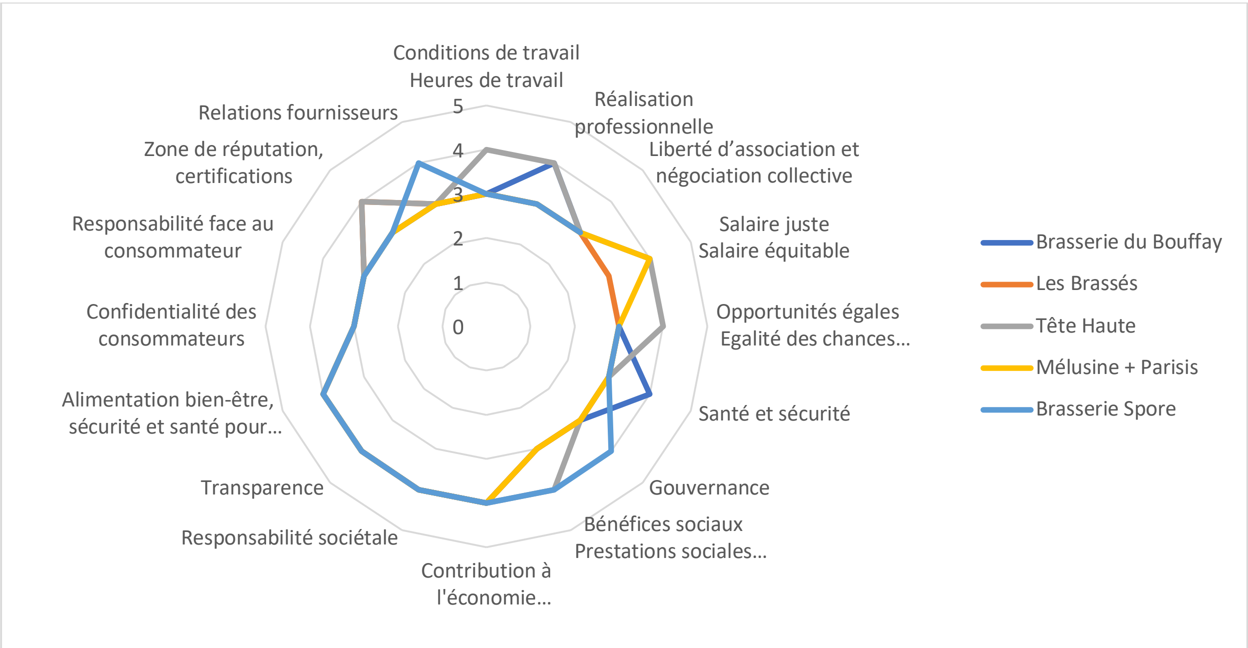

Figure 1. Presentation of brewery performance results

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How can an LCA support investors' and companies' decisions to align impact and financial return?

Laure Peronnin.
Astanor Ventures

Novel foods and protein diversification

14th International Conference

LCA FOOD 2024

HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Mass-based & Nutritional Life Cycle Assessment (nLCA) of Crickets as Human Food

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1. INTRODUCTION

Insect production and human consumption have a long-standing history (Govorushko, 2019). The EFSA panel deems house cricket (Acheta domesticus) safe as novel food in frozen, dried, and ground formulations (Nutrition et al., 2021). Our study analyzed CricketOne´s cricket powder production data from Vietnam using LCA methodology (*ISO 14040:2006*, n.d). Sustainability analysis included edible weight, protein content and digestibility in three functional units, with results compared to literature on conventional protein powder.

2. METHODS

Figure 1 depicts the system boundary for the life cycle assessment (LCA) of cricket powder production. LCA is carried out considering three different functional units of 1 kg of edible mass, protein and digestible protein using the impact assessment methodology of environmental footprint 3.1. Primary data was collected from two separate industries producing cricket flour (CricketOne) and cricket paste as primary products. The secondary data source was from the eco-invent 3.8 and Agrifootprint. Simapro software v9.5.0.2 was use for the life cycle assessment.

3. RESULTS AND DISCUSSION

Figure 2 presents the environmental impact results for cricket powder considering three different functional units. The results indicate negative values for various impact categories, primarily due to the beneficial effects of reusing cassava top (leaf) in the and repurposing frass from fresh insects for crop growth. Additionally, 58.8% of positive environmental impacts can be attributed to soybean meal in the feed. A network diagram (Fig. 3) illustrates the positive and negative environmental impacts contributing to cricket powder production by 1 kg protein weight.

4. CONCLUSIONS

This study´s results show that repurposing insect frass as organic fertilizer, reusing food waste for cricket feed, and implementing other production modifications significantly mitigate environmental impacts across various categories. Additionally considering nutritional factors such as protein weight and digestibility demonstrates sustainability given a substantial protein content in the edible weight with higher digestibility.

5. ACKNOWLEDGEMENTS

The study received funding under project (GiantLeaps). I would like to express my deepest appreciation to my supervisors for their unwavering support throughout this research work.

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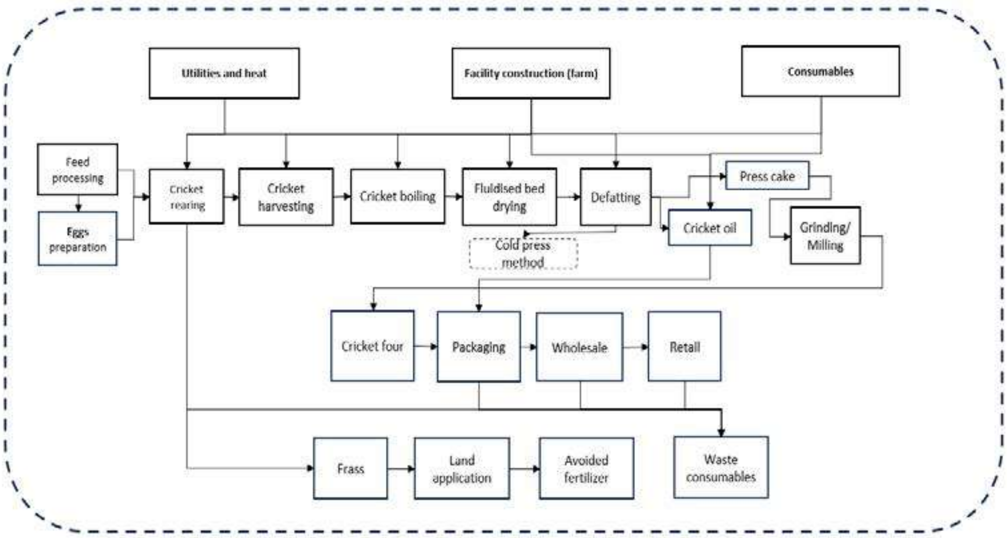

Figure 1. System boundary of cricket production process (*cradle to consumer*)

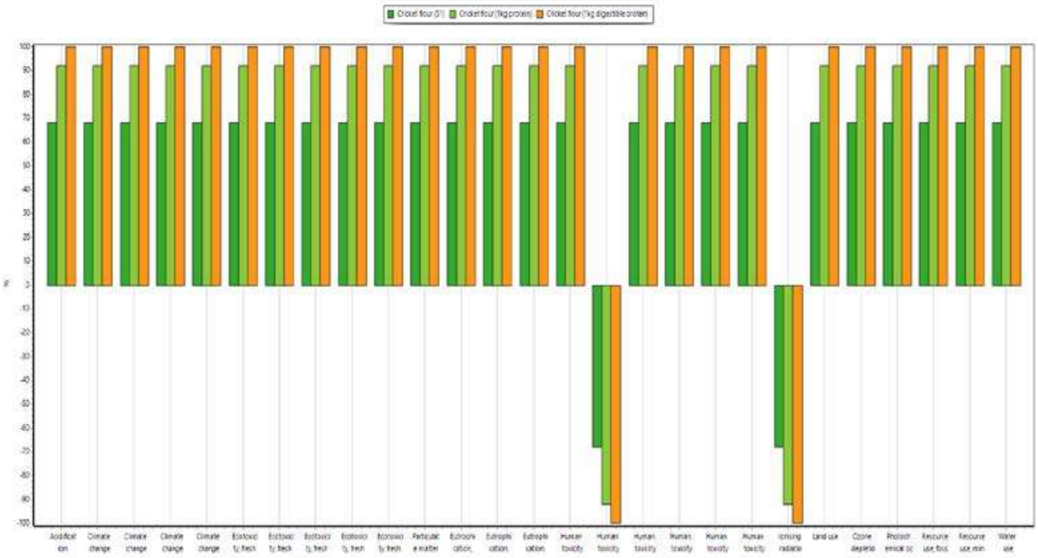

Figure 2. Environmental impact of cricket flour production in three different functional unit

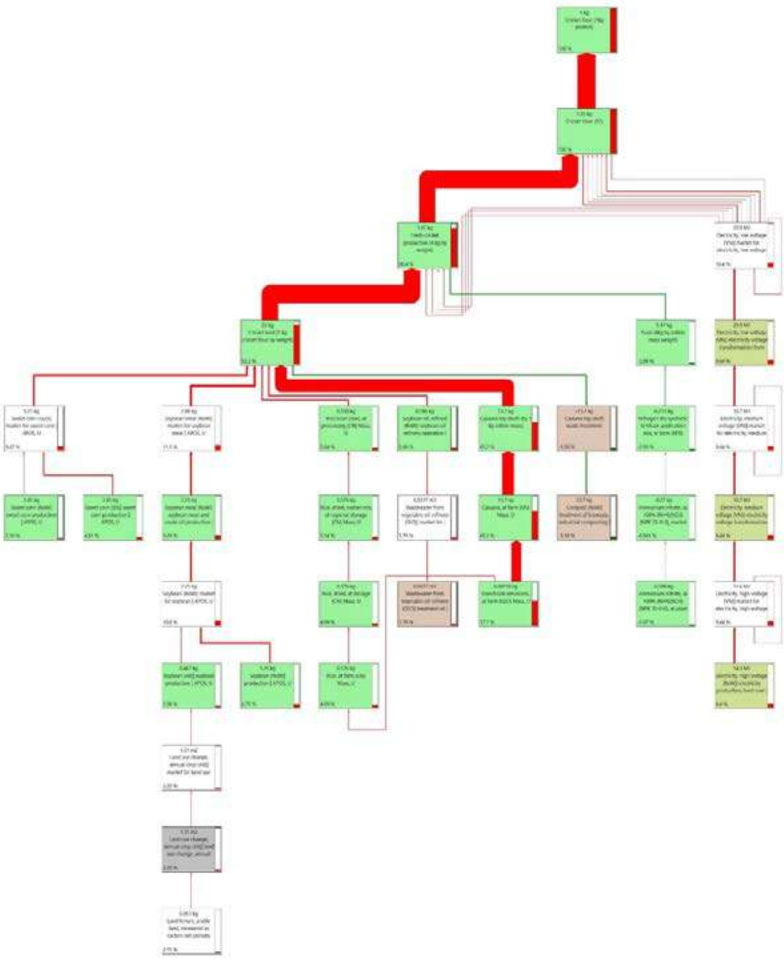

Figure 3. Network diagram of cricket flour production by 1 kg of protein weight

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Environmental impacts of Acheta domesticus flour production with different rearing management

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1. INTRODUCTION

Insect flour can replace conventional animal protein sources, and their production generates lower environmental impacts due to their high feed conversion ratio (van Huis, 2013). Crickets' commercial feed contains around 20% protein (FAO, 2016), mainly wheat bran. As in other animal protein sources, *A. domesticus* feed influences its nutritional and environmental profile (Ssepuuya et al., 2021). At the same time, water system is essential in insect rearing since it can affect feed rotting and the drowning of newborns. This study aims to assess the environmental impacts of *A. domesticus* flour production, considering different diets and watering systems during rearing.

2. METHODS

Life cycle assessment (LCA) was used to assess the environmental impacts of *A. domesticus* flour from cradle to factory gate, considering two functional units, a nutritional one, 1 kg protein (FU1), and an economic one, 1 USD gained (FU2). Eight rearing scenarios were assessed by combining four diets (D1-D4) and two watering systems (W1-W2). The main ingredients of D1, D2, D3, and D4 were distillers' dried grains, soybean meal, corn, and fish meal, respectively. The watering systems were designed using plastic (W1), sponge, and hydrogel (W2). The final insect's protein content in each scenario is presented in Table 1. Foreground data were provided by the company Crickex, and background data processes were retrieved from Ecoivent v3.8 and the Sphera database, in which economic allocation is applied to some feed when required. Environmental impact categories were assessed using the Environmental Footprint 3.1 as recommended by the European Union (OJEU, 2021).

3. RESULTS AND DISCUSSION

The environmental impact scores of each scenario are presented in Table 2. Regardless of the FU, D1W1 is the scenario that impacts CCT and LU the least. Even if D1W1 is not the diet that yields the highest insect protein content, the low impact scores are due to less feed required, and the main ingredient is less impactful. As to WU, D4W2 shows the lowest impact when the results are expressed per FU1, while when considering FU2, D4W1 is the least impactful. This is mainly due to the lowest water consumption in fish meal production. The environmental impacts of *A. domesticus* flour are similar to those of other insects (Dreyer et al., 2021) and lower than those of conventional animal protein sources (Dreyer et al., 2021; Hietala et al., 2021). Using FU2, the relative position of the scenarios' impact is kept, allowing the inclusion of the economic dimension in the assessment results.

4. CONCLUSIONS

The results highlight the importance of choosing an appropriate feeding and watering system for *A. domesticus* to improve the environmental profile of flour production. Using an economic FU allows us to consider the economic dimension in environmental assessment.

5. ACKNOWLEDGEMENTS

We thank the University of Guadalajara for supporting Alejandro Corona Mariscal with the scholarship (V/2020/448) of the program “Beca Institucional UdeG de Talento Global”. We also thank the company Crickex for providing the data to develop this study.

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Table 1. Cricket protein content on a dry-weight basis for each rearing scenario

Scenario	D1W1	D1W2	D2W1	D2W2	D3W1	D3W2	D4W1	D4W2
Protein content %	71	72	72	76	68	64	51	65

Table 2. Environmental impacts of *A. domesticus* flour fed with different diets, featured in two functional units, 1 kg of protein and 1 USD gained.

Impact	Unit	D1W1	D1W2	D2W1	D2W2	D3W1	D3W2	D4W1	D4W2
FU1 = 1 kg of protein									
CC T	kg CO_2 eq.	22.00	27.86	24.61	23.94	30.46	37.30	30.75	27.01
LU	Pt	673.34	1008.41	1076.23	1068.73	993.12	1303.78	844.05	806.60
WU	m^3 world equiv.	42.32	64.75	28.08	28.62	34.82	46.79	19.31	19.59
FU2 = 1 USD gained									
CC T	kg CO_2 eq.	0.46	0.63	0.56	0.59	0.62	0.76	0.52	0.63
LU	Pt	13.94	22.91	24.50	26.19	20.35	26.64	14.29	18.70
WU	m^3 world equiv.	0.88	1.47	0.64	0.70	0.71	0.96	0.33	0.45

Social Life Cycle Analysis for vegan burger production compared to meat burger

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1. INTRODUCTION

The contemporary trend of reducing meat consumption reflects a global shift towards more conscientious and sustainable dietary practices. Driven by concerns related to personal health, environmental sustainability, and ethical considerations, individuals are increasingly opting for plant-based alternatives and incorporating meatless meals into their routines. Vegan burgers have garnered increased popularity not solely within the demographic of vegans and vegetarians but also among individuals who seek to diminish their meat consumption. Since ethicality is a priority to those people it is crucial for them to know and understand the social impacts of those products compared to the conventional ones.

For this purpose, this study aims to identify and analyse the critical areas of concern of the social risks related to vegan burger production compared to a conventional burger.

2. METHODS

The initial phase of the analysis involved identifying the stakeholders within the vegan burger life cycle. In this assessment, four primary stakeholder groups were considered: workers, value chain actors, local community, and society. Given the numerous subcategories and social indicators associated with each stakeholder, initially the most relevant indicators to the system were selected. Subsequently, a questionnaire containing these selected indicators was designed and distributed to the Vegan Burger producers to measure the significance of each indicator from their perspective.

The meat burger assessed in this study primarily consist of beef, while the vegan burger is mainly derived from pea, lentil, and sunflower flour. The software used is OpenLCA, with Soca v2 database. When working with Soca v2, it is crucial to identify the risk level of its indicators. Thus, a survey was created containing both qualitative and quantitative questions, which was distributed among our industrial partners for their responses. Moreover, in order to collect all the required information and to fill the gaps of the data missing, national databases were utilized. For the meat burger production data from literature were applied. Following the data input and computation of working hours for each process in the software, we applied the Social Impacts Weighting method to obtain results, expressed per kilogram of burger. Furthermore, it was crucial to assess the social impact of the vegan burger on consumers. For this purpose, another brief questionnaire was created based on Product Social Impact Assessment method indicators proposed for the users-consumers stakeholder.

3. RESULTS AND DISCUSSION

The initial findings indicate that while certain social standards are afforded protection due to the cultivation of primary raw materials and industrial processes within Europe, disparities persist in social aspects. The analysis demonstrates that the production of vegan burgers significantly mitigates social risks compared to conventional meat burgers. Opting for vegan burger production, as opposed to meat burgers, proves advantageous for all stakeholders involved. These outcomes are visually represented in Figure 1. Notably, the most substantial reduction in social indicators is observed in the category of 'embodied agricultural area footprints,' attributed to the greater land requirement for animal breeding and feed consumption compared to the cultivation of raw materials utilized in vegan burger production. Effective communication of LCA results is essential for ensuring that stakeholders, including businesses and consumers, understand the social impacts of their choices. The results will be presented among VALPRO Path European Project and the social media of the project and further dissemination practices will take place.

4. CONCLUSIONS

In conclusion, it is apparent that the social risks associated with meat burger production outweigh those linked to vegan burger. This analysis underscores the benefits of embracing plant-based alternatives, emphasizing the reduced social risks inherent in the production of vegan burgers. Such findings align with the prevailing trend towards sustainable and ethically conscious dietary preferences, emphasizing the potential positive impact of transitioning away from conventional meat consumption. The effective communication of these results to both businesses and consumers is crucial for fostering informed decision-making and promoting sustainable practices.

5. ACKNOWLEDGEMENTS

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement No. 101059824 and co-funded by UK Research and Innovation (UKRI) under the UK government’s Horizon Europe funding guarantee.

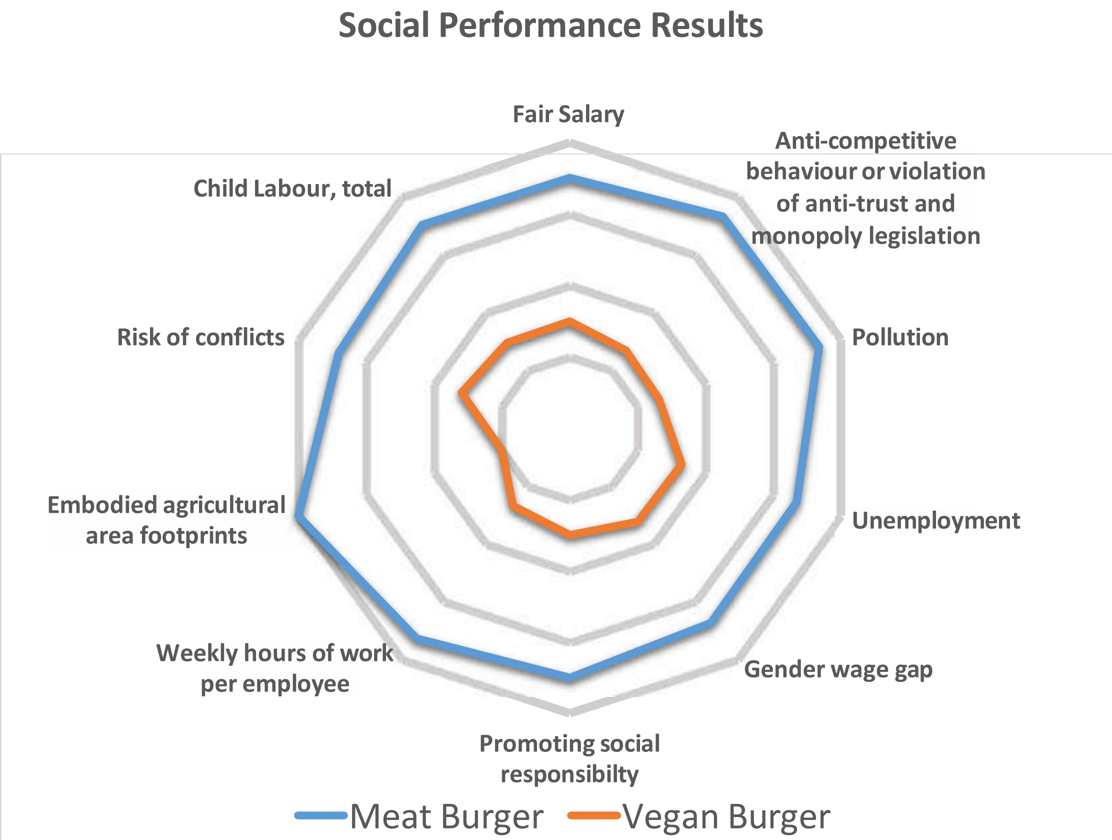

Figure 1. Social impacts of vegan and meat burger

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The relevance of methodological choices and nutritional value in sustainability analyses of waste-to-protein pathways

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1. INTRODUCTION

Research on the environmental sustainability and conversion efficiency of bioconversion technologies applied in waste-to-protein pathways is relevant from an early development stage to identify optimal applications and avoid trade-offs when aiming to replace conventional protein sources. Therefore, this work documents recent advances in the life cycle assessment (LCA) of bioconversion technologies used for alternative protein production and provides an overview of the reported impacts of global warming, water use, land use, and energy demand. A special focus lies on the methodological choices made and their effect on resulting impacts. Due to the importance of nutritional value in sustainable food systems, this work further documents recent findings on protein quantity and quality along bioconversion pathways.

2. METHODS

The Web of Science and Scopus databases were searched for keywords related to sustainability, feed conversion, residual biomass [(RB), i.e. waste- and side-streams], food or feed applications, and protein. Articles published in 2018 or later containing at least one keyword from each category were selected (n = 1441) and screened for quantitative information on environmental impacts, protein quantity, amino acid profiles, and protein conversion efficiency. The final selection yielded 22 articles on LCA and 31 on protein quantity, quality, or conversion efficiency.

3. RESULTS AND DISCUSSION

All but one study focused on feed rather than food applications and research is dominated by insect species, particularly *Hermetia illucens*, commonly called black soldier fly (BSF).

3.1 Life cycle assessment

The range of reported impacts for all types of bioconversion technologies was found to span multiple orders of magnitude (Table 1). However, comparing environmental impacts from different studies is difficult because of divergent methodological approaches. First, the identified articles relied on four different functional units (FUs; Table 1) but the necessary information to convert one into the other was often lacking. Second, the studies differed in their choice of system boundary, method of impact allocation, and consideration of RB burdens. The latter could amount to 70% of total impacts, while the method of allocation and choice of substitution process could determine the general trend (positive or negative) of total impacts. This highlights the strong need for methodological harmonization and transparency when dealing with circular multi-output systems.

3.2 Protein content and amino acid profiles

A wide range of dry-matter protein contents was found for microalgae (13–53%), fungi (17–70%), and insects (20–64%) grown on RB. Hence, depending on the species, growth conditions, and substrate, estimates for environmental impacts of bioconversion technologies could vary by a factor of 3-4 within the same class of organisms if protein-based FUs are applied. Another source of uncertainty is the applied nitrogen-to-protein conversion factor. In the case of BSF larvae, for example, it could vary between 4.76 and 6.25, which results in protein contents differing by 25%. This has major implications for LCA studies intending to use a protein-based FU. Among bioconversion technologies, amino acid (AA) profiles were predominantly found for BSF larvae. The findings demonstrate the capacity of the larvae to enrich all AAs in comparison to RB sources except for cysteine (Figure 1). However, compared with optimal dietary profiles for broiler chickens and fish species, BSF larvae can still be deficient in cysteine, methionine, glycine, and proline. This should be carefully monitored when formulating animal diets and when using the nutritional LCA methodology.

4. CONCLUSIONS

Current research on bioconversion technologies is strongly focused on BSF larvae, while knowledge gaps exist for other technologies (e.g., algae, bacteria, or fungi). The large variability of RB and bioconversion technologies necessitates better methodological alignment to produce comparable results that collectively support decision-making. Nitrogen conversion factors must be aligned and documented to reduce uncertainty. Finally, when using nutritional LCA, the potential for great variability in protein quality indices should be considered.

5. ACKNOWLEDGEMENTS

This work was supported by the European Union's Horizon 2020 Research and Innovation program under grant agreement no. 101059632 project GIANT LEAPS.

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Table 1 Summary of GWP, land, water, and energy use related impacts reported by recent life cycle assessment (LCA) studies investigating bacteria-, fungi-, insect-, microalgae-, or worm-based waste-to-protein pathways. Bacteria include purple non-sulfur bacteria; fungi include Neurospora intermedia and Fusarium venenatum; insects include Hermetia illucens, Musca domestica, Protaetia brevitarsis seulensis, and Tenebrio molitor; microalgae include Galdieria sulphuraria and Chlorella vulgaris; worm species include Eisenia fetida. (Siegrist et al., 2023.)

Category	FU[a,b]	GWP[b] ($kg_{CO2\text{-}eq}$)	LU[b] (m^2 * a)	WU[b] (m^3)	ED[b] (MJ)
Microalgae	1 kg dry protein	8.70 – 12.49	0.25 – 0.32	NA	202.8 – 248.5
Fungi	1 kg dry protein	23.7	4.4	2.2	NA
Insect	1 kg dry protein	2.4 – 18.0	-1.3 – 9.8	-0.07 – 0.39	NA
Microalgae	1 kg dried BM[b]	0.3 – 19.7	0.03 – 0.74	0.2 – 6.4	13.20 – 18.04
Insect	1 kg dried BM[b]	-6.4 – 12.0	-16.8 – 61.0	2.8 – 11.0	-108.0 – 84.2
Insect (c[c])	1 kg dried BM[b]	-2.9 – 8.4	-3.6 – 22.5	-14.0 – 103.9	19.5 – 141.4
Worm	1 kg dried BM[b]	2.2 – 6.3	NA	NA	NA
Fungi	1 kg fresh BM[b]	0.1 – 0.2	0.05 – 0.09	0.02	NA
Insect	1 kg fresh BM[b]	0 – 1	0	NA	1 – 10
Bacteria	1 ton fresh RB[b]	220.3 – 322.2	-62810 – -196	-8.04 – -1.65	NA
Insect	1 ton fresh RB[b]	35	NA	NA	NA

[a] Where possible results based on fresh matter or RB were converted and reported based on 1 kg of dried BM
[b] FU, functional unit; GWP, global warming potential; LU, land use; WU, water use; ED, energy demand; BM, biomass; RB, residual BM.
[c] c = consequential approach (all other studies followed an attributional approach).

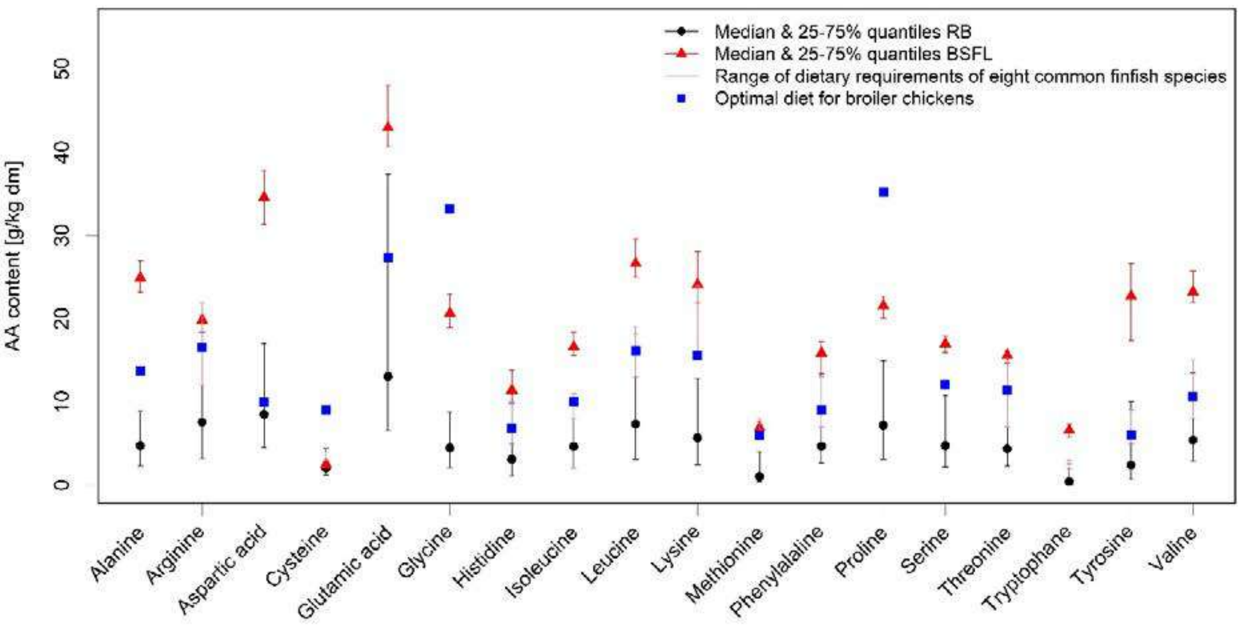

Figure 1 Amino acid (AA) profiles in g/kg dry matter of residual biomass (RB; i.e., waste & side streams potentially used as rearing substrates; n = 1 – 41) and black soldier fly larvae (BSFL; n = 13 – 54). In this context, residuals refer to waste or side-streams of biomass that can be used as rearing substrates for BSFL and not residues from the bioconversion, i.e., BSFL residues. The optimal dietary profile for broiler chicken and dietary requirements for various fish species were added as a reference. (Adapted from Siegrist et al., 2023.)

Microbial Protein from Agro-Industrial Waste: A Century of Progress

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1. INTRODUCTION

The rise in global protein consumption over the past five decades, along with environmental concerns and ethical reasons over animal-based protein production, has sparked interest in exploring alternative protein sources. Microbial proteins (MP), obtained from fermenting agro-industrial by-products, offer a possible alternative. This systematic review delves into the century-long progress in microbial fermentation of agro-industrial by-products for valuable protein production. This exploration aligns with global initiatives aimed at addressing sustainability, nutrition, health, and the changing consumer and business landscapes of alternative proteins.

2. METHODS

This systematic review involved analysing 347 relevant research papers to identify trends, technological trajectories, and critical factors influencing MP production. The study did not impose any time limitations when collecting relevant articles from Web of Science or Scopus; the search extended until September 12, 2023. The analysis encompassed microbial aspects, fermentation methods, feedstock types, and the impact of nucleic acid content on the quality of food-grade proteins. The conditional inference tree model was used to build decision trees and Bayesian factor statistical analysis were used to together evaluate the interaction of different parameters on protein content.

3. RESULTS AND DISCUSSION

Microbial Proteins (MPs) exhibit a high protein content (30-65% on a dry basis), rendering them suitable as protein rich ingredients or supplements for human food. Using waste as feedstocks for MPs production represents a promising trend scientifically, moving away from refined food-grade sugars to non-edible organic streams derived from agro-industrial by-products (Alves et al., 2023). Various parameters affecting protein content were investigated in this study, including feedstock type (lignocellulose, free sugars, gases), fermentation type (solid, liquid, gas), microbe type (bacteria, fungi, yeast, mix), and operating conditions (temperature, time, pH). Fermentation type and microbe type had the most significant impact on protein content. Specifically, gas and liquid fermentation showed higher protein content, averaging 52% and 42%, respectively. Among microbes, bacteria had the highest protein content at 51% (Figure 1). Liquid fermentation studies revealed that bacteria were used in 9% of entries, fungi in 24%, yeast in 50%, and mixed microbes in 17%. The median protein content observed was 42%, with reported optimal operating conditions including a pH of 5.4, temperature of 30°C, and a fermentation time of 51 hours. When categorised by microbe type (Figure 2), yeast and fungi had a median pH of 5, mix had 5.5, and bacteria had 6.5. Yeast and mix shared a median fermentation time of 48 hours, while fungi and bacteria had 72 hours. The narrow temperature range for fermentation was 30°C for fungi, yeast, and mix, and 32°C for bacteria. Median protein levels varied: 51% for bacteria, 49% for mix, 40% for yeast, and 37.6% for fungi. Notably, only 37% of studies reported amino acid quantification, and 13% quantified nucleic acids in microbial biomass (Nadar et al., 2024).

4. CONCLUSIONS

Based on the 347 research papers, the study's findings point out the reported optimal operating conditions for each microbe type. The study further emphasises the need to reduce nucleic acid content to safe levels and enhance the overall quality and consumer acceptability of MPs. These results highlight the challenges and opportunities for ongoing innovation in feedstock selection, microbial processes, and regulatory alignment to fully unlock the potential of MPs in contributing to global food security and sustainability goals.

5. ACKNOWLEDGEMENTS

The author acknowledges the funding received from Fonterra Co-operative Group Ltd to conduct this study.

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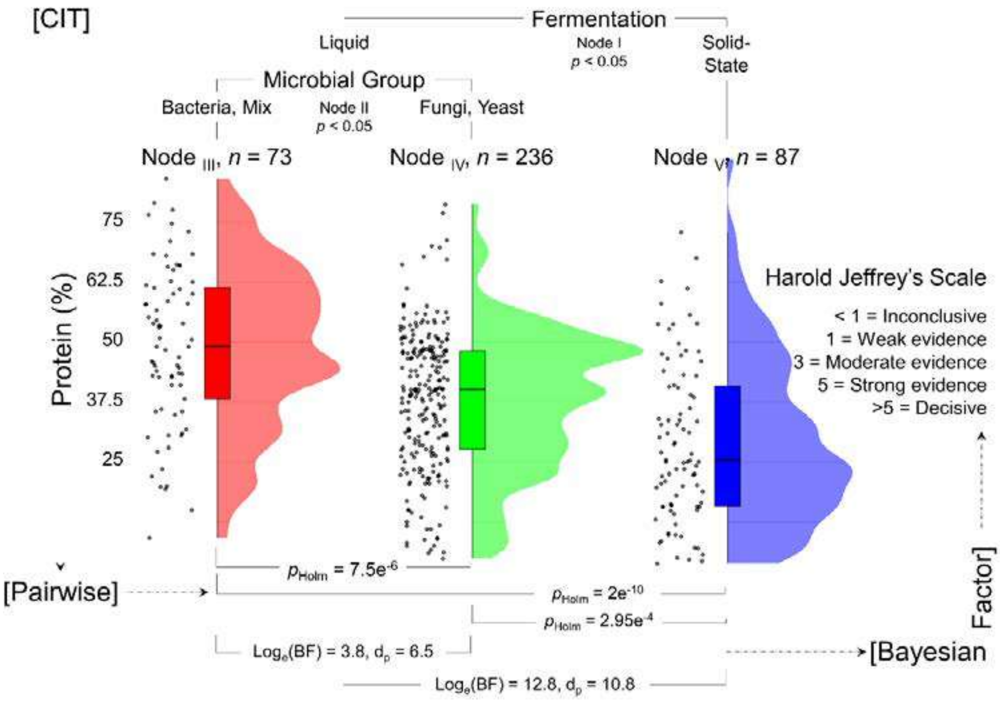

Figure 1: Condition inference tree (CIT) model results representing node 1 (fermentation type), node 2 (microbe type) along with the Welch's t-test results and Bayesian factor analysis results, which was linked to the Harold Jeffreys's scale (Nadar et al., 2024).

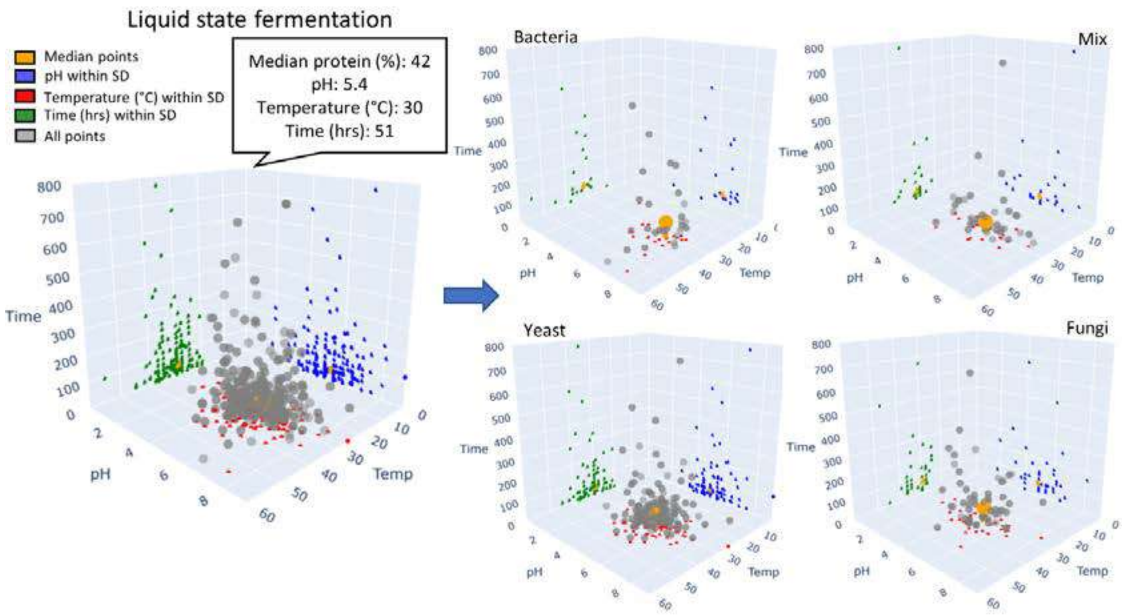

Figure 2: The 3D scatterplot represents the suggested operating parameters for liquid fermentation, further classified in terms of microbe type, namely bacteria, fungi, yeast, and mix (Nadar et al., 2024).

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Designing proteins manufacture lines: sustainability trade-offs for legumes-and fungi-based proteins production and processing

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1. INTRODUCTION

In a context of increased worldwide food demand driven by a growing population (2), alternative protein sources emerge as a promising solution to diversify the global protein supply while mitigating environmental degradation (3). These sources offer resource efficient alternatives to traditional livestock farming or seafood, requiring fewer inputs of land, water, and feed while delivering a comparable or superior nutritional value and possibly, regenerating the environment where they are grown (4). In recent year, legumes and fungi based proteins have gained the spotlight as potential candidates in supplying the world's needs (7). Within legumes, pea protein powder, one of the most consumed, is obtained by extracting it from yellow and green peas (*Pisum sativum*). It is a high-quality and easily digested plant-based protein and has gained attention as a potentially innovative ingredient for creating superior, new plant-based food (6). Pea protein powder can be classified as concentrate (<70% of protein composition) and isolate (>70% of protein composition). Post- treatment processes can improve the protein yield of concentrate and isolates, enhancing flavour, colour, functionality, although there is a limit in terms of environmental impacts on how many processes can be applied until a sustainability breakeven point (5). Investigating different post-treatment processes from an environmental perspective will support manufactures of protein powder to better adapted the product portfolio with regards to demands on both quality and the environment impacts. Mycoproteins as well, derived from fungal organisms such as *Fusarium venenatum* and *Aspergillus oryzae*, have gained attention for their high protein content, low environmental footprint, and versatility in food applications (1). The objective of this research is to perform a Life Cycle Assessment to better understand the trade-offs that needs to be considered in a Swedish context for post treatments of alternative proteins to be used as ingredients in new types of food., supporting the long-term transition of the food system.

2. METHODS

A literature review identifies datasets available in terms of pre and post treatments of alternative proteins, together with data collection from companies operating in the sector. The post treatments identified consist of ultrasonication, electrostatic separation, electromagnetic separation, membrane filtration, high pressure processing, gentle heat treatment, micro fluidization, mild wet fractioning and spray drying. These are modelled on SimaPro and a Life Cycle Assessment is conducted adopting cradle-to-factory-gate boundaries. ReCiPe 2016 v1.1 Midpoint E is utilized to calculate 18 environmental impacts categories, 16 of these included in the PEF methodology.

3. RESULTS AND DISCUSSION

Results from the literature review allow to evaluate which data are available on open access sources. The different supply chains modelled through the Life Cycle Assessment will analyse the environmental impacts based on the 16 PEF environmental impacts categories for pea protein concentrate, isolate, and fungi, establishing how much processing and refining of these protein sources is acceptable from an environmental perspective.

4. CONCLUSIONS

This research aimed at highlight the potential of and trade-offs needed to be addressed the design of three alterative proteins supply chains in a Swedish context considering potential environmental impacts as well as costs associated with the different choices.

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Methodological framework for consequential life cycle assessment of pea fractionation in Canada for increasing production of pea protein

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1. INTRODUCTION

In recent years, there has been significant demand for plant-based proteins to substitute animal proteins as a result of environmental sustainability concerns (Potter and Röös, 2021). Pulse-based products are especially in demand because of their sensory quality attributes, high protein, nutrient, mineral, and vitamin contents and lower environmental impacts. Canada is one of the main producers of different pulses, especially peas (Peoples et al., 2019). An increasing fraction of these is being transformed into pea-based protein concentrates and isolates through dry and wet fractionation, which also results in increased production of pea starch and pea fiber as these are the common co-products in both dry and wet fractionation processes (Byars and Singh, 2016). Increased market availability of these co-products may impact the prices and production volumes of substitutable starch and fiber-based products due to competition with and decreased demand for these substitutable products. Understanding the net sustainability benefits, impacts or trade-offs of these potential market-level substitution effects is hence important from a public policy/environmental management perspective and can be assessed using the consequential life cycle assessment (CLCA) approach. So, this study aims to develop a methodological framework of CLCA of pea fractionation in Canada based on the findings of a systematic review.

2. METHODS

CLCA plays an important role in providing insights for decision-makers on potential market-mediated resource/environmental consequences stemming from changes in product systems. Given that economic models are integral components of CLCA, this PRISMA-based systematic review offers a comprehensive survey of the economic models employed in CLCA studies, shedding light on their strengths and weaknesses. Also, this review identified the common methodological choices for CLCA in the agri-food sector. To demonstrate the appropriate methodological approaches for CLCA of pea fractionation in Canada, this study also identified the marginal markets that may be affected by increased production of pea protein co-products.

3. RESULTS AND DISCUSSION

Notably, the study identifies the use of both Computable General Equilibrium (CGE) and Partial Equilibrium (PE) models for enabling the analysis of large-scale and long-term changes. In the agri-food sector, these models are instrumental in quantifying indirect land use changes (iLUC). For the agri-food sector, this study illustrated different aspects of CLCA studies - the decision contexts, studied market trend, time horizon, identification of marginal market, estimation of LUC impacts, etc. Building upon these findings, the study proposes a detailed methodological framework for CLCA applied to pea fractionation, incorporating considerations of marginal markets that revolve around the utilization of co-products like pea starch and pea fiber (Figure 1).

4. CONCLUSIONS

One of the main aspects of CLCA studies is to consider multiple scenarios/marginal markets, which is also acknowledged in this study. Future research could focus on identifying marginal markets relevant to the Canadian landscape, thereby enhancing the applicability and relevance of CLCA within this region.

5. KEYWORDS

Consequential LCA; PRISMA systematic review; economic models; marginal markets; indirect land use change

6. ACKNOWLEDGEMENTS

This work was funded by the National Research Council of Canada (CSTIP Grant Agreement #SPP121) under the Sustainable Protein Production (SPP) program.

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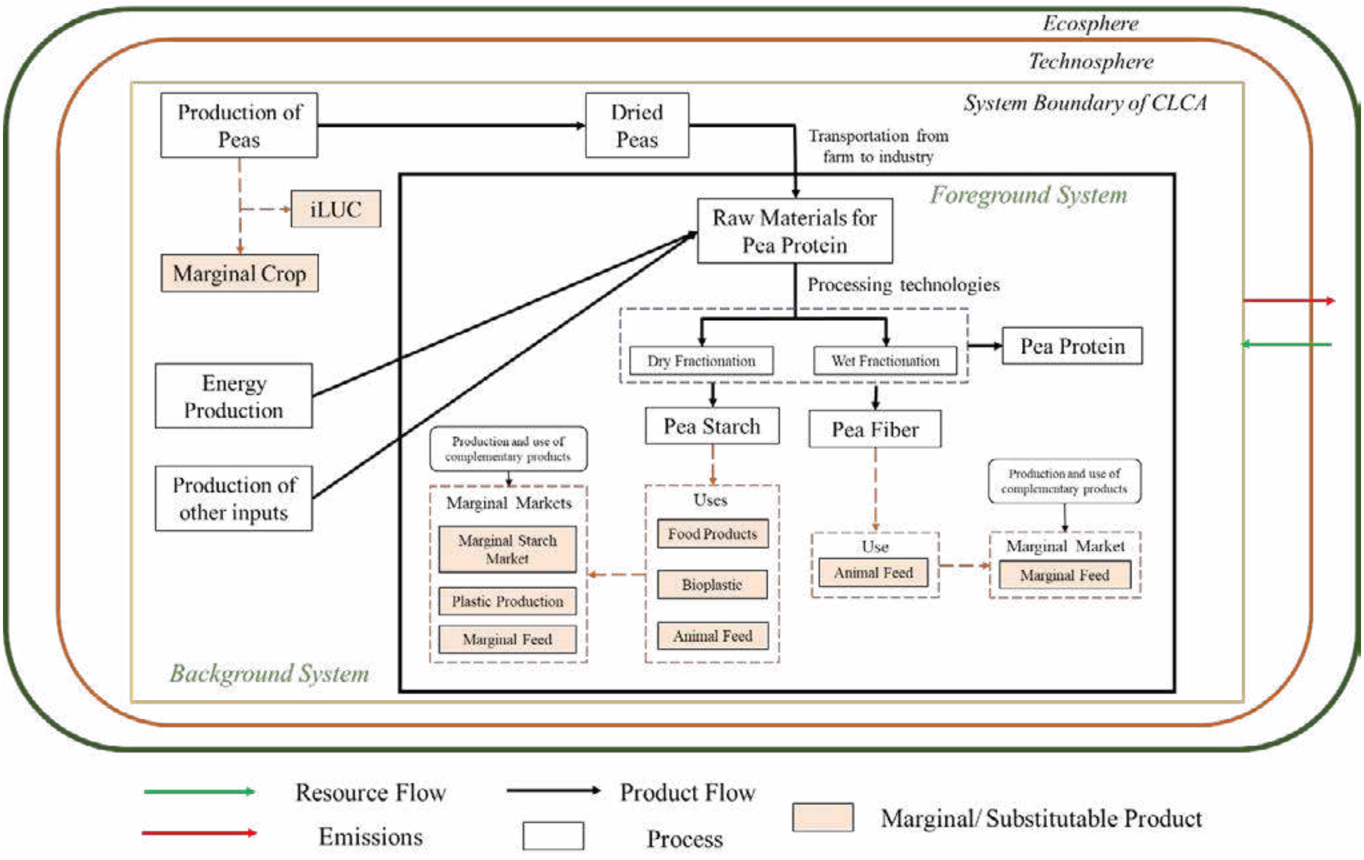

Figure 1. Proposed system boundary for CLCA of pea fractionation

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The environmental impact of mycoprotein-based meat alternatives compared to plant-based meat alternatives: a systematic review of life cycle assessments

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1. INTRODUCTION

The production of meat and meat-based food products has significant environmental impacts (1, 2). Plant-based meat alternatives have lower greenhouse gas emissions (GHGe) compared to animal-based protein sources (3, 4). Fungi-based mycoprotein offers another alternative to meat, but its comparative environmental impacts are yet to be comprehensively reviewed.

2. METHODS

We systematically identified life cycle assessment (LCA) studies of mycoprotein-based meat alternatives reported in ProQuest, Scopus, and Web of Science, as well as the grey literature. Studies were included if they were published in the English language from 1 January 2013 until 18 September 2023 and reported process-based LCAs of any environmental impact measure, using any system boundary, done in any geographical region, with reporting of functional units of impact by product weight. Data for mycoprotein was compared against LCAs of equivalent plant-based meat alternatives for base protein, burgers, mince, and sausage products, and against animal-based meat.

3. RESULTS

LCA data from five studies of mycoprotein and mycoprotein-based products were included and compared against seven studies of plant-based protein sources and meat alternatives. For production of base protein, GHGe were lower for mycoprotein (0.73 kg CO_2eq / kg) compared to soy protein concentrate (1.21 kg CO_2eq / kg) or pea protein concentrate (1.91 kg CO_2eq / kg) across the cradle-to-factory gate system boundary. Median GHGe estimates for all mycoprotein-based meat alternative products were comparable to existing median estimates for plant-based products and consistently lower compared to animal-based meat (Figure 1). Quantification of the GHGe associated with different stages of production for mycoprotein- versus plant-based products was possible due to data imputation and found estimates for the mycoprotein ingredient production stage comparable to those from plant-based meat alternative products. Limited data meant that robust comparisons of environmental impacts such as land use and scarcity-weighted water use were not possible.

4. DISCUSSION

Lower GHGe from mycoprotein-based products can likely be attributed to its production process, where the usual crop cultivation stage necessary to produce plant-based proteins is largely replaced by fermentation done in large industrial vats (5). Emissions from ingredient production, that typically involves crop cultivation with associated energy, water, and land use, are a major contributor to GHGe for most foods (6). The lack of individually specified GHGe for each ingredient used in mycoprotein-based products creates uncertainty regarding the proportions of emissions attributed to ingredient production versus processing.

5. CONCLUSIONS

Mycoprotein is an environmentally beneficial alternative to animal-based meats and its GHGe are broadly like those from plant-based meat alternatives. Differences between the GHGe from mycoprotein- and plant-based meat alternatives are likely to be present for both the ingredient production versus processing stages but will require further data for robust comparisons.

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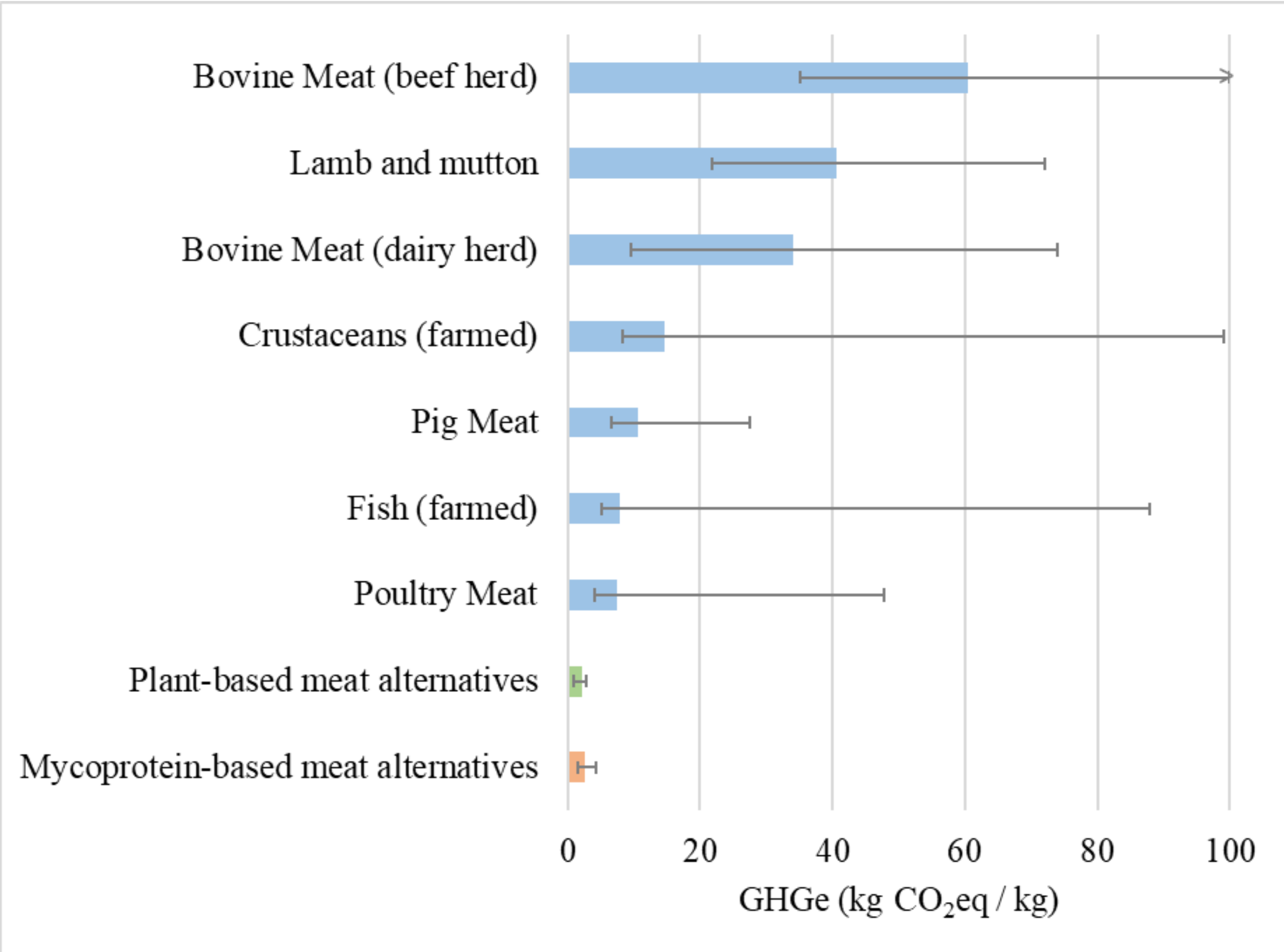

Figure 1. Comparison of median greenhouse gas emissions for all mycoprotein-based meat alternatives (n = 23) from this study, plant-based meat alternatives (n = 23) from Shanmugam et al., 2023 (4) and different types of animal-based meats from Poore and Nemecek, 2018 (3). Emissions are from the cradle-to-retail gate system boundary. Error bars indicate minimum and maximum values; maximum greenhouse gas emissions value for 'Bovine Meat (beef herd) = 432 kg CO_2eq / kg). kg CO_2eq = kilograms of carbon dioxide equivalents.

Assessing the Environmental Costs of different Protein sources

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1. INTRODUCTION

With the global population projected to reach 10 billion by 2050, ensuring adequate and nutritious food provision while considering the environmental impacts within natural resource limits is crucial (UN, 2017). The IPCC reports that 21 to 37 percent of greenhouse gas emissions stem from the global food system (IPCC, 2022). Although the environmental impacts of animal-based and alternative proteins have been studied in different cases, the environmental costs of these product s have not been evaluated. This study aims to evaluate the Eco Cost of 1 kg of 79 animal-based a nd plant-based protein sources across eight groups, from production origin to the supermarket gate, to inform sustainable food choices.

2. METHODS

To calculate the environmental cost of proteins, their environmental impacts were monetized to their environmental prices. Environmental impacts were evaluated using the Life Cycle Assessment approach (ISO 14040, 2020) with the ReCiPe 2016 Midpoint v1.1 method (Huijbregts et al., 2017). LCA was conducted using Simapro v9.5 software with Ecoinvent v3.9.1 and Agribalyse v3.1 databases (Sonderegger & Stoikou, 2023; Asselin-Balençon A. et al., 2022). The impacts are multiplied by Eco Cost factors, which encompass marginal prevention costs and those associated with material depletion, energy, transportation, and emissions (Vogtländer, 2010).

3. RESULTS AND DISCUSSION

Our findings reveal significant variations in Eco Costs of different protein sources. 1 kg of beef and lamb has the highest Eco cost, due to higher impacts of GHG emissions, land, and water usage, followed by pork. Plant-based sources have the lowest Eco Cost, with insects, dairy products, and poultry following, and seafood and processed meat falling in the middle (Figures 1 and 2). These lower Costs reflect the economic and ecological benefits of plant-based protein sources.

4. CONCLUSIONS

To cover the difference between the present market prices and the actual costs of the proteins, it is necessary to quantify and assign a monetary value to their environmental impacts. Nonetheless, it is imperative to conduct additional research to encompass social dimensions within the scope of the study as they could not be measured at this time due to the complexity and availability of information on the social aspect.

5. ACKNOWLEDGMENTS

The authors are responsible for the choice and presentation of information contained in this paper and for the opinions expressed therein, which are not necessarily those of UNESCO and do not commit this Organization.

6. FUNDING

This study is an outcome of the KAIROS-BIOCIR Project, Grant number KAIROS-BIOCIR Project PID2019-104925RB-C33 (AEO/FEDER, UE), financed by the Spanish Ministry of Science and Competitiveness.

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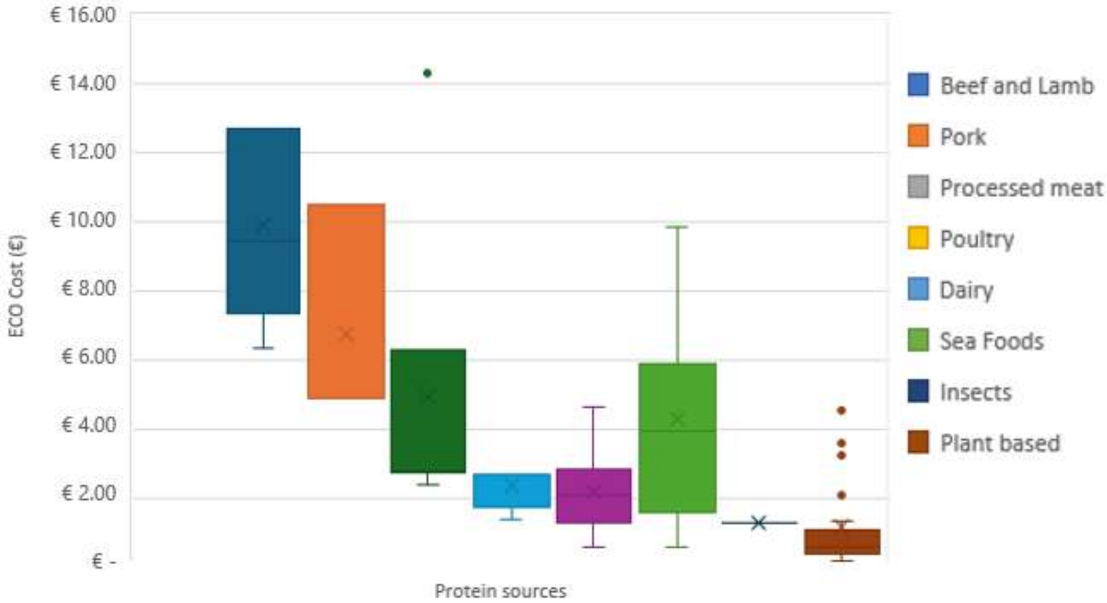

Figure 1. Eco Cost of 1 kg of different protein sources

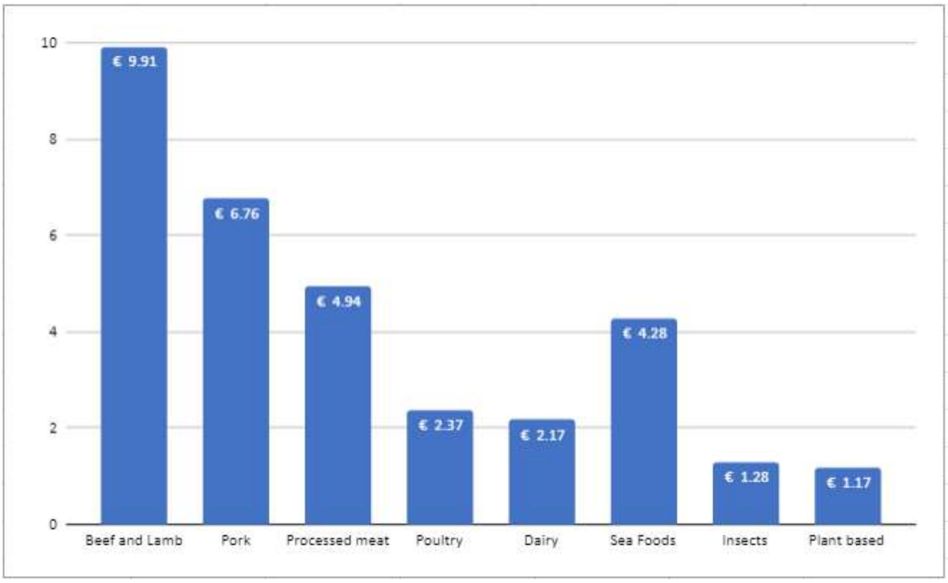

Figure 2. Average Eco Cost of 1 kg of different protein sources

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Are Novel Foods sustainable for the planet and human health? A Literature Synthesis of Life Cycle Assessments

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1. INTRODUCTION

There is resounding recognition that global agri-food systems severely affect the environment and human health by driving climate change, water scarcity, biodiversity loss, and food insecurity. These issues have been primarily linked with agricultural and livestock farming, with the second being responsible for 16.5–19.4% of the total anthropogenic greenhouse gas emissions, 41% of green and blue water use, and over a third of anthropogenic nitrogen emissions (Sinke et al., 2023). In this context, Novel Foods (NFs) have gained prominence for their possible consumption as alternatives/substitutes for animal-source foods, as most of them are advocated to have comparable nutritional properties and reduced environmental impacts. Life Cycle Assessment (LCA) has been poorly applied to this field due to the numerous challenges and high uncertainty associated with emerging technologies (Hospido et al., 2010). The present work reviews the LCAs of NFs to summarise their main environmental issues and/or benefits and provide methodological insights for their evaluation.

2. METHODS

Literature was selected by searching on Scopus and Web of Science “life cycle assessment” alternatively combined with “novel foods,” “algae,” “cultured/cultivated meat,” “mycoprotein,” and “edible insects”. After removing the duplicates, the articles were screened based on their titles and abstracts, and only those consistent with the study’s aims were reviewed. The records were analysed regarding the LCA application and the results.

3. RESULTS AND DISCUSSIONS

A total of 26 published studies developing the LCA of NFs were reviewed. The number of publications has increased in the past three years (Figure 1), reflecting the growing interest in novel foods and the relevance of LCA methodology for this sector. Most of the studies focused on single NFs, while 11% of the sample articles compared the environmental performances of different NFs (Figure 2). Microalgae, edible insects, and cultured meat were the most represented NF categories. Results from the studies on microalgae were consistent with each other, as they assessed cultivation as the primary hotspot of the production systems because of the extensive use of chemicals, nutrients, and energy. Insects were confirmed to be valid substitutes for animal-source products by performing similar nutritional quality and reducing environmental impacts, especially concerning land occupation. The environmental impacts of cultured meat production were due to the preparation and acquisition of culture medium ingredients and the energy consumption in the bioreactors. The findings of the reviewed studies were highly variable, mainly because of differences in the methodological choices adopted, as shown in Table 1. All the reviewed papers utilized an attributional approach, thus indicating a preference for identifying direct environmental impacts rather than decision change effects. Similarly, the prevalence of the ex-post LCAs demonstrates a tendency to analyse existing systems and products instead of focusing on prospective scenarios. Noticeably, a few papers integrated nutritional aspects, and only one nLCA extended the level of assessment to the meal perspective (Mazac et al., 2023). Based on the latter, NF meals were similar to protein-rich plant-based ones and showed lower environmental impacts regarding nutrient richness than most animal-source meals. Adopting nFUs significantly affected the results, and composite indices were recommended for NFs, especially those with high micronutrients and healthy compound contents. Furthermore, many of the reviewed papers' authors performed sensitivity and/or scenario analyses to improve the robustness of the results and highlight study limitations.

4. CONCLUSIONS

Although relatively new, the LCA body of knowledge on NFs clearly points to their potential positive role in addressing most of the major environmental problems of food systems. However, holistic studies are still urgently needed to evaluate the social, economic, nutritional, and health consequences of replacing animal-sourced foods with NFs in diets and food systems.

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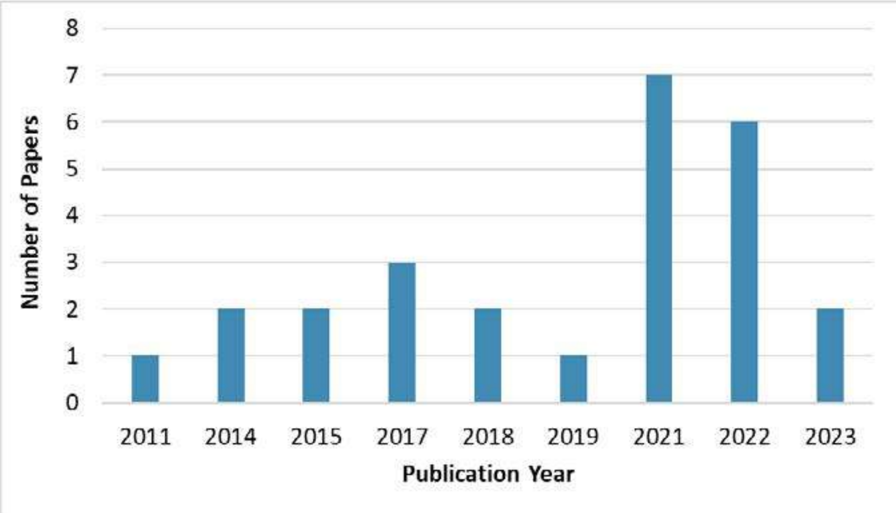

Figure 1. Publication trend

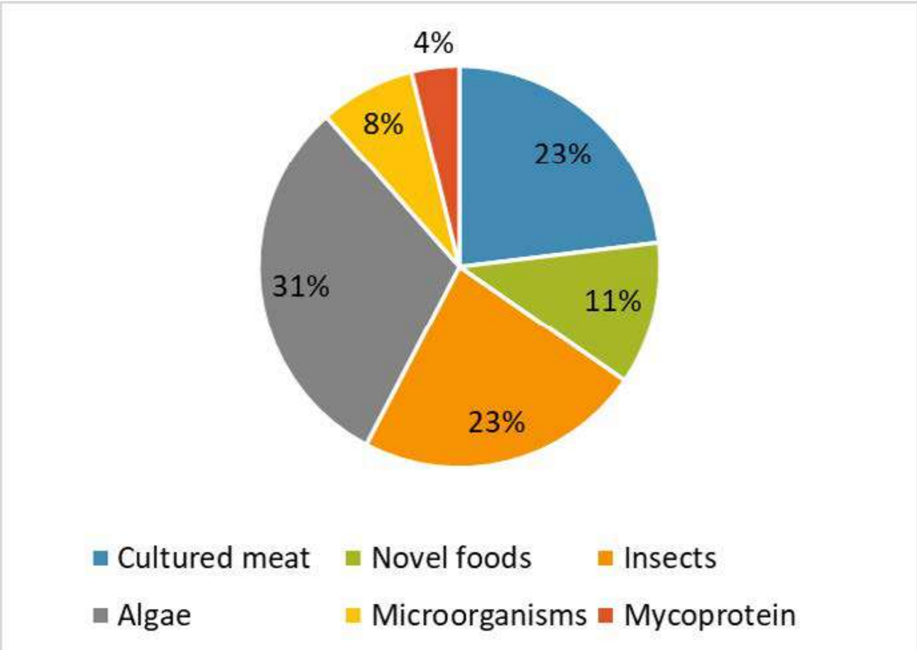

Figure 2. Paper classification based on novel food categories. The novel foods category was derived from LCAs investigating and comparing multiple types of NFs.

Table 1. Key methodological elements of the reviewed LCAs

Key methodological elements		Number of papers
Approach	Attributional approach	26
	Consequential approach	0
Time framework	Ex-ante LCA	3
	Ex-post LCA	23
Functional Units	Conventional FUs	20
	Nutritional FUs	6
Dealing with Uncertainty	Up-scaling techniques and frameworks	5
	Sensitivity/Scenario analysis	16

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Protein supply with controlled environmental agriculture system: a life cycle assessment

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1. INTRODUCTION

Food supply chain contributes about one quarter of the total anthropogenic greenhouse gas emissions. To meet increasing protein demand from growing global population, sustainable protein supply should be realized [1]. Substituting animal foods with alternative protein sources and implementing new agricultural systems for sustainable protein production are proposed to address the global protein challenge [2]. Controlled environmental agriculture (CEA) systems are developed to produce and investigate the potential of four alternative protein sources: wheatgrass, mycelium, microalgae, and edible insects. Production in CEA promises minimizing the vulnerability of crops to external factors and secure a year-round production with higher yield [3]. Due to limited Life Cycle Assessment (LCA) studies, the sustainability of alternative protein sources from CEA is so far unclear. The objective of this study is therefore to assess the environmental impacts of the developed alternative proteins from CEA — in comparison with conventional protein sources.

2. METHODS

LCA following the ISO Norms 14040/44 is carried out using OpenLCA and recommended life cycle impact assessment methods according to the Environment Footprint 3.1 method. The scope of the LCA is cradle to farm-gate and one kg of protein is used as functional unit. The FU is adjusted based on the Amino Acid Score (AAS) (see Table 1) to consider protein quality when comparing the investigated protein sources, so that a more comprehensive and reliable comparison is achieved. Primary data of pilot-scale production are collected for the LCA. The LCA of reference products (beef, milk, and chicken) are calculated using Ecoinvent datasets. The sensitivity of the electricity sources on the impact results is also studied.

3. RESULTS AND DISCUSSION

The results show that the potential of mycelium, wheatgrass and edible insects as alternative protein sources may be limited due to low content of certain essential amino acid (see Table 1). The global warming impact (GWI) shows a higher value for these three protein sources when protein quality is considered. Hence, a combination of various alternative protein source is one solution to compensate for the limiting amino acid. The results also highlight the strong influence of the power source on the carbon footprint for the alternative protein sources (see Figure 1). Edible insects have the lowest carbon footprint among the four investigated protein sources. The GWI is calculated at 390, 152, 92 and 33 kg CO_2-eq. per 1 kg AAS-adjusted protein for wheatgrass, mycelium, microalgae, and edible insects respectively. Electricity demand in CEA, primarily driven by cultivation, is the main contributor to GWI for wheatgrass, mycelium, and microalgae. Considering the relatively high carbon footprint of the current Germany electricity mix, these three protein sources are uncompetitive with the traditional protein sources. All protein sources will show benefit compared to milk and beef protein if the production is supplied with renewable electricity sources, however the GWIs are higher than the chicken protein. Besides, trade-offs with other impact categories should be scrutinised.

4. CONCLUSION

LCA was conducted for the four alternative protein sources produced in CEA. Among these sources, edible insects emerged as the most sustainable protein option, showing lower GWI compared to milk and beef protein. The primary challenge associated with the remaining three protein sources is predominantly attributed to the intensive electricity consumption involved in their production processes. Hence, switching to renewable energy is important to improve the overall sustainability. Considering the early stage of development, these novel protein production technologies have significant potential to contribute to a sustainable protein supply in the future.

5. ACKNOWLEDGEMENTS

The study presented in this paper stems from the project “FutureProteins” The authors would like to thank project partner Fraunhofer IME; IVV; IGB for providing primary data.

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Table 1. Amino Acid Score (AAS) of the protein sources calculated using limiting AA (lowest amount relative to the body's requirements) content in each protein source, divided by the required amount for adults in g per 100 g of protein, as recommended by FAO

Amino Acid	Mycelium	Wheatgrass	Microalgae	Mealworm	Milk	Beef	Chicken
Cysteine + methionine	83 %	114 %	157 %	109 %	166 %	161 %	170 %
Tryptophan	192 %	618 %	318 %	100 %	236 %	167 %	167 %
Threonine	216 %	407 %	192 %	113 %	185 %	160 %	160 %
Valine	151 %	127 %	138 %	90 %	173 %	143 %	118 %
Isoleucine	159 %	114 %	127 %	83 %	207 %	170 %	163 %
Leucine	130 %	114 %	144 %	78 %	169 %	138 %	116 %
Tyrosine + Phenylalanine	209 %	101 %	205 %	223 %	270 %	176 %	168 %
Lysine	172 %	34 %	175 %	63 %	182 %	175 %	165 %
Histidine	159 %	438 %	125 %	159 %	181 %	181 %	181 %
AAS score	83 %	34 %	100 %	63 %	100 %	100 %	100 %

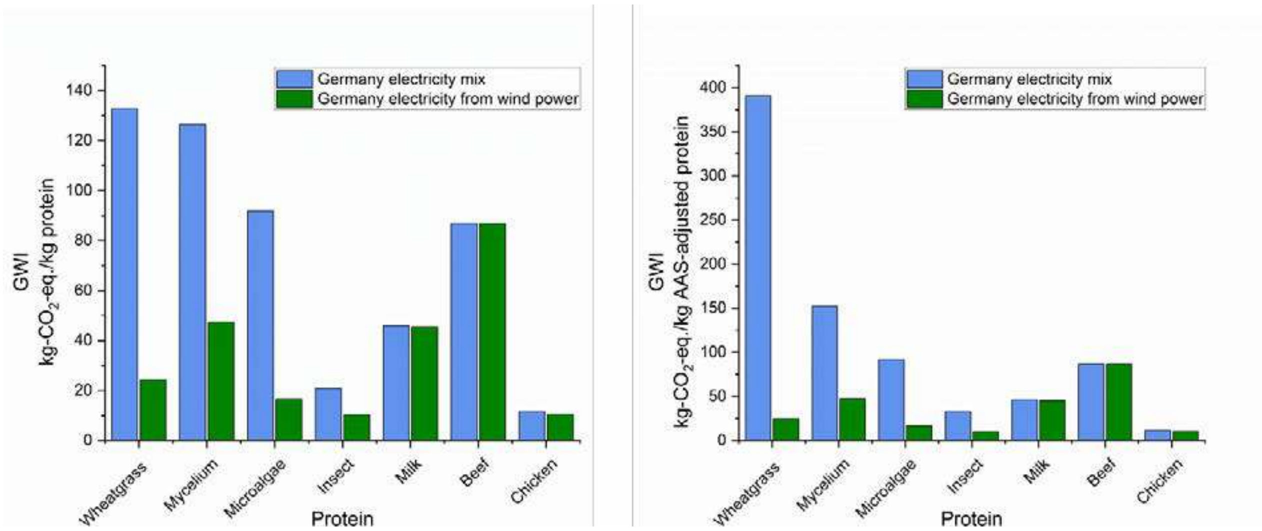

Figure 1. GWI of the investigated protein sources (Left: kg of protein as FU, Right: kg of AAS-adjusted protein as FU)

Sustainable territories and economies

14th International Conference
LCA FOOD 2024

HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Modelling resilience of European Agriculture utilizing synergism of Life Cycle Assessment, macro-economic model (MAGNET) and dynamic crop and livestock models

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1. INTRODUCTION

Climate change and emerging other external and internal factors put pressure on the food system. To make agriculture and farming more resilient to these pressures, while improving biodiversity and preserving food security, the Horizon 2020 ECO-READY project aims to provide support in adapting to the emerging challenges European farmers face by providing a real-time surveillance system. In order to quantify the impacts of the selected shocks (e.g. climate change/pandemic) for the mid- and long-term (2030 and 2050), environmental and social Life Cycle Assessment (LCA) will be linked to the macro-economic MAGNET model as well as to dynamic crop and livestock models.

2. METHODS

A first workshop took place to test the linkages between the three models, by identifying drivers, interventions, and measurable outputs for the first two pilot studies being conducted; wheat in Central Bohemia, and sheep in Occitanie. Next steps are to finalize the selection of regionally important products for the Living Labs, which will be quantified. In a workshop with the stakeholders the relevant S-LCA impact categories will be determined and the data availability of the stakeholders. The aim is to model a baseline scenarios (i.e. the current situation) for the selected products and for the selected impact categories. After this, the mid- and long-term impact of the selected shocks will be quantified. The dynamic crop and livestock models can model product specific component, while MAGNET is a global general equilibrium model, which works with inputs of monetary values (such as capital stock, investment, turn over, but also water consumption, CO_2 and yield). Based on the selected shock the connection between the models (in Figure 1) will be determined (i.e. crop/livestock models/MAGNET/LCA).

3. RESULTS AND DISCUSSION

A workshop took place where the two pilot studies were discussed in more detail, being Wheat from Central Bohemia and Sheep from Occitanie. The results of these pilot studies will be explained, so the possible connections between the models will become more apparent.

The main drivers for the wheat system tend to be climatic in nature, such as climate change, extreme weather events, crop disease, soil nutrition and health, as well as current farming practices. Possible interventions are climate resilience, adaptation measure and managing water reservoirs. The aim is to measure this by means of dynamic crop and livestock models and LCA. For the LCA model, input variables could also include fertilizers and water consumption similarly to MAGNET.

The main drivers for the sheep system are linked to diseases and climate change. For example, climate change affects temperature and precipitation, which in turn affect parasite loads and disease. Possible interventions are breeding for resilience and the incorporation of silvopastoral systems, which the dynamic crop and livestock models can model as an input for LCA. The MAGNET model is more tailored towards the economic and monetary input variables, such as monetary value of yield, land, feed, conversion of land into feed and inputs of CO_2. MAGNET can for example estimate the feed composition for a shock in the economy (e.g. Ukraine war -> no feed ingredients imported from Ukraine anymore -> new equilibrium and feed composition), which can serve as an input for LCA. The LCA model for sheep identified feed quantity/quality, feed conversion rate, product yield and water consumption as potential input variables. By means of LCA the impact of different breeding systems or feed composition can be quantified.

4. CONCLUSIONS

One of the key objectives of the workshop was to derive measurable outputs from the piloted scenarios (wheat and sheep), and link these outputs with inputs to the downstream models, for the purpose of giving further justification and scale to the proposed regional level scenarios. The dynamic crop and livestock models are able to models a lot of details in the regional production systems of a food product, while the MAGNET model operates on a national and monetary level. The aim is to translate outputs from both models to useful inputs for the LCA, so the impact of the selected shocks to the European food system can be quantified.

Concluding, at this moment in time the first attempts have been made to link these models to one another by identifying outputs and inputs of all these models. At the moment of the conference all the results of the Living Labs will be there.

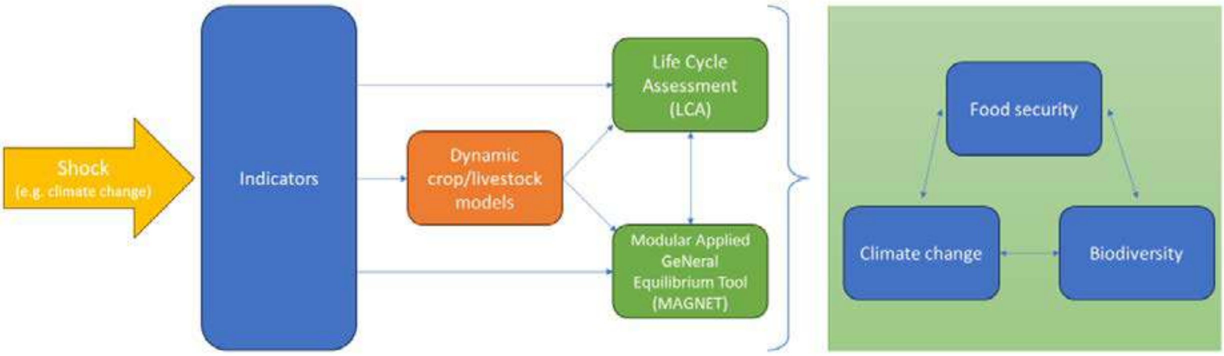

Figure 1 Conceptual outline of the scenario model as developed during the workshop.

Grant Agreement No. 101084201, programme: HORIZON-CL6-2022-CLIMATE-01

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Assessing food consumption patterns in Spain towards LCA of diets: pathways for a just transition

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1. INTRODUCTION

Agri-food systems are important contributors to global socio-environmental impacts directly affecting human health (Gaupp et al., 2021). Typically, life cycle assessments (LCA) of food focus on the environmental profile of individual products (Cambeses-Franco et al., 2022; González-García et al., 2020), frequently overlooking their production aspects and the socioeconomic characteristics of the population. This study aims to gather and interpret consumption data in Spain to assess the sustainability of food consumption patterns with LCAs considering socioeconomic aspects. Specifically, we aim to foster sustainable territories and economies by (a) analysing Spanish consumption patterns considering different socioeconomic strata; (b) examining existing relations between class-related consumption habits, type of food, and territorial productivity (c) outlining transition scenarios based on differentiated results from the survey data and production methods.

2. METHODS

The Baseline Diet (BD) was obtained from the 2022 Household Average Consumption Survey of the Ministry of Agriculture, Fisheries, and Food (MAPA, 2023). Four socioeconomic groups were also considered: high, medium, medium-low, and low socioeconomic household BDs (MAPA, 2005). A statistical analysis of the five BDs was carried out to find any significant difference in consumption patterns and cross them with production methods. In the analysis, the EAT-Lancet Commission Diet was assumed to be healthy and sustainable and thus used as the reference diet. A literature review on products' Carbon Footprint (CF) in Spain was also carried out to understand the environmental impacts of food consumption and production.

3. RESULTS AND DISCUSSION

Preliminary results show an excess in daily intakes in the high-class BD, which accounts for almost one-third of the total average amount of meat consumed (29%, Table 1). The latter pairs with a noticeable increase in consumption of beef and lamb, pork and fish - for which excesses are significantly more pronounced in the high-class BD. This class also consumes more vegetables, fruit, and grain compared with the other BDs (Table 2). Despite the differences in absolute food consumption, all the BDs reveal excess animal-based proteins, dairy products, and added sugars compared to the reference diet, while lacking plant-based proteins, grains, and vegetables (Table 2). We focus our attention on animal-based products, which - due to their CF and class-depending consumption - show a higher degree of improvement. In line with these results, we identify three preliminary scenarios (Table 3): (i) boosting a reduction in the consumption of animal-based products, focusing on high- and middle-class consumption. This scenario aims at evening the CF between high- and low-strata BDs, decreasing consumption by 120-45 g per person^{-1} day^{-1}; (ii) Favouring the consumption of plant-based products for low-classes, which should increase vegetables and plant-based products consumption by 90-93 g per person^{-1} day^{-1}. This scenario aims at improving food security and thus requires a special emphasis on groups in vulnerable conditions; (iii) combining reduction and changing production of different systems taking into consideration systems linked with local resources.

4. CONCLUSIONS

The shift towards sustainable and healthy agri-food systems is a cross-cutting issue that needs to take into account the characteristics of the production systems, as well as socioeconomic aspects affecting consumers' decisions. Further CF analysis related to Spanish BDs is required to explore transition scenarios through LCA studies. Nonetheless, our preliminary results represent a starting point to improve the sustainability of food habits in Spain.

5. ACKNOWLEDGEMENTS

This research is part of the project SWITCH (HORIZON-CL6-2021-FARM2FORK-01-15) funded by the European Union. This research is also supported by María de Maeztu Excellence Unit 2023-2027 Ref. CEX2021-001201-M, funded by MCIN/AEI /10.13039/501100011033.

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7. Annex

Table 1. Daily intake and comparison in g person^{-1} day^{-1} between EAT-Lancet Diet, Spanish Baseline Diets, High Socioeconomic Class (HSC), Middle Socioeconomic Class (MSC), Middle-Low Socioeconomic Class (MLSC), and Low Socioeconomic Class (LSC) Baseline Diets (BD).

EAT-Lancet Diet g person^{-1} day^{-1}	Spanish BD g person^{-1} day^{-1}	HSC BD g person^{-1} day^{-1}	MSC BD g person^{-1} day^{-1}	MLSC BD g person^{-1} day^{-1}	LSC BD g person^{-1} day^{-1}
1312	1233	1457	1227	1211	1154
Differences	-79	+145	-85	-101	-158

Table 2. Daily intake of the Spanish average BD aggregated in eight Food Groups and compared with EAT-Lancet Diet (also Planetary Diet). Differences are displayed both in g person^{-1} day^{-1} and in percentage (%). § Includes fresh and processed items. Daily income for the four income-based BDs: High Socioeconomic Class (HSC), Middle Socioeconomic Class (MSC), Middle-Low Socioeconomic Class (MLSC), and Low Socioeconomic Class (LSC) Baseline Diets (BDs). § Out of the total amount of average meat consumed by the four BDs, the total average amount of meat consumed by the HSC BD accounts for 29%.

Food Item	EAT-Lancet Diet g person^{-1} day^{-1}	Spanish BD g person^{-1} day^{-1}	Difference in daily intake %	HSC BD g person^{-1} day^{-1}	MSC BD g person^{-1} day^{-1}	MLSC BD g person^{-1} day^{-1}	LSC BD g person^{-1} day^{-1}
Grain	232	104	**-55**	118	101	103	103
Starchy vegetable	50	72	45	84	74	69	68
Fruit	200	221	11	271	211	216	213
Vegetable	300	138	**-54**	164	135	132	133
Dairy food	250	277	11	325	283	275	247
Beef and lamb§	7	11	**52**	14	11	10	9
Pork§	7	41	**488**	47	42	41	38
Poultry§	29	37	28	42	38	37	35
Eggs	13	22	**71**	25	21	22	22
Fish	28	53	**88**	68	52	49	49
Legumes	100	9	**-91**	10	9	9	9
Tree nuts	25	9	**-65**	11	9	9	8
Unsaturated plant oil	40	28	-29	32	28	29	31
Added sugar	31	51	**65**	57	52	51	47

Products	**HSC BD g person^{-1} day^{-1}**	**MSC BD g person^{-1} day^{-1}**	**MLSC BD g person^{-1} day^{-1}**	**LSC BD g person^{-1} day^{-1}**
Animal-based §	522	446	433	401
Plant-based §§	456	364	366	363

Table 3. Daily intake of animal-based and plant-based products divided by class. § Includes Dairy food, Beef and Lamb, Pork, Poultry, Eggs, and Fish. §§ Includes Fruit, Vegetable, Legumes, Tree nuts. Increasing and decreasing food consumption scenarios consider the difference in intake between HSC-MSC BDs and MLSC-LSC BDs.

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Brazilian biodiesel mandate: challenges and limitations in future scenarios

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1. INTRODUCTION

To mitigate greenhouse gases (GHG) emissions and increase energy security, Brazil plans to increase biofuel use through, among other strategies, mandates of biodiesel (BD) mix on fossil diesel. From March 2024 onwards, BD added to diesel was $14\%_{(v/v)}$ and, from March 2025 on, $15\%_{(v/v)}$ (CNPE 2023). Demand for diesel is expected to nearly double in 2050 (MME/EPE 2020). Thus, BD use will have to expand to cope with both the rise of blend mandates and the increasing consumption of diesel. In Brazil 60% of BD is produced from soy oil (ANP 2023b) but 63% of soy is exported (ABIOVE 2023). This study investigates the GHG mitigation potential of soy BD in mixing mandates by 2050 using Life Cycle emissions (LCA-GHG) and alternative land demand and direct land use change (dLUC) scenarios, as well as the effects on feedstock supplies.

2. METHODS

Diesel demand is estimated from 2015 to 2050, based on official projections (EPE, 2020) and gap filling by linear interpolation. A low and high range of BD blend was considered: (i) B15 that corresponds to the current mandate is assumed to keep at the same level by 2050 and (ii) B20 from 2024 onward as in the claim pushed by the agribusiness sector. GHG savings were estimated with LCA-GHG of soy BD from RenovaBio (ANP 2023a), assuming it as the only feedstock for simplification. Soy's land demand was calculated using productivity data from RenovaCalc (ANP 2020) and CONAB (2023). dLUC emissions were estimated by carbon stock differences and BRLUC (2021) carbon stocks values weighted on soy production. The dLUC scenario assumes that 100% of additional demand is met with soy expansion over moderately degraded pasture, which matches with Brazil's Degraded Pasture Conversion Program (Brasil 2023). A 33% allocation factor for BD was used based on the lower heating value of the co-products.

3. RESULTS AND DISCUSSION

By 2050, diesel use is 3.4 EJ/yr, being 0.5 EJ for BD considering the current mandate (Figure 1). Cumulative BD demand is 11.8 EJ and emissions savings without dLUC range from 458 to 706 $MtCO_{2e}$ since soy BD's LCe varies from 26.4 to 47.5 gCO_{2e}/MJ. For B20 scenario, both emissions savings and annual demand are 33% higher (Table 1). Brazil produced 0.25 EJ of BD in 2023 so it would need to add 0.27 EJ in 2050. Meeting supply with land expansion demands 12 Mha and dLUC emissions could be 150 $MtCO_{2e}$ with values 64% higher for B20 (Table 2). Just crushing the exported soybean instead, adds 0.69 EJ, meeting demand and, thus, avoiding dLUC. Indirect LUC (iLUC) was not assessed.

4. CONCLUSIONS

Current BD mandates would demand 12 Mha by 2050 if met with land expansion; if this dLUC happens over moderately degraded pastures, the blending would avoid 308 to 556 $MtCO_{2e}$; if dLUC does not occur, savings can be up to 706 $MtCO_{2e}$. Anticipating B20 to 2024 increases savings, but it has a larger impact on land demand that would need to be balanced. dLUC emissions can be minimized or avoided by crushing more soybean, but consequences of that, such as iLUC, were not evaluated. Uncertainties concerning LUC calculations are high and a stochastic evaluation would be needed to confirm the robustness of these conclusions.

5. ACKNOWLEDGEMENTS

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Table 1. Cumulative and annual demands for biodiesel by 2050 and total emission savings for the scenarios of current mandate and of adopting B20 from 2024 on.

	Cumulative biodiesel demand (EJ)	**Annual demand by 2050 (EJ)**	**Emission savings without land expansion ($MtCO_{2e}$) - Soybean**
Current (B15 in 2024)	11.75	0.52	458 – 706
B20 in 2024	15.59	0.69	609 – 938

Table 2. Land use change emissions for different scenarios to achieve additional biodiesel demand by 2050.

	Additional land demand (Mha)	**Emissions from LUC over moderately degraded pasture ($MtCO_{2e}$)**
Soybean expansion – Current B15 scenario	11.85	150
Soybean expansion – B20 scenario	19.48	248

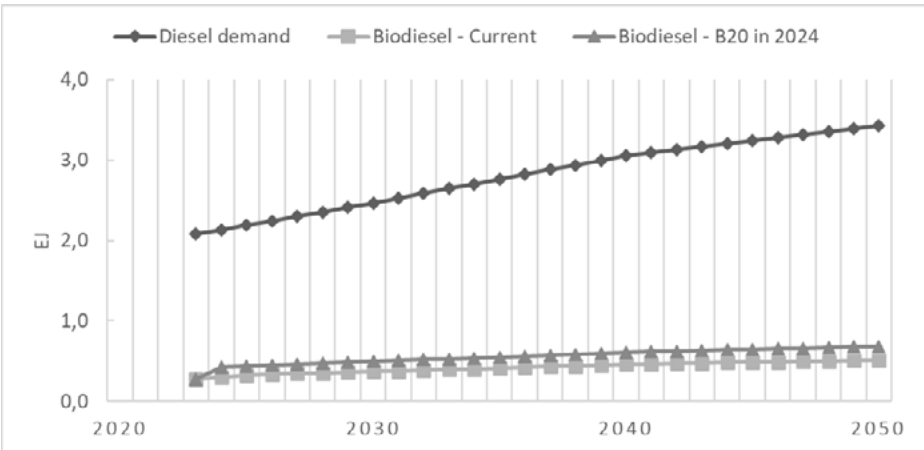

Figure 1. Brazil's diesel and biodiesel demand by 2050 – Estimates based on EPE (2020) and CNPE(2023).

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Environmental Rebound Effects of Embracing Sustainable Diets – A Macroscopic Exploration of Consumption Patterns in Belgium

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1. INTRODUCTION

Unbalanced and unresponsible eating habits exert severe pressures on our environmental planetary boundaries. In response, eating well and healthy within earth's limit, i.e., sustainable healthy diets, are frequently advocated as effective strategies for reducing our environmental footprint. However, few analyses fully account for comprehensive behavioural adjustments. Existing studies indicate significant environmental benefits, yet these outcomes can be influenced by assumptions concerning the substituted food items and overall lifestyle choices, including consumption of other goods (Grabs, 2015). Moreover, rebound effects, which could potentially negate environmental gains resulting from the adoption of sustainable diets, are often overlooked or partially accounted for.

This study aims to quantify the potential economic and environmental impacts, as well as the probable direct, indirect and economy-wide rebound effects associated with the transition of an average Belgian consumer to a sustainable diet.

2. METHODS

We construct a dynamic economy–energy–environment computable general equilibrium (CGE) model of the Belgian economy to simulate the impacts of various dietary shifts in household scenarios on GDP and environmental indicators. This model builds upon the one developed by (Freire-González & Ho, 2021) for Spain and Catalan. The analysis uses expenditure category-specific Belgian household expenditure data, differentiated by income classes, which is based on the household a budget survey of Belgians. This allows to determine the average consumption profile of a Belgian household and constitutes the basis for designing scenarios which are sustainable diets. The developed model is linked to an impact assessment method to convert the environmental pressures of each scenario into characterized environmental impacts using the Environmental Footprint method EF3.1 (Bassi et al., 2023).

3. RESULTS AND DISCUSSION

The anticipated findings will demonstrate the potential economic and environmental savings of transitioning to sustainable diets. The results will further uncover how much the economic and environmental savings will be absorbed taking consistently into account rebound mechanisms (increased income, re-spending, economy-wide effects,…), and will vary according to their current and sustainable diet preferences. Moreover, the expected results will elucidate conditions under which a successful sustainability transition could occur with minimal or no rebound effects.

4. CONCLUSIONS

This study demonstrates the development and application of an integrated model that unifies input-output analysis, life cycle assessment, CGE modelling, econometric analyses and scenario analysis to appraise the impacts of diets shifts considering spillover and unintended side effects (i.e., rebound effects) at economy-wide level.

This model holds significant analytical potential, which is only partially tapped into in this study, leaving numerous avenues for further research across various applications and for the continuous refinement of the model. The findings derived from applying such a model can be instrumental in formulating policy recommendations, particularly in the realm of food policies but also concerning consumption patterns more broadly.

5. ACKNOWLEDGEMENTS

This research is supported by the Fund for Scientific Research (F.R.S.-FNRS) which we thank for that.

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Session: Sustainable territories and economies
LCA of local food chains: the compromise of environmental sustainability

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1. INTRODUCTION

Shortening value chains and giving territories back control over their food supplies is seen as a potential response to improving the sustainability of food systems and making them more resilient in many regions of the world. Indeed, local food chains are perceived as more sustainable than conventional ones. However, according to Brunori and Galli (2016), the environmental sustainability of food chains depends more on the strategies of the actors involved than on their degree of geographical proximity.

Territorialised agri-food chains (FAT) are emblematic of the process of re-territorialisation of the food system in France. They consist of the structuring of agri-food value chains within a territorial (or local) perimeter, with a limited but reasonable number of intermediaries, enabling them to be sufficiently efficient.

In this work, we quantify the environmental sustainability of French FAT bread, and vegetables for catering, through the LCA of 5 case studies with the aim of identifying the technological and organizational determinants of the environmental sustainability of these sectors.

2. METHODS

Flow diagrams are drawn up on the basis of data collected from stakeholders. The diagrams are based on the value chain diagrams, but contain technical details on the nature and volume of the products. These parameters are representative of the different technological and organizational choices made by local stakeholders in the case studies. In terms of method, the product-oriented attributional LCA method was chosen, so that the environmental impacts calculated are attributed to a so-called "functional" product unit. This functional unit differs from one sector to another, but is identical for all scenarios within the same sector. Finally, prospective scenarios, reflecting variations in organizational and technological choices as well as different production scales, are modelled and analyzed. Two types of impact are calculated: impact indicators (mid-point) and indicators of damage to human health, ecosystems and resources (end-point) using the ReCiPe 2016 method.

3. RESULTS AND DISCUSSION

The results confirm the absence of a direct correlation between spatial proximity between stakeholders and environmental performance, as already noted in the scientific literature.

While agricultural production contributes most of the impact, other stages in the life cycle have a major impact on the environmental performance of FATs. In the case of vegetables processed for the catering industry, packaging is one of the stages in the life cycle with the greatest impact. In the bread sector, bread baking and transport are among the stages with the greatest impact.

The hybrid nature of FATs, their connection with the conventional system, can have an influence on the nature of the impacts and their significance. For example, a mix of local and conventional supplies is observed in the processed vegetable sector for the catering industry.

As far as the effect of production scale is concerned, increasing volumes leads to economies of scale for certain impacts or certain stages in the life cycle, but can have rebound effects. As a result, certain technological choices continue to determine environmental performance independently of these effects of scale This is the case, for example, in the bread sector, where, for equivalent technological choices, a regional sector could suffer from its smaller scale compared with a conventional, high-volume sector. However, virtuous technological choices at all stages of the life cycle (i.e. sober and agro-ecological agricultural production, high flour extraction yields, production of a long-life bread generating very little loss or waste at the consumption stage) would counterbalance the effects of scale.

4. CONCLUSIONS

Thanks to LCA modelling, it is possible to vary technological choices and production scales concomitantly in prospective scenarios. This method could make it possible to identify the best potential compromise in terms of environmental performance between different technological choices and production scales.

5. ACKNOWLEDGEMENTS

This work is part of the projet OPERANT (2020-2022), supported by ADEME (Agence de la Transition écologique).

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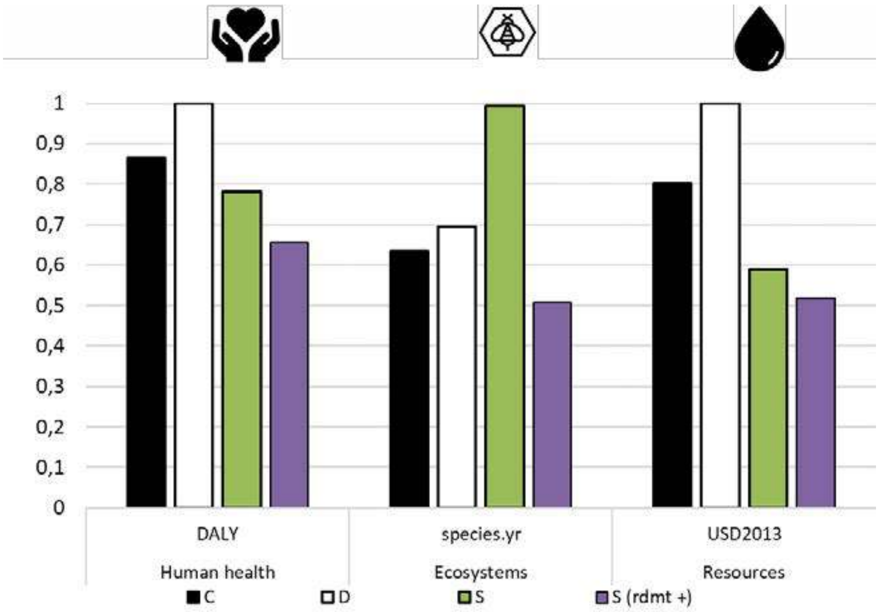

Figure 1: Damage to human health, ecosystems and resources of alternative scenarios for bread consumption D, S dans S(rdm+) compared with the conventional scenario C.

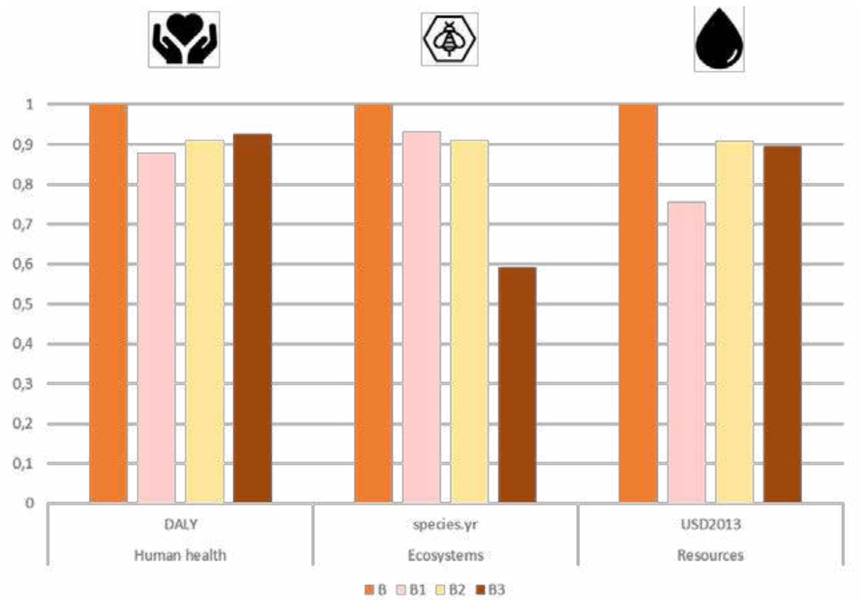

Figure 1: Damage to human health, ecosystems and resources of alternative scenarios for vegetable for catering B1, B2 and B3 compared with the reference scenario B.

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Food system transformation potential of house gardening across Europe – quantifying potential environmental benefits with hybrid Life Cycle Assessment

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1. INTRODUCTION

The food system stands at the intersection of many environmental crises such as climate change or biodiversity loss. Consequently, it needs to transform both to mitigate environmental impacts, as well as to adapt to the changes in Earth System functioning. Alternative ways of food production like house gardening can play an important role in such a transformation. In addition to the role of providing food, the large surface areas covered by house gardens, mostly unused, could bring significant environmental benefits. These benefits, such as greenhouse gas mitigation or biodiversity improvements, are commonly assumed in the literature, but few studies actually attempt to quantify them. So far, there are few studies applying complex environmental impact assessment methods, such as Life Cycle Assessment (LCA). Therefore, the objective of this study is to fill this gap and to quantify the overall potential of gardening to reach sustainable food systems.

2. METHODS

To identify and map European gardens, cadastral data and other available maps are used. Cadastral data, providing detailed information about location and area of house gardens, are processed using GIS software. To calculate the potential quantity of food produced out of this area, data on yields are taken from available literature. Multiple scenarios of gardening are evaluated on the territorial and continental scale combining the type of crop grown, land utilisation rate and specifics of agro-ecological regions. Consequential LCA, utilising the agri-economic model CAPRI, is carried out to analyse the effects these multiple scenarios of food self-provision potentially entail on the global food market and to quantify the environmental consequences. The Environmental Footprint 3.0 impact assessment method with Open LCA is used to evaluate the impacts on relevant impact categories.

3. RESULTS AND DISCUSSION

Since this project is, at the time of abstract submission, still in the early stages, only preliminary results for the Czech Republic are available. Using cadastral data, the estimated area of house gardens in the Czech Republic is approximately 181,540 ha. Assuming that 80% of this area is used, between 0.37 and 0.42 Mtons of CO_2 eq could be avoided from traditional food production (Figure 1). The results also show that the type of crop grown can significantly influence the impacts, especially on water use. The expected results extend such analysis to the European scale and consequential LCA results are expected to illuminate the effects of house gardening on the environmental profile of the entire food system.

4. CONCLUSIONS

While quantitative data on potential environmental benefits from house gardening are missing in the literature, this research combines mapping and consequential life cycle assessment to fill this gap. The outputs of this research can show the transformative potential of house gardening in Europe, considering agro-ecological specifics.

5. ACKNOWLEDGEMENTS

This work was supported from the grant of Specific university research – grant No. A2_FTOP_2024_008.

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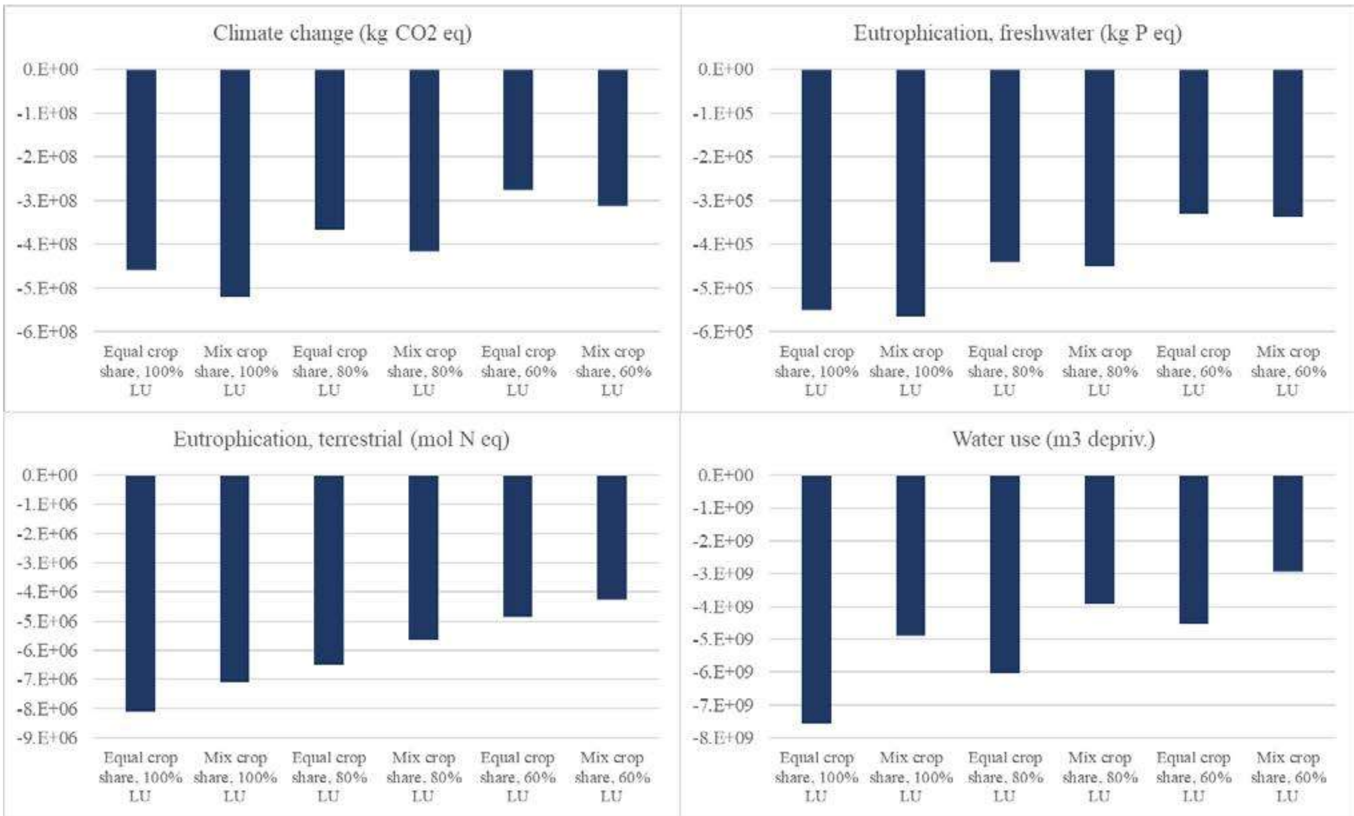

Figure 1.: Results of potential environmental impact savings in the Czech Republic. The total garden area was estimated based on the data by the *State Administration of Land Surveying and Cadastre of the Czech Republic*. Three scenarios of garden area utilization rate (100%, 80% and 60%) were considered. Data on garden produce yields for common vegetables and fruits was taken from the *Czech Statistical Office*, and multiple scenarios of crop share were evaluated (‘equal share’ and ‘mix cop’ share). The results represent potentially avoided environmental impacts stemming from reduced industrial food production (assuming an idealistic situation where house gardening requires no external inputs). The avoided impacts were evaluated based on Agribalyse database models in OpenLCA, evaluating four impact categories using the EU Environmental Footprint methodology. The potential avoided impacts depend on garden area utilization rate as well as on the production mix.

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Land use, crop rotation and emissions consequences of a European transition from meat towards legume-based foods

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1. INTRODUCTION

There is an urgent need to reduce meat consumption and increase legumes intake in the European diet to transform the food system in to one that supports human and planetary health (Willett et al., 2019). Following the sustainable EAT Lancet diet recommendations for Europe (Willett et al., 2019), we perform a consequential LCA (cLCA) to quantify the changes in environmental impacts associated with 1) a gram/gram substitution of excess beef, pork, and chicken products with corresponding highly-processed plant-based meat analogues (*Processed*); 2) a calorie/calorie or gram protein/gram protein substitution of the same meat products for minimally processed legumes (*Non_processed*); 3) a reduction of excess meat products and a capped increase of minimally-processed legumes to match quantities for these categories in the EAT Lancet diet (*Capped*). While the first scenario represents a transition situation that is more likely to happen in the short term, the other scenarios represent a desirable situation that is more favourable in terms of achieving a healthier diet in the long run. Uniquely, unlike previous diet-LCA studies that use generic database footprints and thus do not consider consequences of changes in agricultural rotations, we explicitly model shifts from existing rotations to paired legume-integrated rotations across agro-ecological zones at a European level. This enables a first estimate of European cropping system and land use transformation associated with transformative diet change (including afforestation on spared grasslands). Results indicate the potential to achieve a “net zero” greenhouse gas emission agriculture and land sector in Europe.

2. METHODS

The goal of the study was to quantify the potential environmental outcomes attributable to a shift in the average European diet towards lesser animal protein and higher plant protein under more or less processed forms, from cradle to consumption. A cLCA was performed on scenarios of diet change among 322 million people across 14 European countries where 65 agricultural rotation changes containing 12 crops were available (Reckling et al., 2016), substituting animal-source foods for legume-based meat analogues or minimally processed legumes. Figure 1 is a schematic diagram of the boundaries of the LCA study. Background data were taken from the Ecoinvent version 3.9.1 consequential database (Wernet, 2016), and meat analogues and meat products inventory data were adapted from Agribalyse v. 3.1 (Colomb et al., 2015) and a publication (Saget et al., 2021). Modelling was undertaken in MS Excel, Python 3 (Virtanen et al., 2020), and OpenLCA version 1.11 (GreenDelta, 2022).

3. PRELIMINARY RESULTS AND DISCUSSION

Results will be calculated in terms of greenhouse gas (GHG) emissions to identify the contribution of transformative diet change in achieving the 2050 net zero GHG target (European Commission, 2024). The role of the integration of legumes into agricultural rotations and their benefits in terms of N fertiliser savings will also be highlighted and linked to Planetary Boundaries for nutrient cycling. cLCA results will be benchmarked against the basic attributional LCA approach from the EAT Lancet report (Willett et al., 2019).

4. CONCLUSIONS

To our knowledge, this is the first study to explicitly model potential crop rotation and land use changes linked with EAT-Lancet diet recommendations at a European scale.

5. ACKNOWLEDGEMENTS

Funding for this research was provided by the EU-H2020 framework via the Research and Innovation Actions www.TRUE-project.eu, and www.RADIANTproject.eu Grant Agreement numbers 727973, and 101000622, respectively.

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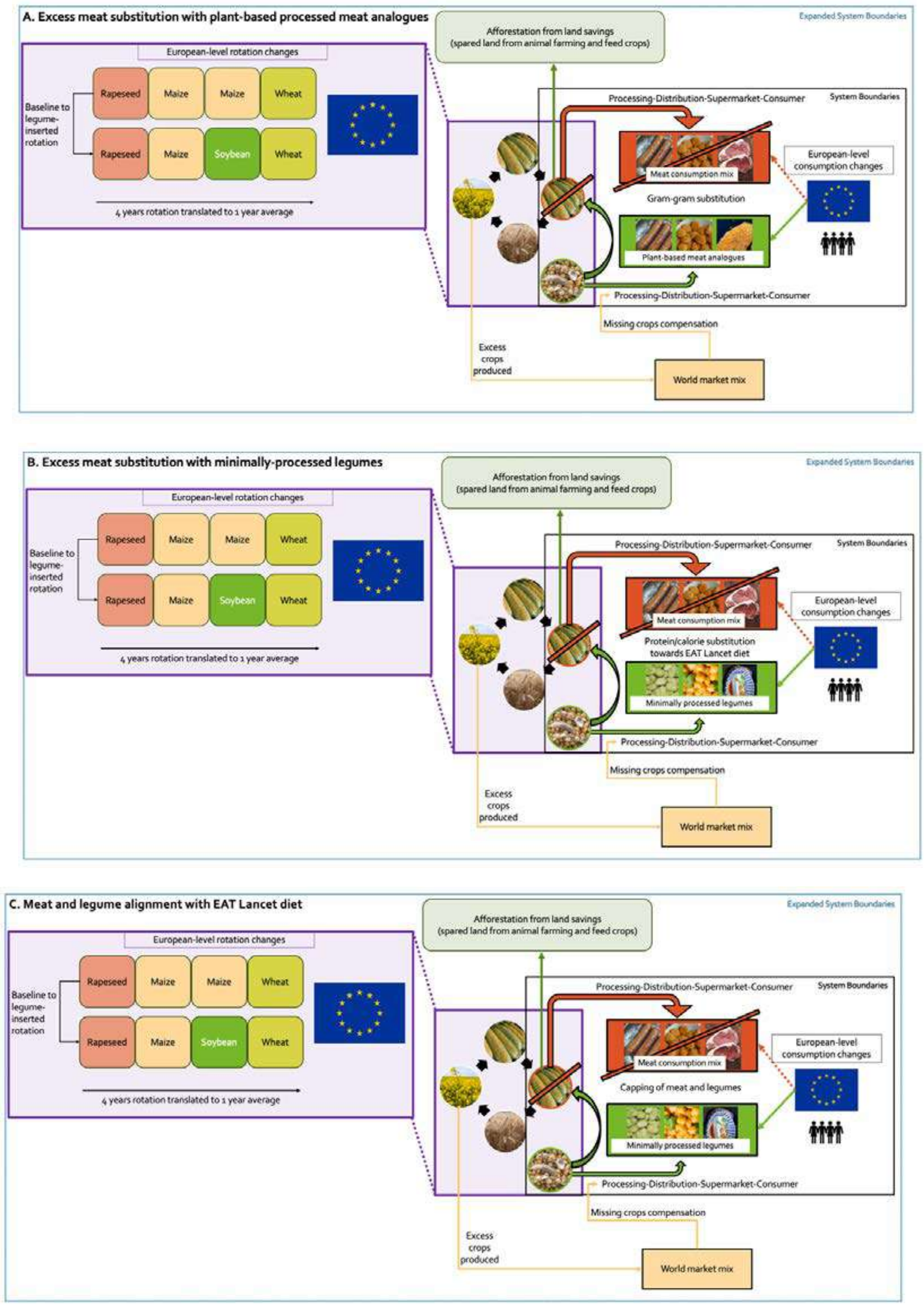

Figure 1. Schematic diagram of the consequential LCA study. **1.A.** *Processed* scenario where meat surplus is substituted with ultra-processed plant-based meat analogues on a g/g basis. **1.B** *Non_processed* scenario where meat surplus is substituted with minimally processed legumes on a g protein/g protein or kcal/kcal basis; **1.C** *Capped* scenario where both meat and legumes intake are adjusted to the recommended amounts by the EAT Lancet report.

Exploring willingness to pay for healthier and more sustainable diets in Iceland: A four-part contingent valuation study

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1. INTRODUCTION

A recent dietary survey of Icelanders characterized the typical diet of Icelanders and identified critical areas of deficiencies and surpluses (Directorate of Health, 2022). In general, Icelanders do not eat enough fruits, vegetables, whole grains, or fish, and 60% of participants exceeded the recommended amount of red meat consumption. Many researchers agree that limiting consumption of animal-based products will lead to environmental benefits by minimizing the impact of food production on the planetary boundaries (David-Benz et al., 2022; Willett et al., 2019). Studies have shown that consumers are willing to pay a 30-40% premium for sustainable food products. Willingness to pay (WTP) studies such as these are useful for every actor along food value chains. Still, they are limited to individual items or industries and there has been no study to estimate the consumer surplus of a whole alternative diet that may reveal broader implications.

2. METHODS

In this study, we applied the contingent valuation method to estimate the consumer surplus for four dietary scenarios in Iceland – vegan, flexitarian, Nordic, and low-carb. The vegan diet consisted of entirely plant-based foods, the flexitarian diet was based on the planetary diet suggested by the EAT-Lancet report, the Nordic diet was based on the New Nordic Nutrition Recommendations 2023 (Blomhoff et al., 2023) report, and finally, the low-carb diet contained proportionally more animal-based foods. Each participant received one scenario at random when responding to the survey. The survey followed a typical contingent valuation format consisting of an introduction that described the typical Icelandic diet and collect behavioural and attitudinal data, followed by a presentation of an alternative diet and payment card WTP elicitation, the third section collected explanations for positive and zero WTP, and the final section collected sociodemographic information. Interval regression was utilized to determine statistical significance of explanatory variables.

3. RESULTS AND DISCUSSION

In partnership with the Social Science Research Institute at the University of Iceland, 3206 responses were received over four weeks. The sample size comprises nearly 1% of Iceland's population. The analysis is currently underway, the regression model is being used to test for statistical significance, and Table 1 depicts mean WTP for each dietary scenario.

4. CONCLUSIONS

The results from this study could be used to inform production and consumption incentives and could be combined with carbon footprint or life cycle analysis of each diet to understand the economic value of carbon savings from the low-carbon diets.

5. ACKNOWLEDGEMENTS

This work has been supported by Rannsóknamiðstöð Íslands (Rannís) in relation to the Sustainable Healthy Diets project (grant no. 200221-5601).

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Table 1. Mean willingness to pay with 95% confidence interval and estimate of total consumer surplus for each dietary scenario.

	Mean WTP	95% Confidence Interval	Estimated Consumer Surplus
Nordic	4947 ISK	[4465 – 5428]	79 billion ISK
Flexitarian	4740 ISK	[4257 – 5223]	76 billion ISK
Vegan	4450 ISK	[3950 – 4950]	71 billion ISK
Low-carb	4271 ISK	[3826 – 4717]	68 billion ISK

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Environmental assessment of intermediate processes in fresh vegetable supply chain: a case study of tomatoes in Japan

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1. INTRODUCTION

The Emirates Declaration at COP28 has redirected focus toward the resilient food supply chain, prompting a re-evaluation of the entire system. Shifting towards a future food system necessitates a transition in focus from consumer and producer to intermediary behavior (Li et al., 2022). Japan has a complex food system involving numerous actors, which ensures economic benefits (Miyake et al., 2010). However, the effect of this coordination in mitigating environmental impacts remains uncertain. This study investigates the conditions for establishing a sustainable food supply chain by assessing the environmental impacts of Japan's tomato supply chain.

2. METHODS

The tomato distribution process considered in this study is illustrated in Figure 1. The functional unit employed was defined as 1 ton of large tomatoes consumed in the Tokyo metropolitan area. Wholesaling processes commonly occur at wholesale markets, where approximately 80% of domestically produced fruits and vegetables (by volume) pass through (MAFF, 2022).

The study's eight scenarios outlined in Table 1 are composed of six elements (Cultivation method, Production area, Logistics method, Logistics location, Wholesaler presence, and Sales method). The Tokyo Metropolitan Central Wholesale Market served as the distribution hub due to its proximity to Tokyo. The targeted production areas were Kumamoto Prefecture, which is distant from Tokyo, and Ibaraki Prefecture, which is a suburban region. Tomato prices at wholesale and retail levels varied based on cultivation methods: conventional and pesticide-free approaches. The yield change rate for pesticide-free cultivation and the weight of tomatoes and associated inputs, such as cardboard boxes and containers, were considered in the analysis.

Impact assessments were calculated using the life cycle impact assessment method based on endpoint modeling v.2 (LIME2) for eight areas: Climate change, Acidification, Urban area air pollution, Photochemical oxidants, Toxicity to terrestrial creatures, Eutrophication, Land use, and Water resources consumption. The primary data for these assessments were sourced from IDEA v3.3 (JEMAI, 2023).

3. RESULTS AND DISCUSSION

The pesticide-free cultivation consistently exhibited higher environmental impacts across seven impact assessment areas, except for terrestrial ecotoxicity, irrespective of the settings of the five other elements besides the cultivation method (S-1, 3, 6, 8). Regarding terrestrial ecotoxicity, conventional cultivation showed higher impacts (S-2, 4, 7) attributed to pesticide usage. As for the wholesaler presence, pesticide-free tomatoes from Kumamoto showed a reduction in environmental impact when traded through the wholesale market (S-1, 3), while the effect was less for Ibaraki (S-6, 8). In Japan, pesticide-free fruits and vegetables are currently minimally traded on wholesale markets. Our results suggested that increased wholesale markets and logistics capacity to handle pesticide-free tomatoes could reduce their environmental impact.

4. CONCLUSIONS

This study constructed a model of Japan's tomato supply chain and assessed its environmental impacts. We found pesticide-free cultivation generally resulted in higher environmental impacts, except for terrestrial ecotoxicity. Furthermore, the wholesale trading of pesticide-free tomatoes from Kumamoto demonstrated a reduction in environmental impact compared to Ibaraki. The results underlined the potential of intermediaries to mitigate environmental impact.

5. ACKNOWLEDGMENTS

This work was supported by the JSPS KAKENHI Grant Number JP23K17084. This work was conducted under the partnership program of the Toyota Foundation at the Institute for Future Initiatives, the University of Tokyo.

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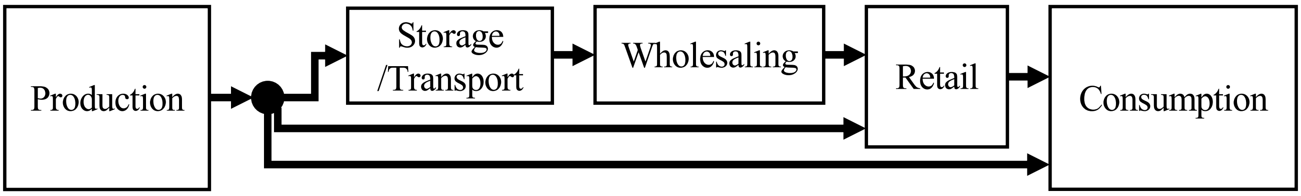

Note: A black circle means a junction.

Figure 1. Tomato distribution process

Elements	Scenario							
	S-1	**S-2**	**S-3**	**S-4**	**S-5**	**S-6**	**S-7**	**S-8**
Cultivation method	Pesticide-free	Conventional	Pesticide-free	Conventional	Pesticide-free	Pesticide-free	Conventional	Pesticide-free
Production area	Kumamoto	Kumamoto	Kumamoto	Kumamoto	Kumamoto	Ibaragi	Ibaragi	Ibaragi
1st Logistics method	Light van	20 t truck	20 t truck	Ferry	Airplane	Light van	20 t truck	20 t truck
1st Logistics location	DC	WM	WM	Port	Airport	DC	WM	WM
2nd Logistics method	Light van	4 t truck	4 t truck	4 t truck	4 t truck	Light van	4 t truck	4 t truck
2nd Logistics location	Home	SM	SM	SM	SM	Home	SM	SM
Wholesale Presence	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Sales methods	Home delivery	SM	SM	SM	SM	Home delivery	SM	SM

Notes: DC = Distribution Center, WM = Wholesale Market, Supermarket = SM

Table 1. Settings of scenarios

Sustainability of food systems in developing and emerging economies

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Some environments aspects of Brazilian typical meal preparation in restaurants

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1. INTRODUCTION

Food is the basic of human life and food production has major implications for the use and alteration of natural resources. Feeding a population of 7.6 billion requires the use of land, energy, water and has serious implications for the environment. Given that eating outside of the home has become increasingly significant, the project in which this abstract takes part focuses on evaluating the preparation efficiency of the basic Brazilian dish in restaurants, consisting of rice, beans, red meat steak, and salad. In this paper, some of the environmental aspects of the composition of this meal are presented and discussed. The completed project will be published subsequently.

2. METHODS

Data related to the preparation of the basic Brazilian dish were collected in São Paulo city during visits to nine restaurants which together prepare a total of 1880 meals daily. The food preparation processes on industrial-scale stoves were surveyed for cooking rice and beans, frying red meat steak and cleaning and sanitizing lettuce. The boundaries of this study included the agricultural, processing, and transportation stages to the meal preparation sites. Data inventory of the upstream chains of restaurants was extracted from the scientific literature. The study was modelled using the Gabi Professional software.

3. RESULTS AND DISCUSSION

The inventories of the food components were combined to simulate the typical Brazilian meal (used as a functional unit). The average weight of 442 grams, composed of 39% cooked rice, 19% cooked beans, 14% grilled steak, and 27% lettuce salad washed and sanitized according to the Food Guide for the Brazilian Population (Brazil, 2014).

The analysis of the contribution of components (Table 1) on the average meal reveals that the consumption of beef steak is a major contributor to the main impacts measured, contributing to practically 91% of the impact of climate change (CC), 86% of blue water use (BWU), 84% of land use (LU) and 47% of primary energy demand (PED). The portion of cooked rice is almost twice the size of the portion of cooked beans, which due to the specifics of its production processes, make their contributions to be respectively about 28% and 10% of PED, and 10% and 5% in LU. The lettuce serving also consumes around 16% of PED and 4% of BWU. As shown in previous work (Santillo and Mourad, 2023) about 77% of blue water consumption comes from the sanitization process, due to the high consumption of water when washing vegetables under running tap water.

4. CONCLUSIONS

The analysis of the contribution of the components of the average meal prepared in restaurants shows that the consumption of beef steak is the major contributor to the main impacts measured, being responsible for practically 100% of the impact of climate change, 86% of the consumption of blue water, 84 % of land use and 47% of primary energy demand. The great impact that meat consumption has on the environment is well known around the world and for these reasons there are several studies to develop foods that offer substantial amounts of proteins to nourish the needs of living beings, but at the same time having lower environmental costs. In reality, Brazilians have a huge range of foods available, made up of varieties of vegetables, fruits and other meats. Although their meals are made up of several items, this research focused on the data regarding the typical Brazilian meal.

5. ACKNOWLEDGEMENTS

The authors are grateful to the restaurant partners for the infrastructure, to ITAL for offering the master program, and to CNPq - National Council for Scientific and Technological Development (Process 440170 / 2019-2) for the financial support.

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Table 1. Contribution analysis of the components of the basic Brazilian meal.

Parameter	lettuce	rice	beans	beef
	Relative contribution (%)			
Primary energy demand (MJ/meal)	16.6	27.9	8.7	46.8
Blue water use (kg/meal)	4.2	3.4	6.3	86.0
Land use (m^2a/meal)	0.8	10.2	4.8	84.2
Climate change (kg CO_2 eq./meal)	0.4	7.7	0.3	91.0

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Environmental assessment of an artisanal production system of minipigs in Brazil

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1. INTRODUCTION

The swine is an important animal model for biological and medical research and education. Conventional livestock pigs can be difficult to host and manipulate and costs related to keeping them indoor are high. Miniature pigs, also called minipigs, are small breeds of domestic pig and easy to manipulate. There is a growing number of scientists choosing the minipigs as an optimal animal model for research and education. However, very little attention has been paid to the environmental impacts related to the production and maintenance of these animals. To inform the scientific community interested in using the minipig-br1 as the optimal animal model for research and education, the purpose of this work was to identify the main environmental impacts on the production of the Brazilian minipig-br1.

2. METHODS

The environmental impacts related to the production of the minipig-br1 were assessed. The inventory consisted of input-output registration for the entire year of 2022. A cradle to hospital entry gate LCA was performed. The functional unit was 1 live animal delivered at the entry gate of the hospital in Sao Paulo city. Brazilian minipigs were raised on farm and delivered at hospital for two different purposes, for research or for educational use. On this respect, an economic allocation was applied to estimate the environmental impacts related to each type of use. Figure 1 illustrates the system boundaries and both types of Minipigs-br1 marketed for Brazilian scientists. An attributional LCA was performed (Baitz, 2016) and the ReCiPe 2016 method was selected. Emissions were estimated based IPCC (2019). To calculate the environmental loads associated with the production of the feed ingredients, maize silage and combustion of fossil fuels, consumption of electricity and transport, Ecoinvent version 9.3.1 database with data specific for Sao Paulo - Brazil in the LCA software SIMAPRO version 9.5 was used.

3. RESULTS AND DISCUSSION

Table 1 presents the main impacts attributed to each type of use of Minipig (Type 1 - education and Type 2 - research). It was observed that the feed ingredients purchased outside the farm (inclusive transport of those ingredients to the farm) represented approximately 44.5% of the total emissions of GHG. The second hotspot identified, contributing with almost one third of the total GHG emissions was the manure management (29.7%). In addition to GW, other impact categories relevant to pig production systems were investigated, like fossil resource scarcity. It was observed that the impacts more than double when animals were delivered to hospital entry gate for a second time. In respect to soil acidification, it came mainly from the farm stage, associated with supplementing feed to the minipigs and partly in relation to manure management. The maintenance of minipigs for four more months as estimated for the Minipig Type 2 had prompted that a doubled impact compared to the farm stage of minipigs Type 1. The impacts on nitrogen and phosphorus released occurred mainly at farm stage. They were mostly related to feeding the minipigs and to the management of the manure. For this impact category, it was observed that the extra time minipigs Type 2 stayed at farm, their impacts almost tripled compared with the Minipigs Type 1. Water used by minipig-br1 Type 2 was the double when compared to the minipig-br1 Type 1 also due to the extra time spent in the farm.

4. CONCLUSIONS

Feeding the minipigs and manure management were the main causes of environmental impacts observed. It is important to consider that as the more time the minipigs remain at farm (Type 2), higher is the environmental footprint related to the research protocol elaborated.

5. ACKNOWLEDGEMENTS

The authors want to thank the Federal University of Sao Carlos for the capacitation leave allowing the first author to go abroad and to IRTA that hosted the first author as visiting scientist at Torre Marimon from 23 of March to 15 of June, 2023.

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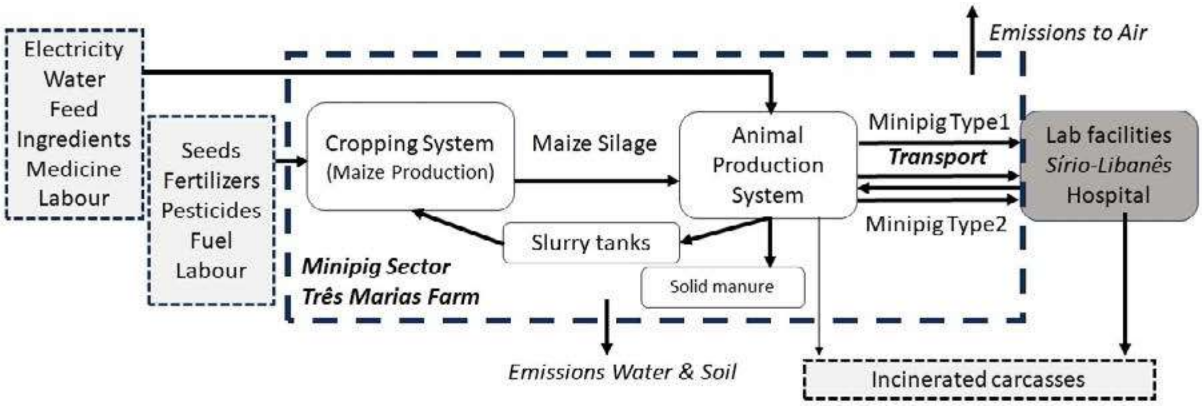
Figure 1. System boundaries. Foreground information is presented at large rectangle with dashed line. Upstream and downstream processes in light grey. Impacts inside the laboratory in the use of animals was not considered – dark grey.



Source: the authors

System boundary		Farm Gate			Hospital entry Gate	
Impact category	Unit	Sow	Minipig Type 1	Minipig Type 2	Minipig Type 1	Minipig Type 2
Global warming	kg CO_2 eq	31.21	82.16	195.07	95.08	220.91
Fossil resource scarcity	kg oil eq	4.46	11.74	27.88	16.09	36.58
Terrestrial acidification	kg SO_2 eq	1.00	2.63	6.23	2.67	6.32
Freshwater eutrophication	g P eq	4	11	30	11	30
Marine eutrophication	g N eq	140	360	850	360	850
Water use	m³	3.77	9.94	23.59	9.97	23.66

Table 1. Total impacts based on both FU (minipig Type 1 – used for education and minipig Type 2 – used for research) for the six impact categories under investigation at farm gate and at hospital gate.

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Chosing the most promising technological route for extracting collagen from tilapia skin, considering environmental and economic criteria

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1. INTRODUCTION

The use of fish processing waste for extracting collagen minimize the problem of organic waste disposal by adding value to this waste. The comparison of the potential environmental impacts and costs of technological routes at laboratory stage can support developers' decision about which route to invest further (Piccino *et al.*, 2018). This study compares two alternative technological routes to produce collagen from tilapia skin, considering their total costs and ex-ante LCA.

2. METHODS

Two routes for extracting collagen from Nile tilapia skin at lab sacle were compared in terms of environmental and econmic performance: the acid-soluble route (ASC) and thea pepsin-soluble route (PSC), established by Menezes *et al.* (2020). The Superpro Designer software was used to model both routes at pilot scale. Environmental and economic assessments refered to 1 kg of collagen/year, considering tilapia production, filleting, production of inputs and collagen extraction. The environmental assessment was calculated by the PEF (Product Environmental Footprint) index, while the economic, by total costs (capital and operational costs). The PEF index and total costs results were combined in a graphic, following the strategy proposed by Piccino *et al.* (2018). Uncertainty analysis was performed using Monte Carlo.

3. RESULTS AND DISCUSSION

Emissions from production of acetic acid, water, ethanol and sodium chloride are the main sources of environmental impacts and total costs. Inputs contribute approximately to 93% of impacts and 84% of costs.

From the integrated analysis for both routes, it was observed that the ASC route shows the best results (Figure 1). This route consumes the least amount of inputs, results in higher yield (17,720kg/year) and requires the shortest processing time (40 hours per batch). The comparative uncertainty analysis shows the significance of this result (Figure 2).

4. CONCLUSIONS

According to this study, the ASC route performed better than the PSC route, due to its lower use of inputs and higher yield in collagen production. Despite showing significant results, this route needs to be optimized in order to reduce costs and impacts.

Some optimizations proposed for the ASC route are the recovery of inputs (ethanol, water and sodium chloride), reducing the consumption of acetic acid (which cannot be recovered in the process), replacing the dialysis process used to purify collagen with diafiltration in order to reduce process time and increase collagen production yield.

5. ACKNOWLEDGEMENTS

The National Bank for Economic and Social Development (BNDES), The National Council for Scientific and Technological Development (CNPq), The Brazilian Agricultural Research Corporation (EMBRAPA) and the Coordination for the Improvement of Higher Education Personnel (CAPES).

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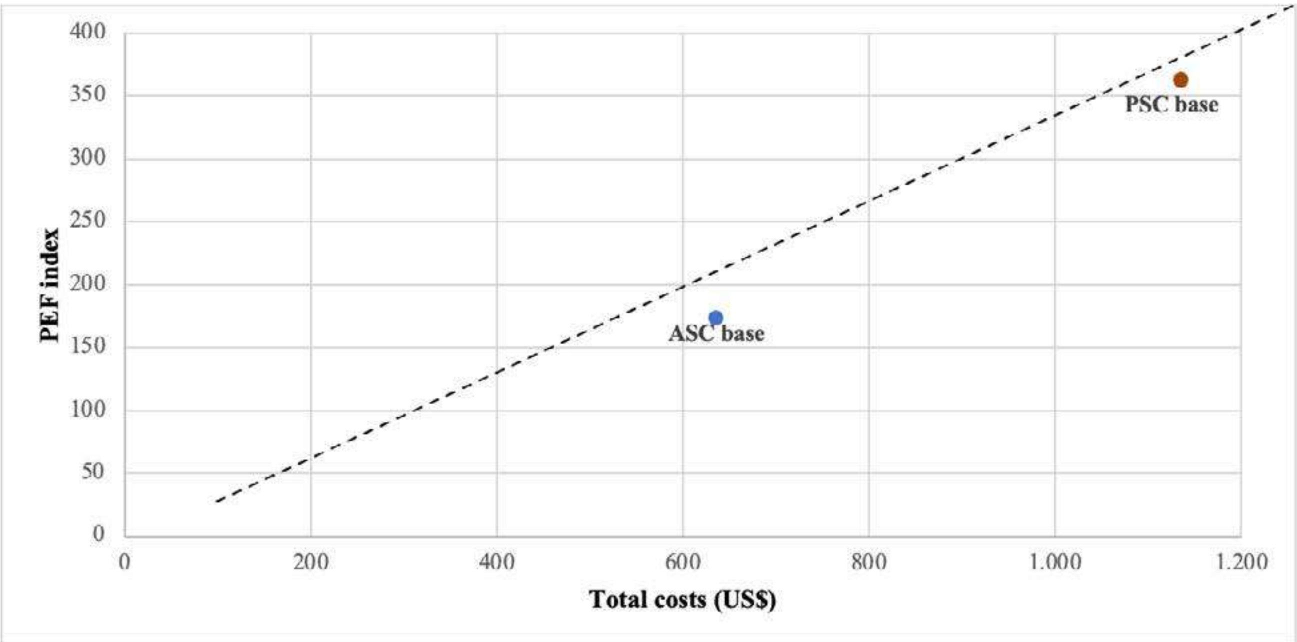

Figure 1. Analysis of base routes ASC and PSC

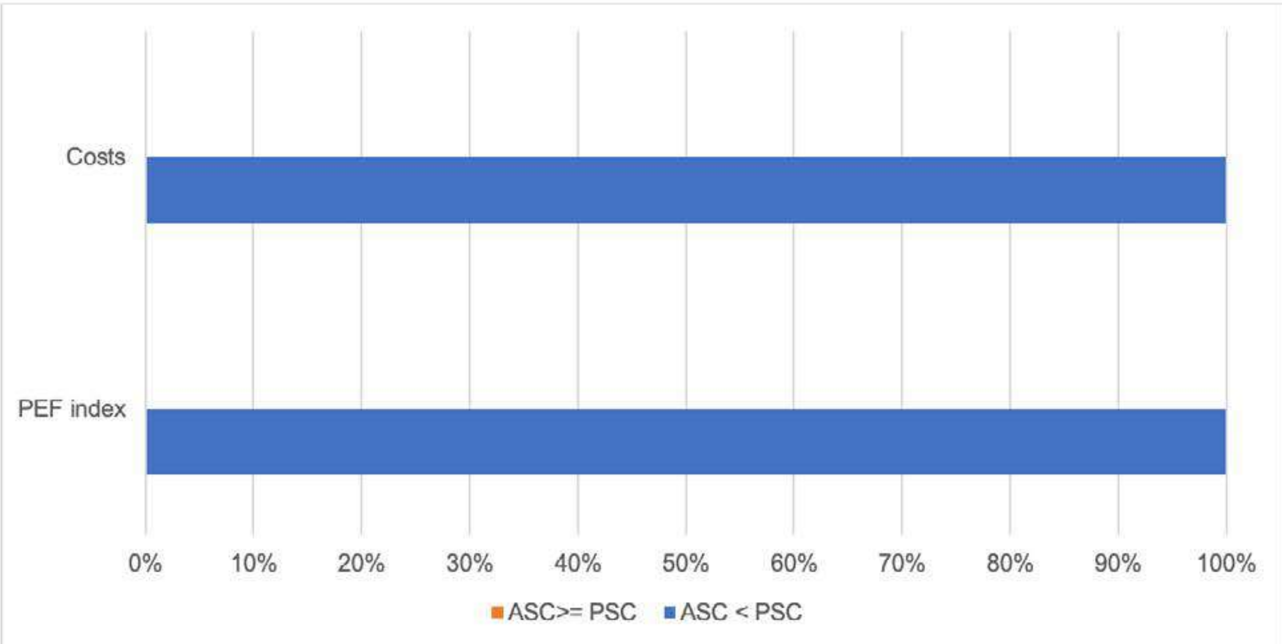

Figure 2. Comparison of ASC and PSC, considering uncertainty

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Integration of industrial process modeling with environmental assessment applied to a Mango Biorefinery layout

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1. INTRODUCTION

The mango is among the tropical fruits that generate the most waste after its processing for pulp and juice extraction, increasing the pressure on natural resources with mango pulp processing and generated biomass pollution (Yadav et al., 2022)

In this study, a mango biorefinery model was proposed for the integral use of mango and its ex-ante environmental impacts evaluated. We combined process simulation and environmental assessment at early technological development to obtain starch, pectin, lignin and cellulose at pilot scale.

2. METHODS

Lab data from the experiments developed by Silva (2019) were used to build a computational model of a biorefinery using mango as a feedstock to obtain fruit pulp, starch, pectin, tegument and lignin at pilot scale. The mass balance at pilot scale was used to perform an ex-ante LCA to identify hotspots. The functional unit used was 1 ton of mango processed per year. The scope of the study was from cradle to gate, considering the processes of mango crop production, mango transportation, extraction of fuit pulp and bioproducts, and waste treatment (conventional treatment for liquid effluents and composting for solid organic waste). The inventories related to input production and effluent treatment were from the Ecoinvent database v.3.6. The Product Environmental Footprint (PEF) method was applied to assess Climate Change (CC), Acidification (A), Freshwater Eutrophication (EAD), Marine Eutrophication (ME), Freshwater Ecotoxicity (ECT), Carcinogenic Human Toxicity (THC) and Non-Carcinogenic Human Toxicity (THNC). The impact on water scarcity (HE) was assessed by the AWARE method.

3. RESULTS AND DISCUSSION

Pectin extraction was the most impactful phase in all the categories analyzed (Fig. 1). In the categories of acidification, ecotoxicity, climate change and human toxicity, the extraction of pectin played a decisive role in the impacts because it used a greater quantity of acid and because the production of acetic acid indirectly produced greater quantities of carbonic acid oxides in parallel reactions (Cheung et al., 2002). These large quantities of acid and alcohols are linked to the pectin extraction method. Even if the inputs used are replaced, the impacts will remain.

The two phases of liquid-solid extraction with quantities of methanol and citric acid solutions and alcohol treatment meant that water consumption in this phase was significantly higher than in the other production phases (Table 1). Manhongo et al. 2021 also simulated scenarios for a mango biorefinery and also found the pectin extraction phase to be the most impactful for HE.

4. CONCLUSIONS

The pectin extraction stage had the greatest impacts on the eight categories analyzed. The water demand required was high and the operational yield low for extracting pectin from the peel. The starch and pulp extraction stages caused lower impacts. The mango biorefinery is an alternative in the strategy of better managing unused fruit processing wastes with the benefit of providing bioproducts from an applicable circular economy concept. To expand this study, our next step is to investigate the best scope for mango biorefinery to reach financial and environmental viability with scenarios analysis.

5. ACKNOWLEDGEMENTS

Cearense Foundation to support Scientific and Technological development (FUNCAP), Coordination for the Improvement of Higher Education Personnel (CAPES), and the Brazilian Agricultural Research Corporation (EMBRAPA).

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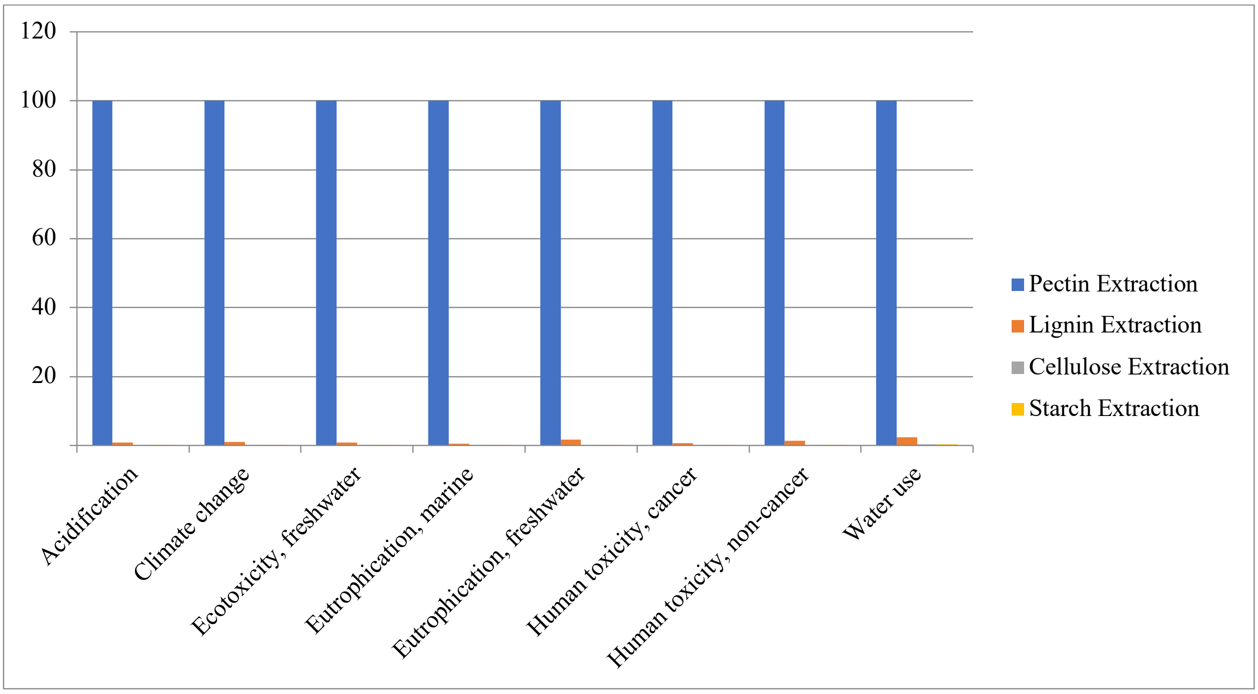

Figure 1 - Environmental impacts from LCA stages of the mango biorefinery (%)

Impact Categories	Unit	Stage 1 - Extraction with methanol	Stage 2 - Extraction with Citric Acid	Stage 3 - treatment with ethyl alcohol	Etapa 4 - Freeze Drying
Acidification	mol H+ eq	9,44E+03	1,23E+04	7,03E+03	2,77
Climate change	ton CO2 eq	4,27E+03	1,32E+06	4,46E+04	936,9
Ecotoxicity, freshwater	CTUe	1,15E+07	2,04E+07	1,80E+07	1,10E+03
Eutrophication, marine	ton N eq	2,57	2,57E+03	4,50E+03	0,33
Eutrophication, freshwater	ton P eq	0,4	563,06	46,36	0,03
Human toxicity, cancer	CTUh	0	0	0	0
Human toxicity, non-cancer	CTUh	0,02	0,03	0,01	0
Water use	m^3 depriv.	1,11E+06	1,22E+06	3,06E+05	5,87E+03

Table 1 – Absolute values of the environmental impact caused by the four stages of mango pectin extraction.

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Life Cycle Assessment applied to biochar from green coconut husk

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1. INTRODUCTION

Coconut husks is a high volume and problematic waste in tropical countries that cultivate green coconut for water extraction (Nunes et al., 2020). Pyrolysis of these husks has been presented as one of the alternatives for producing biochar, bio-oil and bio-gas.

Bioachar is an important input for crop production since it stocks carbon in soil, playing an important role on soil fertility by changing chemical, biological and physical properties (Awad et al., 2018)

The pyrolysis process occurs through thermochemical degradation caused by heat in the absence of oxygen, allowing biomass to be transformed into three fractions: solid (biochar), gaseous (non-condensable gas - NCG) and liquid (bio-oil). The aim of this work was to evaluate the environmental impacts of green coconut biochar from two pyrolysis conditions: (i) slow (450°C) and (i) fast (600°C).

2. METHODS

Life Cycle Assessment (LCA) was applied for data obtained at lab scale. The scope of the study was from cradle to gate, considering green coconut production, transportation, husk separation, husk palletisation and pyrolysis. Results relate to 1 kg of biochar. Mass allocation wast applied, considering the percentage of biochar, bio-oleo and bio-gas produced in conditions i and ii. Brazilian energy mix for energy was used and inputs inventories for crop production were from ecoinvent, v.3.6. ILCD Midpoint 2011 and the AWARE method were used to evaluate environmental impacts. Uncertainty analysis in the comparison of pyrolysis conditions was performed applying Monte Carlo.

3. RESULTS AND DISCUSSION

In slow pyrolysis, the following yields were obtained in relation to coconut fibepellets: 48% biochar, 16% bio-oil and% bio-gas in slow pyrolysis. In fast pyrolysis, the yields were 22.75% biochar, 39.17% bio-oil and 38.07% bio-gas.

The results achieved in the pyrolysis process are in line with the existing studies in the literature, as they indicate that the increase in temperature results in higher production of non-condensable gases, while a lower temperature, a slower pyrolysis results in higher proportions of biochar (ZHU, 2024).

The fast pyrolysis condition caused significant higher impacts per kilogram of biochar than the slow one. Although the slow condition required higher time, its higher yield resulted in smallest impacts between main categories analysed: 0,000813 CO_2-eq/kg for Global Warming, 0,00014 kg-SO_2 eq for Terrestrial Acidification, CO_2-eq/kg, 0,00043 m^3 for Water Consumption, 0,0011 kg 1,4 - DCB for Freshwater Ecotoxicity and 0,035 kg 1,4 - DCB for Human Carcinogenic Toxicity.

4. CONCLUSIONS

Slow pyrolysis generates less environmental impact due to the reduced need for energy consumption. The new step of this work is the upscaling of the pyrolysis process, consideration of different allocation criteria and the economic analysis of both pyrolysis conditions.

5. ACKNOWLEDGEMENTS

State University of Ceará (UECE), the National Council for Scientific and Technological Development (CNPq) and the Brazilian Agricultural Research Corporation (EMBRAPA).

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Comparison of life cycle environmental impacts of a traditional roof and a green roof using non-conventional food plant

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1. INTRODUCTION

Pereskia aculeata Miller is an Unconventional Food Plant (UFP) commonly called Ora-pro-nobis. This plant is a perennial species native to South America, belonging to the Cactaceae family. It can be planted in pots or directly in the ground, adapting to different soils and climates. In Brazil, *Pereskia aculeata* is used in the regional cuisine to prepare soups, sauces, and salads, and in the vegetarian diet because it is rich in protein (Garcia et al., 2019). No studies have been found about the environmental performance of this plant used in green roof systems, and this paper aims to fill this gap. Thus, this study compared the life cycle impacts of green roof modules with a plantation of *Pereskia aculeata* and a conventional ceramic tiles roof.

2. METHODS

Two roof systems were compared in this study: 1m² of ceramic roof, which consists of clay tiles and a wooden structure, and 1 m² of green roof with *Pereskia aculeata* planted in plastic boxes. The cradle-to-use phase was adopted, considering the main inputs for constructing and maintaining of the roofs during the service life of one year. *Pereskia aculeata* was planted in modules and daily monitoring to obtain experimental data (e.g., plant growth and irrigation required), which were used in the inventory of this study. Plant seedlings were obtained from a residential garden. Construction materials data were obtained through the Brazilian database 'SICV Brasil' and ecoinvent 3.7. Material transportation was calculated assuming the distances between the place of materials acquisition to the construction site in the region of Sorocaba city, São Paulo state of Brazil. Tables 1 and 2 show details about materials and transport. During the first year after ceramic roof construction, no maintenance was required. The green roof has two functional outputs (roof, and food) while the ceramic roof only provides the roof functional output. Life cycle models were built using OpenLCA 1.10.3 software. The impact categories evaluated were Climate Change and Resource Depletion-Water. The impact assessment method was ILCD 2011, midpoint [v1.0.10, August 2016].

3. RESULTS AND DISCUSSION

The results of Climate Change and Water Depletion are shown in Fig. 2 and 3. For Climate Change category, the green roof system resulted in 23% more negative impacts than the ceramic roof. Kim et al. (2018) compared the Climate Change impacts of a flat roof with a green roof and the green roof also had higher impacts. These results may have been associated with the construction process of green roofs, which required more demand for materials than conventional roofs. Furthermore, the maintenance step for the ceramic roof was not accounted for, which may underestimate the life cycle impacts. For the Water Depletion category, the green roof presented lower impacts than the ceramic roof, as shown in Fig. 3. Rasul and Arutla (2020) studied green and non-green roofs, concluding that the green roof could show lower abiotic depletion (water) impacts. *Pereskia aculeata* roof may have presented a better result associated with this category due to the module's capacity to absorb rainwater, generating less wastewater than the ceramic roof.

4. CONCLUSIONS

The green roof presented the best environmental performance in the Water Depletion category, while the ceramic roof was the best option for reducing Climate Change impacts. The main study's limitation was the life cycle assessment of the roofs for a short time life period (only one year), and for this reason, the inputs for ceramic roof maintenance were not considered.

5. ACKNOWLEDGEMENTS

Florence Leite is grateful for the support by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) - Finance Code 001, and Diogo Silva for the support by the Conselho Nacional de Desenvolvimento Científico (CNPq) – Grant Code 303343/2022-2.

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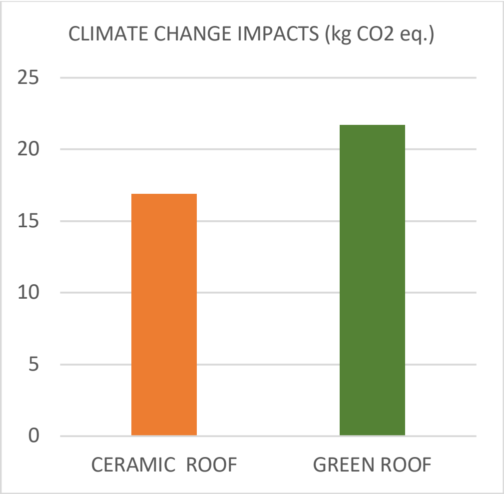
GREEN ROOF		
Inputs		
Construction layer	**Database-material**	**Weight (kg/m2)**
Plastic box	Polypropylene fibres (PP), production mix, at plant, crude oil based, PP granulate without additives - EU-27	3.5
Drainage layer	Expanded clay production | expanded clay | Cutoff, U - RoW	7.2
Filter layer	Textile production, non woven polyester, needle punched | textile, non-woven polyester | Cutoff, U - RoW	0.3
Substrate (90% manure and 10% sand)	Waste, organic Sand quarry operation, extraction from river bed | sand | Cutoff, U - BR	51
Pereskia aculeata Miller	Carbon dioxide, in air	0.84
Maintenance	**Database material**	**(l/m2 – 1 year)**
Irrigation	Irrigation, drip | irrigation | Cutoff, U - BR	**150**
CERAMIC ROOF		
Construction layer	**Database material**	**Weight (kg/m2)**
Ceramic tile	Roof tile production | roof tile | Cutoff, U - RoW	45
Wood trellis	Trellis system construction, wooden poles, soft wood, tar impregnated | trellis system, wooden poles, soft wood, tar impregnated | Cutoff, U - RoW	25
Varnish to protect the wood	Acrylic varnish production, product in 87.5% solution state | acrylic varnish, without water, in 87.5% solution state | Cutoff, U - RoW	0.0011

Table 1. Materials required for the construction of 1m² of each roof. The concrete slab to support the two roofs is not included.

Transport route	Database-transport	Distance (km)
Construction materials store to São Paulo State University	Transport, freight, lorry 3.5-7.5 metric ton, EURO5 | transport, freight, lorry 3.5-7.5 metric ton, EURO5 | Cutoff, U - RoW	16.0

Table 2. Transport of materials



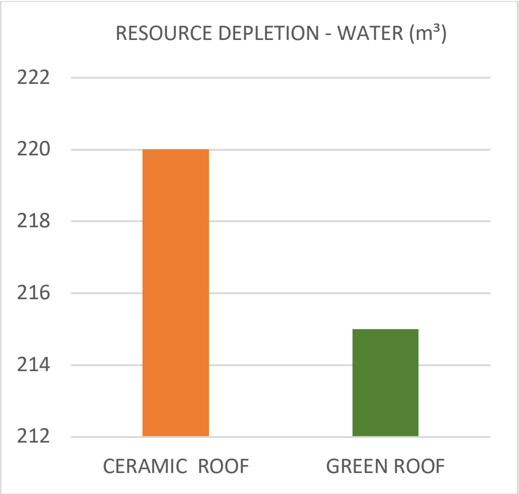


Fig. 1 and 2: Roofs impact results

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Socially-oriented approach for LCI construction: accounting Environmental Footprints in Peruvian Agroforestry Systems

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Keywords: cocoa production; coffee production; Life Cycle Assessment; Peruvian Amazon.

1. INTRODUCTION

Life Cycle Assessment (LCA) is a widely utilized methodology to comprehensively evaluate environmental impacts associated with production (Holka et al., 2022). However, conventional research in this field often relies on labor-intensive processes for acquiring primary data, mainly through questionnaires assigned to producers, neglecting farmers from opportunities to engage with the principles of life cycle thinking and the potential added in emerging sustainable markets. To address these limitations, this research proposes a socially oriented approach for LCA dissemination among rural farmers, using virtual tools to construct Life Cycle Inventories (LCIs) and estimate environmental impacts.

2. METHODS

The methodology proposes a holistic perspective for the environmental assessment of agroforestry products in Peru, involving multi-dimensional aspects and actors such as NGOs, enterprises, governmental entities, farmers, and academic researchers. This approach has been implemented by the Peruvian LCA & Industrial Ecology Network since 2021 in collaborative projects, aiming to establish environmental footprint benchmarks, covering agroforestry crops such as cocoa, coffee, and Brazilian nut. The strategy developed covers three phases: capacity building, construction of the LCIs, and the delivery of environmental impact reports to stakeholders.

The initial phase consists of face-to-face workshops that introduce participants to environmental issues such as climate change and other planetary boundaries. Moreover, the main principles of LCA and environmental labels are presented, showing their importance in terms of cleaner production, certification, and competitiveness in a global market, among other aspects. Thereafter, a second stage constructs the LCI using primary data to determine environmental impacts. The project employs LCA methodology through a series of environmental calculators that have been developed to reflect the local conditions of agro-forestry products in the Peruvian Amazon, such as CalCafé and CalCacao. Finally, in the third stage, a comprehensive LCA report is compiled. Through this analysis, critical hotspots within the crop production supply chain are pinpointed, guiding the formulation of recommendations or actionable steps aimed at mitigating or reducing environmental impacts. Cocoa or coffee producers and associations receive access to this LCA document, empowering them with insights into their environmental performance.

3. RESULTS AND DISCUSSION

Firstly, the number of participating associations or cooperatives diminishes as we advance through the stages. This decline is primarily attributed to the reluctance of some to allocate human, financial, and time resources to these training sessions. Secondly, regarding participant numbers, Phase 1 comprises participants who attend the training sessions, whereas phases 2 and 3 include producers who have contributed information regarding their production systems.

For the second stage, environmental impact estimations have been carried out for organizations located across Peru during 2021-2023. The carbon footprint obtained from these measurements ranges from 1 to 2 kg CO_2eq (Table 1). These values fall within the range observed in various coffee-related research conducted worldwide (Pramulya et al., 2022; Ratchawat et al., 2020), with variations linked mainly to the production systems and composting practices within crop residues (Figure 2). When producers and/or associations were measured in more than 1 year it was possible to verify the changes in environmental impact derived from interventions in the crops, such as fostering composting, transitioning to organic practices or controlling the use of fertilizers.

4. CONCLUSIONS

Associations implementing recommendations experienced significant reductions in environmental impact upon reevaluation, showcasing the practical benefits of the approach. In conclusion, an approach that goes beyond mere quantification of environmental impacts not only promotes sustainable practices within crop plots but also sets the stage for long-term environmental impact reduction at a wider scale across the country.

5. ACKNOWLEDGMENTS

The authors thank UNEP, PromPeru, and Mincetur for funding the environmental calculators used in this project.

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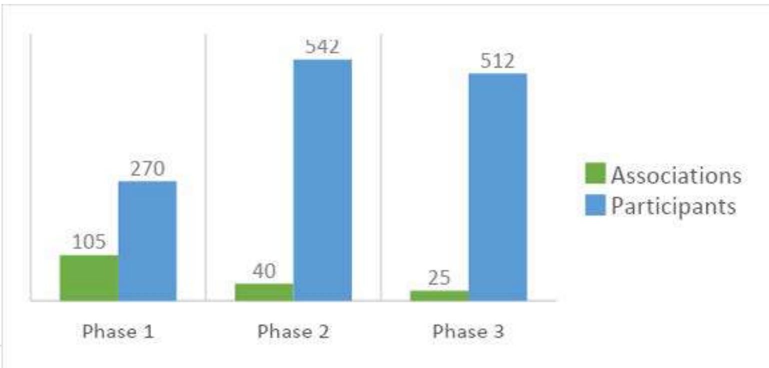
Table 1. Results of the carbon footprint of coffee and cocoa for different region in Peru covered in measurements made between 2021–2023.

TYPE OF CROP	REGION	CARBON FOOTPRINT (kg CO_2eq/kg of crop)
Coffee	Apurimac	2.19
	Cusco	1.90
	Cajamarca	2.06
	Junin	1.92
	Puno	1.65
	San Martin	0.94
	Huánuco	1.43
Cocoa	Amazonas	2.01
	Junin	2.83

Figure 1. Number of associations and individuals present in each phase of implementation of the developed methodology in Peru.



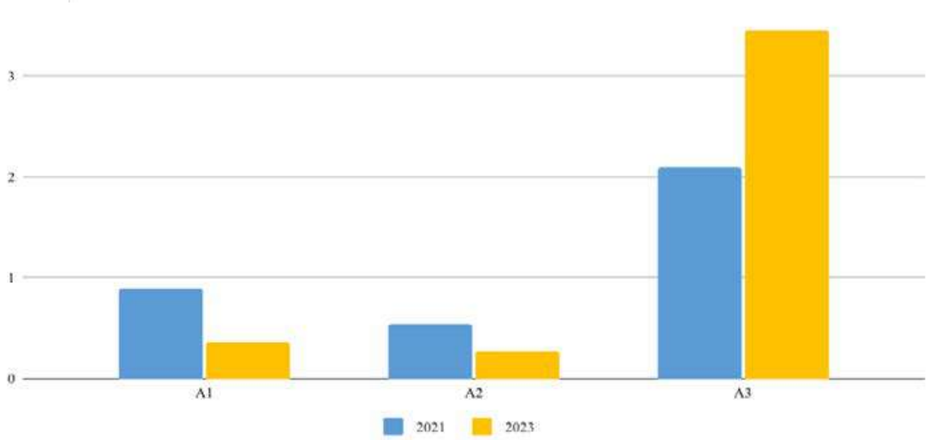


Figure 2. Results of the comparison of the carbon footprint of 3 coffee associations measured in 2021 and 2023.

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Compiling a Life Cycle Inventory for avocado production in Ecuador: challenges and future steps

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1. INTRODUCTION

Transforming agri-food value chains for enhanced economic, social, and environmental sustainability is now crucial. Avocados dominated global trade in major tropical fruits in 2022, comprising over 50% (excluding bananas). With the primary importer being the United States, and Mexico facing significant supply challenges, the average export unit price of avocados surged to nearly $3,400 per tonne in 2022 (FAO 2023). As a result, more countries are interested in producing avocados. In Ecuador there are three active projects supporting avocado production: PIDARA (Ecuador government), HIH initiative (FAO) and CREA (European Union). This research is part of the CREA project, which is developing water and carbon footprints of major export commodities. Existing LCA studies on avocado value chains in Latin America have found that a high contributor to GHG emissions is the production of mineral fertilizers; other studies found that the use of fertilizers and fungicides in the agricultural stage has a bigger impact (Solarte-Toro et al. 2022). This research will focus on developing a structured Life Cycle Inventory (LCI) for Ecuadorian avocado farms gathering data in situ.

2. METHODS

The LCI for avocados is based on data from six farms in the Sierra region, ranging from 11 to 90 ha in size, focusing on the Hass variety, the primary export type (Figure 1). The farms were engaged in preparatory meetings starting in early 2023 to introduce them to the project and the basics of water and carbon footprint, aiming to demonstrate potential benefits for farmers. Subsequently, two master's students from KU Leuven, supported by Ecuadorian researchers, visited the farms to assist with scientific and practical aspects. Each visit involved field observations and data collection.

3. RESULTS AND DISCUSSION

LCI analysis was done for primary and secondary data. In both cases, uncertainty was assessed using Data Quality Indicators (DQI's), DQR was based on parameters such as reliability, completeness, temporal, geographical and technological representativeness (Table 1). The data quality analysis established that farms with a spraying diary, show a lower data quality score (higher data quality) particularly for inorganic pesticides and fertilizers. Nevertheless, organic fertilizers posed more uncertainty due to higher unregistered quantities and unclear composition. Fuel use was often unrecorded, requiring estimation. Hurdles were debated for primary data collection, where eight specific challenges were described and discussed (Table 2). The emission factors utilized for agricultural-related product categories such as pesticides and fertilizers are derived from the global IPCC guidelines. However, it's likely that these global emission factors are inadequate for Sierra's conditions due to the limited coverage of tropical conditions. Another source of uncertainty is the limited availability of organic agriculture flows in LCIs databases, raising difficulties to model organic and biologically based input products.

4. CONCLUSIONS

We noticed significant variation in data collection and storage between farms which can be challenging when developing an LCI. A few lessons learned are: i) farms with spraying diaries have better quality data, ii) special attention should be given for registering precise quantities of organic fertilizers and fuel use, iii) there is a challenge on integrating appropriate organic LCI production flows, iv) it is crucial to constantly engage stakeholders and convey to farmers the importance of measuring the environmental impact of their production.

5. ACKNOWLEDGEMENTS

We kindly acknowledge the participating farms and Corpoaguacate for their time and dedication, and the other partners of the CREA-project including Rikolto (Quito) as coordinator. The project is supported through the EU, project number EuropeAid/171445/DD/ACT/EC and by the Belgium VLIR-UOS, awarding a travel Grant to AVO and SP.

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Figure 1. Ecuadorian avocado farm: avocado trees aligned, irrigation system, and mulch used to avoid water evaporation.

Table 1. Fragment of the outcomes for the assigned data quality indicators (DQI), for 1 of the 6 farms, per process “fertilizers & pesticides”, “energy use” and “output”. Criterion: reliability (R), completeness (C), temporal, geographical and technological correlation (TeC, GC, TiC).

APU	Subcategory per process		DQI of Collected Foreground Data					
			TeC	GC	TiC	C	R	DQR_F
1	Fertilizers	Inorganic	1	1	1	1	2	1,56
		Organic	1	1	1	2	3	2,22
	Pesticides	Chemical	1	1	1	1	2	1,56
		Biological	1	1	1	1	2	1,56
	Energy use	Fuels	1	1	1	1	3	2,11
		Electricity	1	1	1	1	1	1,00
	Output	Yield	1	1	1	1	1	1,00

Table 2. List of eight specific challenges faced in the primary data collection process.

Challenge	Description
1. Dependency on farmer input	Without independent verification, register validation faced obstacles. Collaboratively creating registers with producers necessitated time-consuming meetings, especially in the absence of application diaries.
2. Data fragmentation	Multiple data sources, including Excel files, paper records, hand notes, sales data, invoices and oral information, complicated data consolidation and data gaps identification.
3. Limited availability of technicians	The researcher was dependent on the availability of an agronomic technician on the field to interpret registers.
4. Obsolete product registration	Many registered products were no longer in use, requiring help from the producers or online retrieval of technical sheets which was not always possible.
5. Ambiguous organic compound formulation	Vague organic compound formulations on technical sheets of fertilisers, such as ‘organic matter’, ‘organic carbon’, ‘organic extract’ and ‘algae extract’, posed modelling challenges. For the first two, an EI of zero was attributed, for the latter, the flow ‘organic fertiliser, 3-2-3, bulk {RER} U’ was used.
6. Complicated contact with farmers after fieldwork	The iterative LCA process involved repeated inquiries to farmers, revealing data gaps for APU 3 and 6, and leading to data adjustments for APU 5. Engaging producers in these updates posed challenges and consumed time.
7. Validation and correction	Identification of outliers in application quantities in registers helped eliminate inconsistencies which were later confirmed by the producers.
8. Lack of a format for data collection	The specific modality of data formats hindered direct integration of data into an LCI format.

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Ex-ante environmental impact assessment of extracting natural colorant from dragon fruit

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1. INTRODUCTION

Currently, obtaining natural colorants from plant sources for use in the food industry has great economic importance (Pavoković et al., 2011). This is a consequence of the growing demand in the consumer market, which is increasingly looking for healthy foods (Sawicki et al., 2016). Red pitaya is a good source for extracting a natural coloring agent for the food industry. This study assessed the ex-ante environmental impacts of an extraction process to obtain this colorant from pitaya pulp

2. METHODS

Ex-ante LCA was applied to identify hotspots in the extraction process. The scope was from cradle to gate and the functional unit was the production of 1 kg of colorant. A mass balance was performed in the laboratory, and the data was used to model production at the pilot scale, with the following unit processes: separation of the pulp from the seeds, enzymatic treatment of the pulp, microfiltration, vacuum concentration, and daily equipment cleaning. SuperPro Designer software v.10.0.0 was used to model a pilot plant. SimaPro software v.9.5.0.0 and the Ecoinvent database (v. 3.9.1) were used to calculate the Product Environmental Footprint (PEF) index.

3. RESULTS AND DISCUSSION

Pitaya farming was the main process contributing to 49.1% of the PEF index (Figure 1). The use and production of nitrogen fertilizers contributed most to climate change, freshwater eutrophication, and ecotoxicity. The use of sodium hydroxide to clean equipment in the colorant extraction process was the second most important source of impacts (29.1%).

4. CONCLUSIONS

The main source of environmental impacts in the pitaya colorant process was farming, due to the use of synthetic nitrogen fertilizers. The use of biofertilizers, such as manure and nitrogen-fixing leguminous crops, should be further investigated to determine their potential to reduce impacts at the farm level. The impacts of using sodium hydroxide could be reduced by lowering its concentration in the washing solution. Furthermore, pitaya peel might also be a source of colorant, and its use should be investigated to improve yield and reduce impacts.

5. ACKNOWLEDGMENTS

The authors would like to thank the Brazilian Agricultural Research Corporation (EMBRAPA) and the Coordination for the Improvement of Higher Education Personnel (CAPES) for the financial support.

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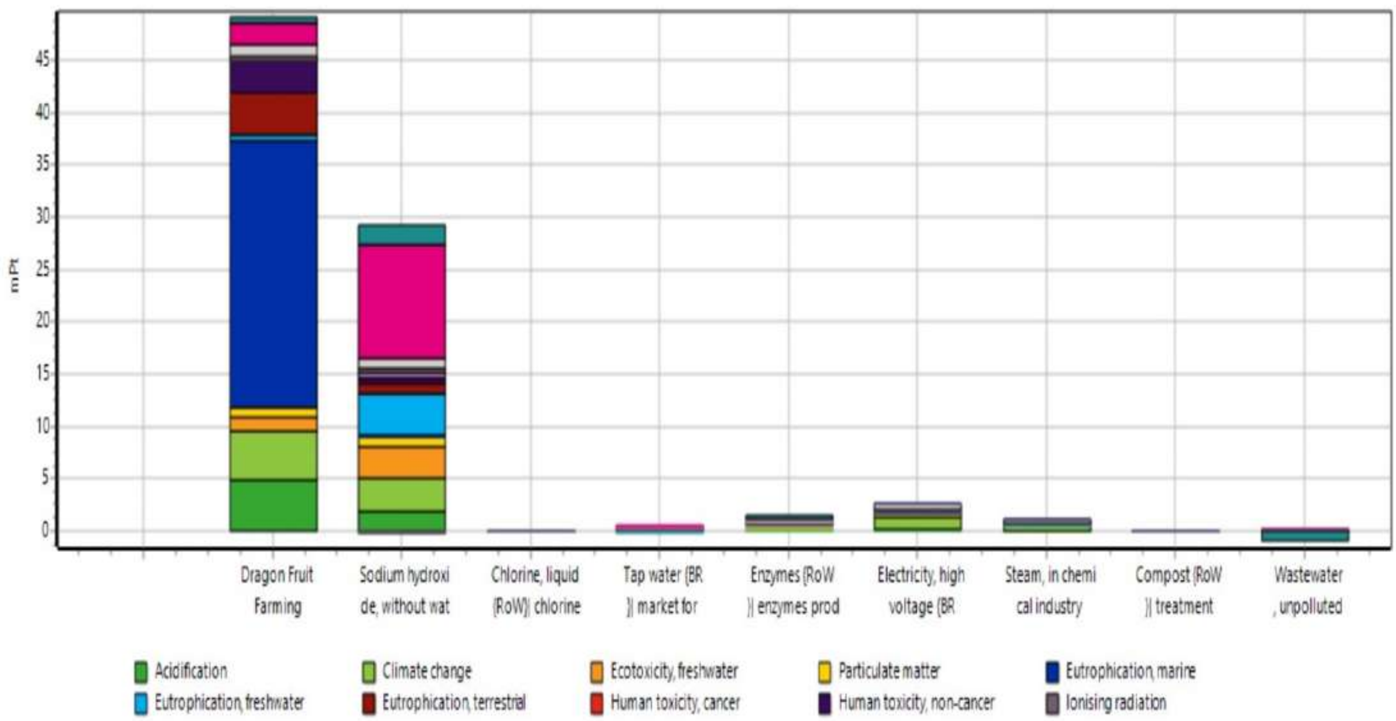

Figure 1. Analysis of the production of natural colorant from pitaya pulp.

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Ex-ante Life Cycle Assessment of the dry methanization process of organic waste from horticultural wholesalers

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1. INTRODUCTION

Energy from biomass has been widely explored as a way of reducing the damage caused by unbridled extraction of fossil fuels and greenhouse gas emissions. Anaerobic digestion is considered a promising source of energy contributing to the treatment of organic matter that would occasionally go to landfill. This work assess the contribution of unit processes to the environmental impacts of a modelled pilot anaerobic plant that process fruit and vegetable wastes (FVW) to generated biogas and biofertilizer.

2. METHODS

The mass balance of a batch process at experimental stage (TRL5) at the Biomass Technology Laboratory was used to model a pilot-scale plant producing 17 tons of FVW per day. FVW were from The Central Wholesale Market (CEASA-Maracanaú), located in Ceará State, northeastern Brazil. The software SuperPro Designer (SPD) v.11 was used to develop this model and generate a pilot scale inventory. Equations were used for the anaerobic reactor, based on the study by Petraglia *et al.* (2021). Mass allocation was used and impacts were calculated using Simapro v.9.4.03, with electricity data from ecoinvent v.3.7. The functional unit was one ton of FVW. Environmental impacts calculated with Recipe midpoint 2016 v.1.08.

3. RESULTS AND DISCUSSION

The contribution analysis shows the processes related to the production of biomethane and biohydroge n were responsible for most of the environmental impacts, due to the high consumption of electricity (Figure 1). O n the other hand, steam consumption, especially inthe drying operation, had the greatest impact on the biofertiliz er process chain. Similar results were observed in the study by Tian *et al.* (2023), which indicated that the high e nergy consumption in the anaerobic digestion plant compromised the this process performance. To mitigate imp acts, González *et al.* (2020) suggested that the energy produced should be incorporated into the system. Anothe r possibility is to use solar energy instead of Brazilian energy production mix.

4. CONCLUSIONS

The production of biomethane and biohydrogen contributed most to the environmental impacts. It is recommended assessing the environmental and economic impacts of replacing the Brazilian electricity mix by a plant based on biogas combustion and/or solar energy.

5. ACKNOWLEDGEMENTS

The Brazilian Agricultural Research Corporation (EMBRAPA), The Ceará Energy Research and Innovation Network (Rede Verdes) and the Coordination for the Improvement of Higher Education Personnel (CAPES).

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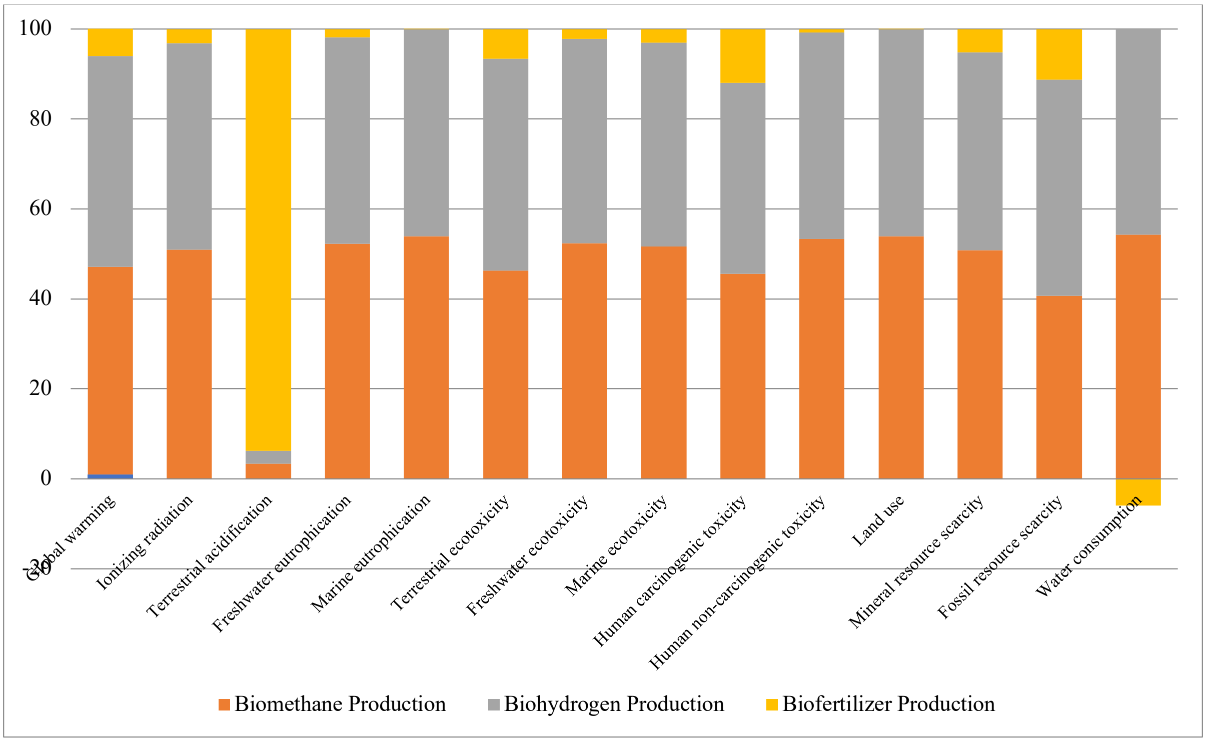

Figure 1. Analysis of the production of biomethane, biohydrogen and biofertilizer produced from FVW.

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Greening Growth: Expanding Data Perspectives from Social Life Cycle Assessment Databases for Agricultural Innovation in Ghana

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1. INTRODUCTION

START (Sustainable greenhouse production types and resource efficient technologies for future cultivation) is a project funded by the German Federal Ministry of Education and Research. It pioneers the exploration of self-sufficient and sustainable plant production within closed deep water culture cultivation systems tailored for African countries, specifically Ghana. By meticulously selecting locally relevant crops, the initiative aims to enhance both the quantity and quality of food security. This effort aims to tackle prevalent micronutrient deficiencies in the region, a challenge expected to intensify due to the anticipated impacts of climate change in the coming decades (World Bank Group, 2020). Furthermore, the project aims to generate opportunities for education, local employment, and economic growth. Nonetheless, the initiative presents complex challenges in the realm of social impacts. Preliminary modeling using generic social databases can lay the groundwork for understanding fundamental social mechanisms in a country, revealing potential areas of vulnerability for stakeholders. It can serve as a preliminary step for subsequent fieldwork in later project stages. However, it does not provide definitive conclusions and should not be the sole frame of reference for addressing the social impacts. The upcoming research seeks to complement database-derived data, offering a more holistic and nuanced picture.

2. METHODS

Utilizing both PSILCA and SHDB databases for modelling the greenhouse provides a unique opportunity to compare the differences in data obtained from the established GTAP and Eora Multi-Regional Input Output (MRIO) models. A thorough literature review will reveal the most pertinent social themes for the case study, which will then be compared with the themes arising from the analysis conducted with the two databases. The social hotspots identified using each database will be extracted and catalogued to compare key terminologies and contextual considerations embedded in their definitions. This process will extend to evaluating the units of measurement and underlying assumptions, particularly those amplifying the weight of indicators based on perceived associated risk levels. Additionally, the assessment will scrutinize the sources of data supporting the indicators. This involves a review of the reliability, representativeness, and credibility of the integrated data sources within each database. The temporal and geographical coverage of the data will be considered to align with the study's scope, and efforts will be made to cross-validate the data against external sources whenever feasible. New indicators, unavailable in the PSILCA and SHDB generic databases, will be added based insights gained during the literature review and original contributions.

The expected positive impacts of the greenhouse project, e.g. the creation of work and education opportunities, will be discussed through the concept of a social handprint. The research recognizes that seemingly positive project outcomes can also introduce risks to vulnerable members of society if they amplify underlying social and governance weaknesses in the country. By prioritizing the resolution of underlying social deficiencies, the investigation will allow to identify the strongest links between the 'social handprint' and 'social hotspots' concepts and to discuss the possibilities to strategically address the existing vulnerabilities, such wage, education and infrastructural inequalities.

3. RESULTS AND DISCUSSION

At this early stage of the project, detailed modelling and analysis have not yet taken place. The necessary data is actively being collected, ensuring that comprehensive modeling and analysis will be completed for presentation at the conference.

The proposed research process will serve two primary purposes. Firstly, it will facilitate an evaluation of the reliability of results generated by each database, shedding light on their inherent strengths and limitations. This comparative analysis will provide insights into the consistency and accuracy of the data obtained from the PSILCA and SHDB databases, offering a foundational understanding of their reliability for subsequent stages of the project. Secondly, this approach will underscore the intricate vulnerabilities inherent in drawing conclusions when disparate reference points and data sources are employed. By incorporating the social handprint dimension, an additional layer of case study-specific social themes will emerge, enriching the analysis beyond the scope of the initial database evaluation. This inclusive evaluation aims to capture nuanced social considerations that might not be fully reflected in generic database assessments and may offer broader conclusions about the generalizability of results from these databases to similar cases in the region. Additionally, this process will illuminate potential information gaps, revealing discrepancies between reality and modelling using generic data. Identifying these gaps will be crucial for refining the data collection and modelling processes, ensuring a more accurate and representative portrayal of the real-world scenario in future analyses. This evaluation marks a critical step toward refining methodologies and enhancing the reliability of data-driven insights for social sustainability assessments.

4. CONCLUSIONS

The START project holds immense potential not only in shaping sustainable greenhouse technologies but also in fostering substantial positive impacts on the lives of communities involved. By methodically identifying and strategically addressing social vulnerabilities along the value chain, the project aims to ensure that the positive impacts envisioned are not confined to theoretical figures but translate into tangible improvements in the lives of local communities. A key focus lies in addressing social hotspots while maximizing the social handprint, aiming to create outcomes that are distinctly community-centric and inclusive. Navigating these intricate social dynamics is fundamental to realizing the project's meaningful impact on resilience of food security and ensuring a transformative contribution to the Ghanaian economy and society.

5. ACKNOWLEDGEMENTS

My mentors Professor Dr. Marzia Traverso and Dr.-Ing. Roland Meyer have played pivotal roles in shaping the trajectory of this work and I am grateful for their contributions to my academic and professional development.

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Environmental performance of intensive and alternative soybean production systems in Minas Gerais and Paraná states, Brazil

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1. INTRODUCTION

For the transition to sustainability in agri-food systems, alternative systems have gained momentum and been backed as a solution to halt the ecological crises caused by intensive soybean production in Brazil, and its related agri-food value chains. This study aimed at assessing the ecological footprints of soybean production systems to unravel how sustainable are productions pathways and identify specific hotspots of environmental burden at farmgate level, in west of Paraná and south of Minas Gerais states, in Brazil.

2. METHODS

Different soybean production systems were studied from cradle to farmgate using lifecycle assessment (LCA) method. The intensive, inputs reduced, conventional, intercropped and organic production systems were investigated. Inventory data was collected through interviews and observations and complemented with relevant scientific literature data and the database Ecoinvent 3.9.1. Emissions were calculated using the ICVCalc tool. Inventory modelling and impact assessment were computed with Activity Browser software. For carbon footprint, the IPCC 2021 GWP100a method was used. For other impact categories, the ReCiPe midpoint characterization factors were used (Huijbregts et al., 2016); and biodiversity impact of land use, expressed in potential disappeared fraction (PDF) of species loss per m^2, was calculated using the method of Scherer et al. (Scherer et al., 2023).

Mass and economic allocation was considered, and all the impacts was allocated to the harvest beans. For the intercropped system, case of soybean with coffee, mass and economic allocation were also considered, and on top, the system expansion will be carried out to obtain the impact of intercropping versus monocropping, with the impact of single crop subtracted from the impact of the intercropped.

3. RESULTS AND DISCUSSION

The results obtained showed that climate change impact varied between 0.52 and 1.08 kg CO_2-eq kg^{-1} $soybean^{-1}$, in organic soy and soybean-coffee intercropped respectively, with the organic production still emitting as much as intensive with reduced inputs system. The ecological toxicity and acidification of all the systems beside organic, are significantly high compared to other systems, as they are input intensive (lime, diesel, pesticides). All the farms were located in the Atlantic forest biome and in all the biological taxa considered, the organic production system had as high biodiversity loss impact as the conventional or intensive systems (e.g. plants species PDF/m2 between $0.4e^{-13}$ and $1e^{-13}$ for all the farming systems). Other impacts aswell as allocation ans sensitivity análisis are under calculations.

The direct planting, weed control, biofertilizers and bioinputs production on farms were found to be among the factors hindering sustainable and organic soybean adoption and intensification.

Environmental performance of the soybean cropping system can be improved with the use of more organic resources.

4. CONCLUSIONS

From this study, it was found that alternative systems, if not designed considering ecological interactions and closing nutrients loops, could result in the same footprints as intensive monocultures, with just shifted impacts. More benefits would be achieved if a transition to more diverse and less intensive systems is adopted.

Ecological footprint results obtained need to be coupled with food systems agent-based studies and stakeholders' participations to understand the most realistic approach to transitions sustainability in the soybean system in Brazil.

5. ACKNOWLEDGEMENTS

This research was funded by the Swiss National Science Foundation. Acknowledgment to farmers and cooperatives that welcomed and shared data and information with us.

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Life cycle impact assessment: new developments

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HEALTHY FOOD SYSTEMS FOR A HEALTHY PLANET

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Challenges in creating Product Category Rules for biobased fertilizers aligned with Product Environmental Footprint method

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1. INTRODUCTION

Bio-based fertilizers (BBFs) can help reduce the need for mineral fertilizers by providing alternatives towards more sustainable food production. Bio-based fertilizers are fertilizer products with a valuable content of nutrients for soil and plants that come from biomass feedstocks, normally considered co-products, residuals, or wastes. These comprises, therefore, a wide set of products that can be defined by i) the origin; ii) the processing; and iii) the chemical composition of the final product. Within the Environmental Footprint initiative of the European Commission harmonized guidance for assessing the environmental impact of products with Life Cycle Assessment methods are created (EC, 2021). In addition to the developed general Product Environmental Footprint (PEF) method, each product category has its own rules; Product Environmental Footprint Category Rules (PEFCR). The paper aims to present a PEF-wise Product Category Rules (PCR) for bio-based fertilizers to enhance comparability of fertilizer products by unifying methodological decisions, with the potential to serve as a first draft towards a proposal of PEFCR for bio-based fertilizers for the posterior validation.

2. METHODS

This work was aligned with the Product Environmental Footprint method (EC, 2021) as much as possible, however, not aiming yet for an official PEFCR. Also, other relevant guidance (ISO standards, Environmental Product Declarations, and scientific literature, etc.) was utilized.

3. RESULTS AND DISCUSSION

The functional unit (FU), system boundaries and allocation methods that shall be used are set in the developed Product Category Rules. BBFs are defined as intermediate products in the agricultural system and embedded in other supply chains. For intermediate products, the FU has limitations to be defined as BBFs can often fulfil multiple functions, have major differences in the nutrient content and fertilization efficiency, and the whole life cycle of the product is not known. A declared unit (DU) (equal to reference flow) is applied (1 kg of BBF), but as the final aim of the PEF method is comparability between products, it shall also be mandatory to use complementary FUs (e.g., kg soluble N) and include data on the application stage as “additional environmental information” according to the developed PCR. The system boundaries for BBFs as intermediate products shall be limited to a Cradle-to-Gate perspective according to the PEF method (EC, 2021), and thus, it shall include: i) feedstock and raw material acquisition ii) the transportation and collection of the feedstock until the manufacturing plant iii) manufacturing process; and iv) distribution until the farm/retail. Further guidance, on the application and use stage on field are presented in a separate section 2 in the developed PCR, however, which is to be included in other products’ Product Category Rules under agricultural modelling (Figure 1.). The environmental burdens related to feedstock production and management before entering the transportation phase to the BBF manufacturing process shall be allocated by using the relative economic value (market price) of feedstock. Economic allocation is commonly used when co-products have very different physical relationships or end use in the market (Kyttä et al. 2022). If biomass feedstock has no market price it is regarded as a residual (utilized biomass without market price) or waste (not utilized e.g., landfilled) with zero emissions allocation of an upstream burden and limited outside the system boundary (Fig 1).

4. CONCLUSIONS

The BBFs are a very heterogenous product group. This aspect caused major challenges for drafting the PCR (e.g., functional unit, system boundaries, allocation rules). This raises the question what the optimal size of a product category would be; too small category does not allow comparison of different options, but too large category makes setting a PCR difficult.

5. ACKNOWLEDGEMENTS

This work was supported by the Novel procedures and sustainable guidelines to enhance the use of alternative fertilising products (NOVAFERT) project, funded by the European Union’s Horizon 2020 research and innovation program under grant agreement ID: 101060835.

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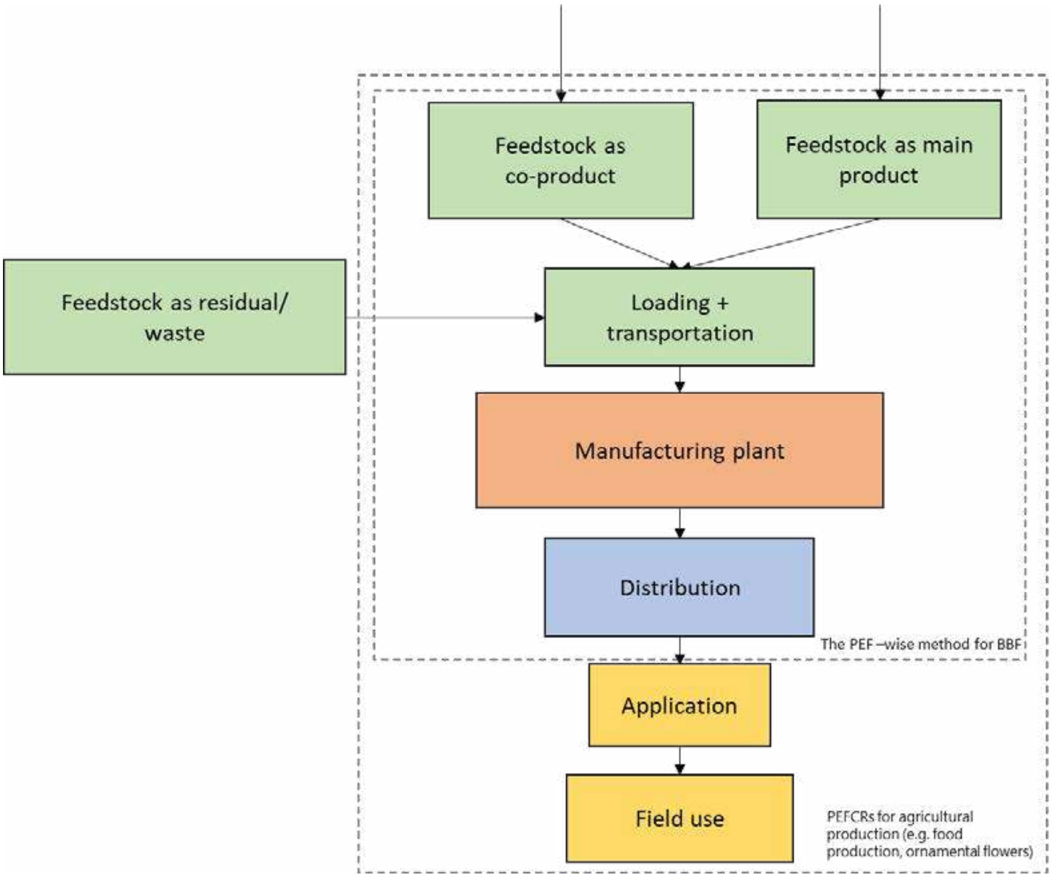

Figure 1. System boundaries of Product Category Rules for bio-based fertilizers aligned with Product Environmental Footprint method.

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Taxa and reference state in LCA methods for biodiversity impact assessment

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1. INTRODUCTION

Biodiversity impact assessment of agricultural products is crucial to advance the UN SDG for promoting sustainable production and consumption. The LCA methods for assessing the biodiversity impacts can be divided into two groups: expert scoring-based (ESB) and biodiversity indicator-based (BIB) methods. ESB methods, exemplified by the Swiss Agricultural LCA-Biodiversity (Lüscher et al., 2017), rely on expert judgments to assess biodiversity impacts. In contrast, the BIB methods, such as the Species Area Relationship (Pezzati et al., 2018), typically employ direct algorithms for biodiversity indicators and/or biodiversity models. However, a comprehensive evaluation of the characteristics of these two LCA methodologies in assessing biodiversity impacts is still pending.

2. METHODS

We systematically reviewed the scientific literature on biodiversity impact assessment methods in LCA. We initially identified 476 scientific articles. After screening out non-English, duplicated, methods not related to agriculture, 111 remained. We further narrowed it down to 43 method items by excluding reviews, discussion papers, and non-method items, of which 11 were ESB methods and 32 were BIB methods.

3. RESULTS AND DISCUSSION

The most frequently evaluated taxonomic groups were Birds (42%), Mammals (37%), Vascular plants (33%), Amphibians (30%), and Reptiles (30%) (Fig. 1). Six of the 11 BIB methods did not specify the evaluated taxon but assessed affected organisms in general. Most of the studies focused on terrestrial organisms, while few focused on aquatic species (especially ocean creatures), soil fauna, soil microbes, etc.

A reference state can significantly influence the assessment results. It is noteworthy that almost half of the BIB methods used semi-natural or undisturbed ecosystems as a reference, while about 36% (4) of the ESB methods did not apply a reference state or value (Fig.2). Choosing the optimal reference state for biodiversity assessment within LCA is challenging and could also take into account biodiversity targets to align with society's conservation frameworks (Vrasdonk et al., 2019)

4. CONCLUSIONS

Despite ESB methods covering fewer species compared to BIB methods, they showed a higher potential to include more species through expert opinions or by assessing biodiversity impacts on general organisms. BIB methods showed higher accuracy in assessing species richness and diversity due to the use of robust biodiversity models. However, it is challenging to include more species and define a good reference state.

5. ACKNOWLEDGEMENTS

This research was funded by the PATHWAYS project (Grant No. 101000395) and partly funded by the MIXED project (Grant No. 862357) under the HORIZON 2020 program.

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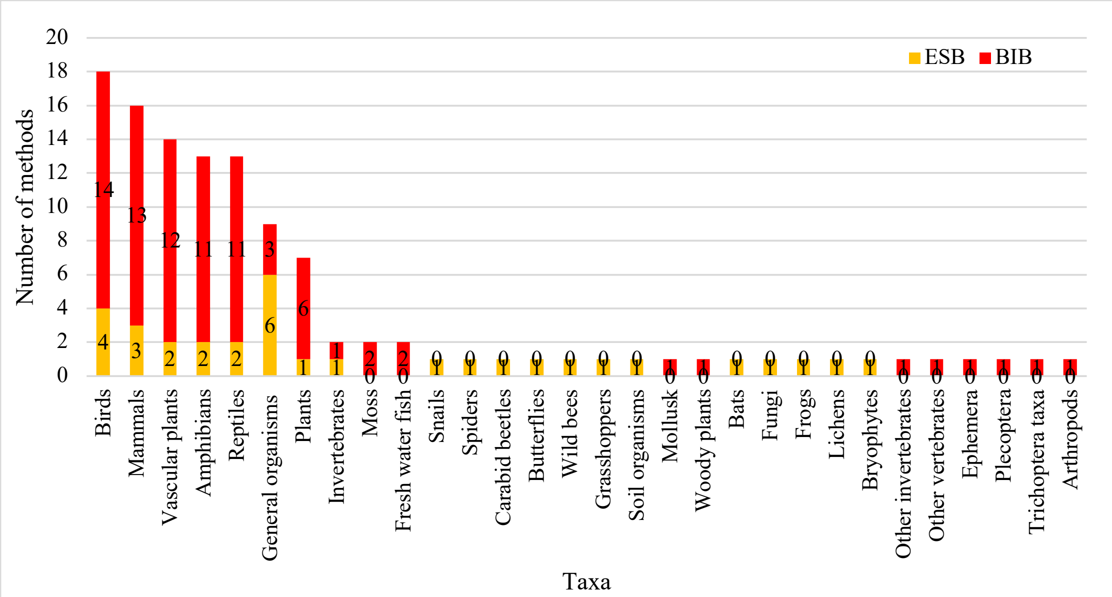

Fig.1 Taxa considered in different types of LCA methods for biodiversity impact assessment. ESB: expert scoring-based method, BIB: biodiversity indicator-based method.

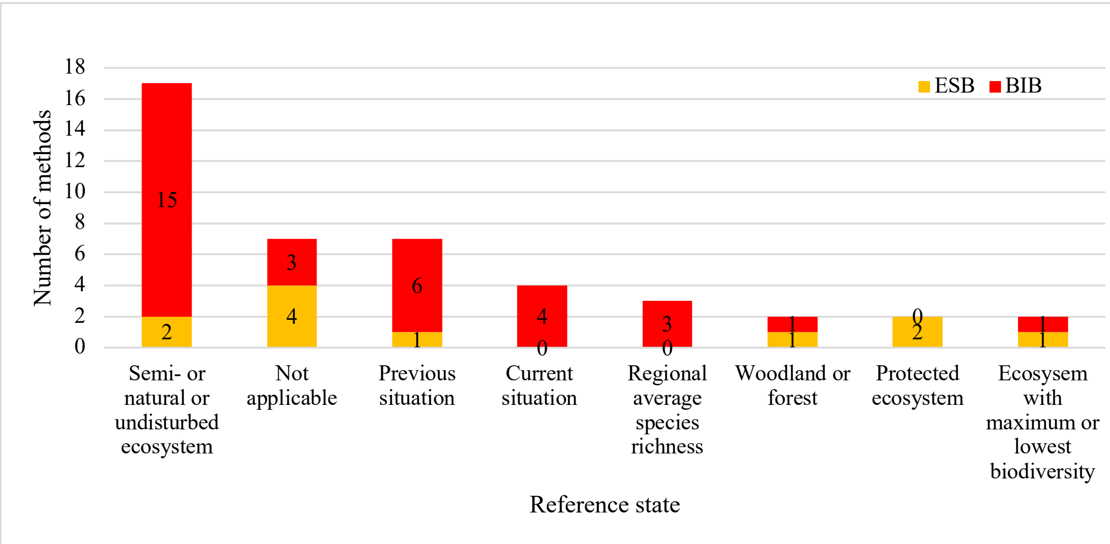

Fig.2 Reference state in different types of LCA methods for biodiversity impact assessment. ESB: expert scoring-based method, BIB: biodiversity indicator-based method.

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Biodiversity efficiency vs. effectiveness at the product level

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1. INTRODUCTION

Several approaches and methods have been put forth for addressing biodiversity in LCA, including the Biodiversity Value Increment (BVI) method by Lindner et al. (2019) based on principles described by Fehrenbach et al. (2015) and Lindner et al. (2021). In this presentation, we show selected organic vs. conventional comparisons using the BVI method and highlight the drivers that tip the comparison in either direction. We also discuss how the methodology can be engineered to reflect preferences in the efficiency vs. effectiveness debate. Organic agricultural practices may be more benign than conventional (more effective in terms of avoiding impact on a given plot), but the lower yield can raise the impact per product unit significantly (less efficient).

2. METHODS

The BVI method was used to calculate impacts for over 2,600 food products from the Agribalyse database (Lindner et al. 2022). The list includes many products in organic and conventional varieties that can be readily compared. The BVI method calculates impacts from the location, the intensity, as well as the occupation (areatime) of land using processes. Intensity is further broken down into fertilization, pesticide application, and tillage.

Making use of the Life Cycle Initiative land use framework, the BVI method defines a quality axis to determine a quality difference for a given land using process. It uses a naturalness gradient for quality, but higher naturalness levels are more squeezed together and lower levels are more spaced out (see

Figure 1). From one naturalness level to the next, the quality difference (which translates into impact) rises roughly by a factor of 2. The implication is: If the same product is obtained in a more intensive manner, the more intensive process is one naturalness level lower, but achieves twice the yield of the more benign process, the impact is the same.

3. RESULTS AND DISCUSSION

Table 1 shows the calculation of the biodiversity impacts of two unit processes for soft wheat production from the Agribalyse database, representing conventional and organic production. The conventional process achieves a higher yield (occupies less areatime), but the land management is more intensive, leading to a lower local biodiversity value (BV_{loc}) and a higher local quality difference (ΔQ_{loc}). The ecoregion factor (EF, which gives regional weighting) is equal, so the comparison comes down to yield vs. intensity. In this case, the organic product shows a lower impact per unit, but this is not the case for all such comparisons.

Beyond the organic vs. conventional debate, the question remains how strongly biodiversity indicators should magnify intensity differences, and how much more yield justifies how much more intensity. The spacing of the naturalness levels on the quality axis used in the BVI method gives a starting point (factor 2), but also facilitates a conscious discussion about efficiency vs. effectiveness.

4. CONCLUSIONS

Organic vs. conventional comparisons are of particular interest both from a philosophical and a political perspective. More generally, the comparison is about effectiveness vs. efficiency, and the BVI methodology offers a way to quantitatively discuss preferences on the issue.

5. ACKNOWLEDGEMENTS

These results are derived from the BVI to AGB project conducted with ADEME, the French Agency for Ecological Transition, financed by a grant from the French Ministry for Ecological Transition. The project also builds on intermediate results of the BioVal project, funded by the German Federal Ministry for Education and Research. The authors are grateful for the support.

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Process	Areatime [m²a]	BV_{loc} [BVI]	ΔQ_{loc} [BVI]	EF [ ]	ΔQ_{glo} [BVI]	Impact [BVIm²a/kg]
Soft wheat, conv.	1.33	0.722	0.278	3.30	0.916	1.22
Soft wheat, org.	2.14	0.898	0.102	3.30	0.338	0.72

Table 1. Comparison of biodiversity impacts calculated with the BVI method of conventional and organic soft wheat from Agribalyse datasets (from Lindner et al. 2022)

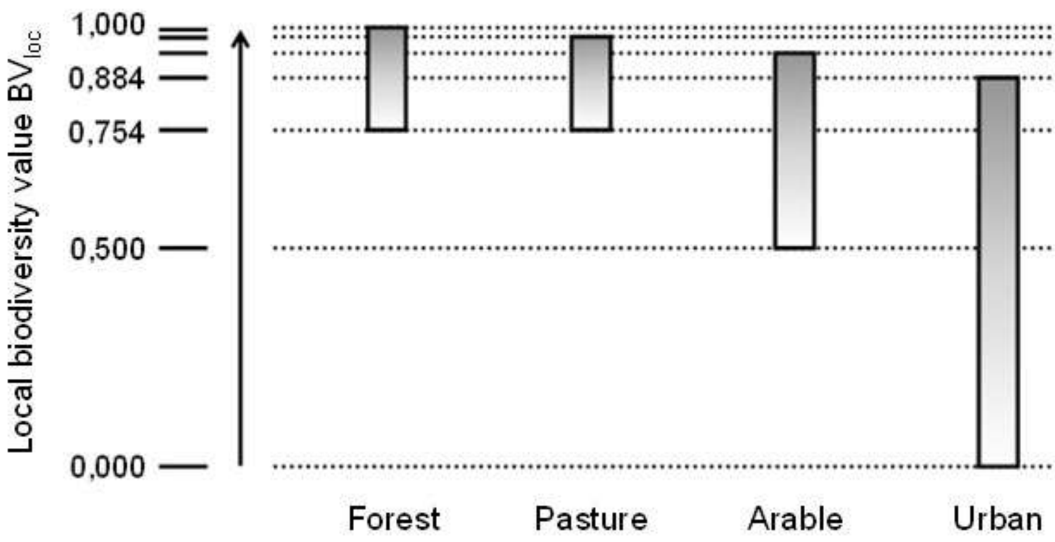

Figure 1. Naturalness levels (horizontal dotted lines) and local biodiversity value intervals of various land use classes distinguished by the BVI method

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Phylogenetic diversity as an indicator for biodiversity loss

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1. INTRODUCTION

The biodiversity crisis is severe, and action is needed. An adequate method for quantifying the impacts is important for efficient decisions on biodiversity mitigation and preservation. Current practice is associated with a two-sided problem; firstly, the approaches for biodiversity impact assessment give the same weight to the loss of a species, independent of the conservation value of the species; secondly is the failure to link habitat transformation with its drivers based on a cause-effect relationship. This paper presents a method that addresses both issues. The differentiation between species is addressed by using phylogenetic diversity, expressed as lost years of evolutionary history, as an indicator. The second issue is addressed by integrating the biodiversity model with a model for indirect land use changes (iLUC).

2. METHODS

The UNEP Life Cycle Initiative has identified land use characterisation factors (CFs) by Chaudhary and Brooks (2017) as the current best practice and recommends this for evaluating land use impacts of products in life cycle impact assessment (UNEP 2017). This approach quantifies the potential species loss per m^2 for different land use types, management intensity levels, and ecoregions, without differentiating between species. It can be argued that biodiversity value of a region is better estimated by the amount of evolutionary history hosted by it than just the species richness. The main argument is that maximizing evolutionary history (phylogenetic diversity: PD) in a region maximizes the evolutionary information preserved within its flora/fauna and provides the region with both more functional diversity and more options to respond to a changing world. In the current study, we first update the data used in UNEP (2017), with newly available land use maps and estimates of species affinity to different land use types. Then, we convert and update the species losses into PD loss (in units of million years) using the data for mammals, birds, and amphibians from Chaudhary et al. (2018), updated with new characterisation factors (CFs) for reptiles. The CFs were calculated for five land use types (cropland, pasture, urban, managed forests, and plantations) under three management intensity levels (minimal, light, intense) in each of the 804 terrestrial ecoregions and 245 countries and regions.

To account for the fact that the resulting land use change caused by occupying land for e.g. crop production in a specific region is most often taking place in another place, the biodiversity characterisation factors (CFs) are integrated with a model for iLUC (Schmidt et al. 2015).

3. RESULTS AND DISCUSSION

The characterisation factors calculated with the proposed method express the biodiversity impact in units of million year PD loss/m^2 land conversion, relative to undisturbed land. When integrated with the iLUC model, the occupation of land for e.g. crop production is linked with land use changes in other regions. Hereby, the PD loss can be linked with land use for any purpose anywhere in the world.

4. CONCLUSIONS

This paper proposes to use phylogenetic diversity as an indicator for biodiversity loss in life cycle impact assessment. This provides a better measure of biodiversity loss compared to current best practise, which does not distinguish between species. When combined with an iLUC model, the biodiversity impact can then be linked with it'd drivers using a cause-effect based approach.

5. ACKNOWLEDGEMENTS

This work was commenced and supported by A.P. Moller Maersk (https://www.maersk.com/).

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Applying existing four biodiversity assessment methods to Agribalyse : similarities and differences among methods ?

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1. INTRODUCTION

Primary drivers of biodiversity collapse include land-use change, climate change, pollution, natural resource use, and invasive species. Depending on the driver, current LCIA does totally, partially or not-at-all account for the human pressures on biodiversity. Land-use change is the major human influence on terrestrial habitats and can include land cover change, land management change or landscape change. This study falls within roadmap priorities of the REVALIM group and focuses on assessing the impact of agriculture on biodiversity at field level specifically addressing the "land use change" pressure associated with agriculture.

2. METHODS

Four promising methods HCFg [1], LUIS [2], BVI [3] and BSS [4] have been reviewed and tested on twenty crops and animal production datasets from conventional and organic agriculture from Agribalyse database.

3. RESULTS AND DISCUSSION

3.1 Different approaches, metrics and operability among methods

Divergent outcomes in the 20 cases studied stem from varied approaches, metrics, and specificity levels (

Figure 1). HCFg, LUIS, and BVI employ a classic LCA framework, assessing biodiversity variations linked to the product, expressed in PDF.year or dimensionless for BVI. BSS differs, with no direct link to the functional unit, assessing a stock of biodiversity, without unit. BSS fails to consider surface mobilization per production unit. HCFg and LUIS underline the significant impact of including land transformation data in inventories. The HCFg and BVI consider habitat fragmentation within the studied ecoregion.

3.2 The importance of the geography indicator in methods

The HCFg, aligned with GLAM 1 consensus, assesses impacts at (eco)regional or global levels, while LUIS provides only a global assessment. Depending on the location of crop, methods assess biodiversity loss differently. All other things being equal, the biodiversity loss is not the same according to method if crop is grown in Brazil or Canada. In HCFg and LUIS, higher percentages of endemic or vulnerable species intensify loss of biodiversity in an ecoregion. For BVI, the severity is influenced by the percentage of grasslands, forests, wetlands, roadless areas, high species endemism and vulnerability in the ecoregion. BSS completely ignores this geographical criterion.

3.3 The effect of agricultural land management practices within the methods

A critical factor was how agricultural land management practices affected the sensitivity of the results. HCFg does not take practices and intensity into account, LUIS has a discrete parameter depending on the level of intensity, with a rather low sensitivity. For BVI and BSS, tests carried out on semi-natural habitats (SNH) and field size displayed a substantial influence on the results.

4. CONCLUSIONS

The study acknowledges biodiversity's multidimensional nature, highlighting the complexity of capturing it with a single indicator based on current methodological developments. It underlines the need for multiple biodiversity indicators in LCA to comprehensively represent product and supply chain impacts on biodiversity. It also highlights the current lack of inventory data, especially at landscape level (eg. SNH, field size, ...).

5. ACKNOWLEDGEMENTS

The authors thank the REVALIM group and its partners and ADEME for its financial support.

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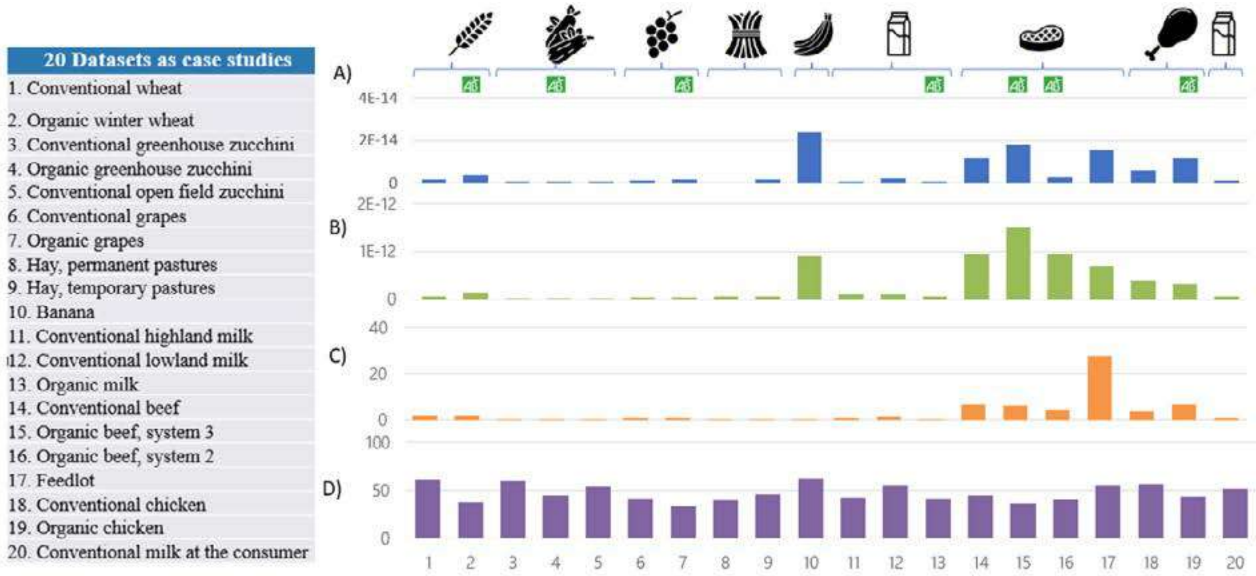

Figure 1. Outcomes from 20 case studies assessed with A)HCFg B)LUIS C)BVI D)BSS

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Regional characterisation factor to assess biodiversity loss in high diversity areas

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Keywords: Biodiversity loss assessment, Species richness

1. INTRODUCTION

Biodiversity threats from human-induced land use and land-use change are the main drivers of global biodiversity loss. In life cycle assessment this impact category is assessed using widespread and state-of-art approaches to obtain characterisation factors (CFs) of biodiversity loss (Chaudhary et al., 2015; Chaudhary & Brooks, 2018; Scherer et al., 2023) that estimate species richness diversity (RR) based on different versions of the species-area relationship (SAR). Despite these valuable contributions, SAR assumes an unrealistic uniform distribution of biodiversity (Pereira & Daily, 2006), showing insufficient information on a particular biological dimension (Oliveira et al., 2019). This study aims to develop CFs of biodiversity loss considering RR estimated from a spatially explicit model, which improves the accuracy of the estimation. In addition, insects, namely bees and butterflies, are included.

2. METHODS

Similar to previous studies (Chaudhary et al., 2015; Chaudhary & Brooks, 2018; Scherer et al., 2023), the CF is an estimated potential disappear fraction (PDF) of species per m2. Interim, the study estimates land use occupation CF at the region level for a sample of 906 patches in African and South American ecoregions with different types of land use (i.e. managed forest, pasture, cropland and urban) and intensities (i.e. minimal, light and intense uses). To estimate current and reference RR the model used was Optimising Combined Evidence in Unique Biota (OCEUB), which are the inputs used to calculate the PDF of species (Oliveira et al., 2019). OCEUB is a spatially explicit model based on the genetic algorithm technique that estimates RRs more accurately than classical models, especially in tropic ecosystems, home to the most extensive biological diversity (Oliveira et al., 2019).

3. RESULTS AND DISCUSSION

The aggregated land occupation CFs (PDF/m^2) show values between 1.155704e-10 (0.025 quantiles) and 7.224856e-09 (0.975 quantiles) (Figure 1). These CFs are 10^3 times higher than the ones recently obtained by Scherer et al. (2023), evidencing the underestimation of biodiversity when traditional approaches are applied in high-diversity areas such as our sample (Oliveira et al., 2019; Pereira & Daily, 2006). Including two new animal species groups could also improve the estimation accuracy; however, sensitive analysis has not been applied in this interim result.

4. CONCLUSIONS

The study highlights the value of the OCEUB model to improve the accuracy in estimating biodiversity loss CF, based on RR, for high diversity of the OCEUB model to improve the accuracy in estimating biodiversity loss CF, based on RR, for high-diversity regions. Future studies aim to extend the approach to other ecoregions and develop global and land transformation CFs as well as CFs beyond RR by considering different biodiversity dimensions such as species composition and endemism estimated with OCEUB.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the funding from the European Union's Horizon Europe research and innovation programme through project 101060765, “Creating leverage to enhance biodiversity outcomes of global biomass trade-CLEVER”.

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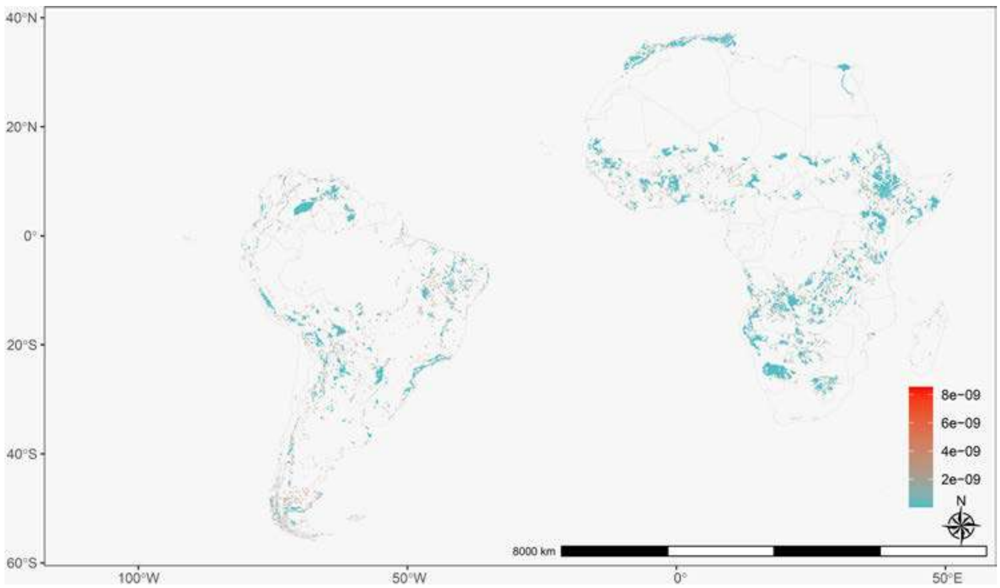

Figure 1. Aggregated land occupation characterisation factors at the ecoregion level. The unit and fill-in map is the average potential disappear fraction (PDF) of species per m2 for different land uses (managed forest, pasture, cropland and urban) and intensitive levels (minimal, light and intense uses).

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Foundation Earth Methodology

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1. INTRODUCTION

Foundation Earth (FE) is an independent, non-profit organisation that has developed a certification and labelling system to assess the environmental impact of food. This system is helping businesses to build a more resilient and environmentally sustainable food system, as well as giving consumers and B2B actors the tools they need to make sustainable buying choices.

The FE Farm-to-Fork Methodology, which underpins the certification and labelling system, was developed in collaboration with Blonk Consultants and DIL e.V. and approved by an independent Scientific Committee of experts in Life Cycle Assessment (LCA), behavioural science and consumer behaviour.

The FE Methodology is open-source and was published in March 2023. This method has been tested with a wide range of food companies in 2023 and continues in 2024.

2. METHODS

The FE Methodology was developed to establish a harmonised LCA methodology, reflecting the European Commission's (EC) Product Environmental Footprint (PEF) guidance. The FE Methodology is based on the PEF and provides additional guidance to address conflicts between sector-specific Product Environmental Footprint Category Rules (PEFCRs) including functional units and system boundaries. This harmonised approach allows comparisons of environmental impacts across all food categories. The FE Methodology also specifies minimum requirements for primary data collection and sets clear guidelines for secondary data sources, data quality assessments and emission calculation rules. The same LCA impact assessment method as proposed by the PEF is used to calculate the environmental impacts of the analysed products, expressed as single scores. The methodology is transparent and open-source.

3. RESULTS AND DISCUSSION

Results from live testing continue to be gathered and reviewed. FE has been analysing and aggregating insights from the LCAs across food categories and life cycle stages, feedback from LCA providers on method application, plus client expectations on grades outcomes.

In 2024, FE will be using these learnings to inform a review and upgrade of the FE Methodology. The aim of this project is to improve the current system and seek opportunities for further harmonisation. In addition, and complimentary to this work, FE will run a B2B pilot to develop and test a B2B method suitable for actors earlier in the supply chain. Both projects will be developed in collaboration with Blonk Consultants.

4. CONCLUSIONS

Foundation Earth and Blonk Consultants would like to present insights from the development and testing of the FE Methodology, as well as outcomes from the B2B pilot which will conclude before August 2024.

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Urban symbiosis of a Vertical Hydroponic Farm and a Mushroom Farm: an environmental assessment

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1. INTRODUCTION

Stockholm County' population is expected to grow by 60% in the next decades, putting significant pressure on a nation characterized by limited arable land surface and a high dependency on imported food. Urban farming, the practice of growing and distributing food in urban areas (Sanjuan-Delmás *et al.*, 2018), has emerged as a potential solution taking advantage of shorter supply chains and use of urban resource flows (Goldstein *et al.*, 2016). Moreover, different studies have highlighted how the implementation of circular approaches can improve environmental performance (Martin, Poulikidou and Molin, 2019; Dorr *et al.*, 2021); however, the quantifiable environmental potential remains untapped. The following study evaluates the environmental performance using Life Cycle Assessment (LCA) of an urban symbiosis between a vertical hydroponic farm (VHF) and a mushroom urban farm, comparing different circular scenarios for improvement scenarios. In particular, the organic waste produced by the vertical farm (mainly composed of growing media, stems, and roots) is used as a substrate for growing oyster mushrooms (*Pleurotus ostreatus)*, substituting the conventional substrate made of wheat straw.

2. METHODS

The assessment is based on the annual production of 840 kg of oyster mushrooms. The cultivation of mushrooms followed conventional growing practices where the substrate was inoculated with mycelium and required roughly 2 months to grow (Sánchez, 2010). The environmental assessment was performed employing LCIA Scores (Muñoz-Liesa et al., 2024), a Brightway2 based tool to facilitate environmental modelling. The ReCiPe 2016 (v1.03) life cycle impact assessment method was employed focusing on Global Warming (GW, in kg CO_2-eq) while background data was retrieved from Ecoinvent v. 3.9.1. Two scenarios are considered: *Linear* and *Circular.* The *Linear* scenario represents the current production system where the substrate is made of straw pellets along with gypsum, mycelium-inoculated wheat seeds, and municipal tap water. In the *Circular* scenario, straw pellets are substituted by organic waste. The functional unit was set at 1 kg of mushroom produced and impacts were allocated based on mass and the economic value of co-products when assessing systems circularity.

3. RESULTS AND DISCUSSION

Results suggest that the use of organic waste is a feasible solution for mushroom growing as a substitute for wheat straw. The *Circular* scenario showed an improvement of 87% compared to the *Linear* one regarding the GW impacts (Fig. 1). The improvement is explained by the reduced transportation of the substrate material and by a shorter supply chain, reduced from 500 km to 24 km. Also, the higher impacts of the *Linear* scenario are mainly explainable due to the use of electricity needed to pelletize the wheat straw, unneeded when using organic waste. Thus, the first synergy between the two companies showed potential benefits. However, the environmental burdens of the organic media were allocated for the VHF, according to the economic allocation criteria, since no costs were assumed from the mushroom farm (Martin, Svensson and Eklund, 2015). Thus, we expect different allocation criteria will greatly influence environmental results. The exploration of additional circular scenarios such as the use of excess CO_2 and the use of Spent Mushroom Substrate (SMS) will be assessed in further research.

4. CONCLUSIONS

The study shows the feasibility of growing *P. ostreatus* in a substrate composed of 100% organic waste coming from a VHF. Moreover, the use of organic waste could increase the environmental performance of the mushroom farm, avoiding the waste being discarded through incineration.

5. ACKNOWLEDGMENTS

The authors would like to thank the Vertical Hydroponic Farm and Mushroom Farm owners for their time during the interview and data collection. Financial support was provided by FORMAS.

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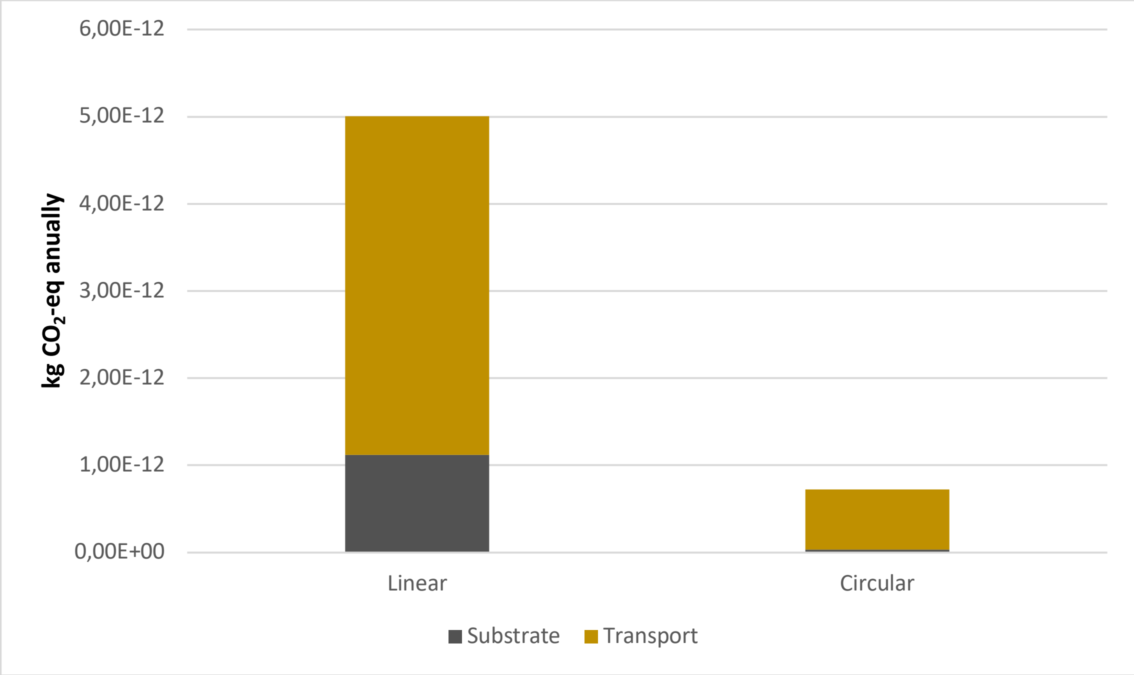

Figure 1. Contributions of the processes to the annual GHG emissions for the different scenarios.

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