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TOWARDS SUSTAINABLE AGRI - FOOD SYSTEMS

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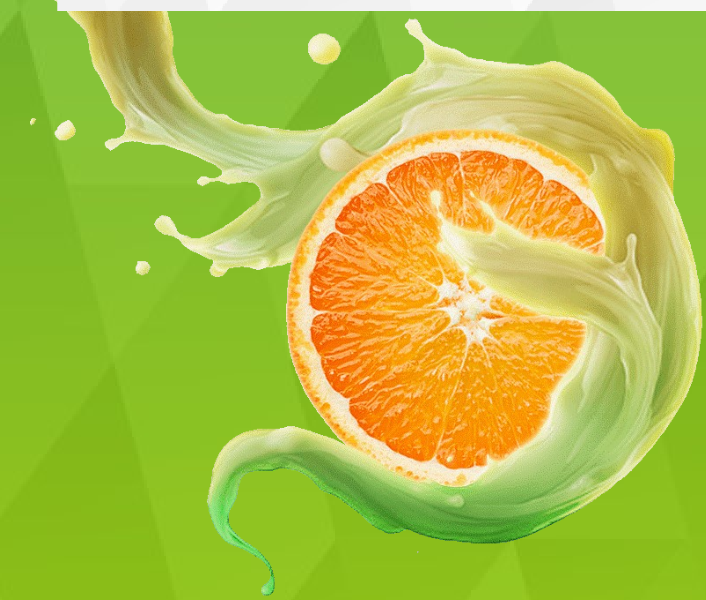

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Oral Presentations

Topic 1:

Planetary Boundaries:

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Balancing China’s food production within the planetary water boundary

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Abstract

Purpose. The global freshwater use boundary must be spatially downscaled to reflect differences in water availability, because water scarcity is a local or regional phenomenon. In China, as in most countries, irrigation is the major freshwater user, closely linking food security to the freshwater boundary. This study aims to explore how a grain production shift affects the national water scarcity and the potential to reach sustainable water use limits while maintaining the current grain production level.
Methods. We quantify the spatial shift of the production of the main staple crops (maize, wheat and rice) by mapping the location (longitude and latitude) of the centroids under China’s dramatic land-use change from 1980 to 2015. We estimate the water-scarcity footprint (WSF) of the three crops, which incorporates a water scarcity index to link water consumption to potential impacts from water scarcity. The AquaCrop model was applied to simulate crop yields and irrigation, which were used to calculate crop WSFs. By conducting a sensitivity analysis, we explore how the breadbasket shift affects the national WSF. We then examine the balance of both irrigation water and grain production under a downscaled water boundary, considering also crop redistribution and yield gap closures.
Results and discussion. We found that the historical breadbasket shift towards water-scarce northern regions has increased the WSF by 40% during 1980–2015. To operate within the boundary, national irrigation needs to be reduced by 18% in hotspot regions, with implications of a 21% loss of grain production. However, this loss can be reduced to around 8% by closing yield gaps in water-rich regions. It demonstrates the high potential of integrating crop redistribution and closing yield gaps to achieve grain production goals within freshwater boundaries.
Conclusions. We identify that China’s historical shift of grain production has exacerbated national water scarcity and illustrate the potential to achieve grain production goals within freshwater boundaries. The pressure which land-use change puts on China’s freshwater arises from the current pattern of water consumption, which often occurs in highly water-scarce regions. China must reverse its grain production shift towards water-scarce regions. National crop redistribution can also be combined with existing technologies and knowledge, but priorities should be given to the hotspot regions to satisfy the more urgent needs and obtain a higher positive impact.

Keywords: *Water scarcity; food security; planetary boundary; crop redistribution; yield gap.*

Introduction

Freshwater use has been identified as one of the nine planetary boundaries and it appears that current global water consumption is within the safe operating space for humanity (Steffen et al.

2015). However, as freshwater is spatially heterogeneous and often dominated by local dynamics, the global boundary must be downscaled to reflect differences in water scarcity. Currently, major parts of global freshwater withdrawals occur in water-stressed regions, indicating that the spatial water consumption pattern rather than the absolute shortage requires further assessment to reduce the pressure humanity puts on freshwater (Ridoutt and Pfister, 2010a).

In China, as in most countries, irrigation is responsible for the highest freshwater use, closely linking food security to the freshwater boundary. It is therefore necessary to set food production goals within the downscaled planetary water boundary. Over the past decades, China's agricultural production remarkably increased and underwent a spatial shift along with its rapidly growing economy and food demand (Zuo et al. 2018). Both the increase and shift of agricultural production could cause enormous water-related impacts because of the geographical mismatch between cropland and water availability. China's current food production paradigm is experiencing a paradox: producing food in drier regions and transferring the food to wetter regions by agricultural trade (Dalin et al. 2014). To address the water for food dilemma, strategies have been put in place on water transfer project construction (Liu et al. 2013), virtual water trade (Dalin et al. 2014), and water productivity improvement (Kang et al. 2017). Undeniably, the combination of these solutions can substantially reduce the pressure on water resources. However, these strategies, which usually ignore the potential environmental impacts from water scarcity and lack a regional water use boundary, might conflict with the goal of water scarcity mitigation. Davis et al. (2017) found that global redistribution of crops would feed an additional 825 million people while reducing the water consumption. However, crop redistribution at global scale is less policy relevant, because most governance takes place at the regional rather than global scale. Therefore, strategies aimed at sustainable water use and food security must integrate water consumption patterns and downscaled water boundaries. This study explores how a breadbasket shift affects the national water scarcity, and whether China can reach sustainable limits while maintaining the current grain production level by closing yield gaps (Huang et al. 2020). Our study aims to enable policies to set national agricultural water use priorities across regions by considering the environmental implications of meeting food security.

Material and methods

We applied county-level production statistics of maize, wheat and rice to quantify the spatial shift of the production by mapping the location (longitude and latitude) of the centroids in 1980, 1990, 2000 and 2015. We estimated the water-scarcity footprint (WSF) of the three crops from 1980 to 2015. The WSF incorporates a water scarcity index (WSI) to link water consumption to potential impacts from water scarcity. The AquaCrop model (http://www.fao.org/aquacrop) was applied to simulate crop yield and irrigation water consumption, which were subsequently used to calculate the crop WSF. To separate the impact of the crop production shift on national water scarcity from other factors, we conducted a sensitivity analysis by changing one-factor-at-a-time. The parameter perturbations for the sensitivity analysis are: P1—change in the national total production of the three crops from 1980 to 2015; P2—change in the WSF per kg for each crop in each county from 1980 to 2015; P3—change in the national crop mix from 1980 to 2015; and P4—change in the production centroid per crop from 1980 to 2015. We defined the sustainable water boundary in an area with grain cultivation as the water consumption level at which the WSI would be 0.5, indicating a water scarcity threshold between moderate and severe (Pfister et al. 2009). We then examined the balance of both irrigation water and grain production under the boundary and checked whether China can reach the sustainable limit while maintaining the current production level by crop redistribution and closing yield gaps (reaching 75% and 80% potential yield, respectively). Details on data sources and methods can be found in our published work (Huang et al. 2020).

Results

China's national WSF for grain production was 6.0×10^{10} m^3 H_2Oe in 2015, which was 2.6 times higher than in 1980 (Fig.1a, b). Compared with 1980, the WSFs of all the sub-regions in 2015 have increased. The counties with higher WSFs were found in the regions with higher water scarcity, higher production, or a combination of both, such as Huang-Huai-Hai, the middle-lower reaches of Yangtze basin, the northwest and northeast. The regions with a higher increase in the WSF were found where the WSFs in 2015 were much higher than the counties' average. Thus, the major contributors to the increase were also Huang-Huai-Hai (25%), the middle-lower reaches of Yangtze basin (21%), the northeast (21%) and northwest (18%). Based on four parameter perturbations (P1–4) in the sensitivity analysis (Fig.1c), we found that, apart from the change in the crop mix (P3), the other perturbations (P2–4) significantly contributed to the increase of the total WSF from 1980 to 2015. The increase of the total WSF (increase by 130%) under P1 kept pace with the increase of production and was the highest among all the parameter perturbations. The total WSF under P2 was also much higher than that in 1980 (increase by 60%), because of higher WSF per kg grain. The shift of the production centroid has increased the total WSF by 40%. While most southern regions reduced their WSFs, the main increase happened in the northeast (65%), the northwest (23%), and Huang-Huai-Hai (20%). Rice, wheat and maize contributed to the total increase by 62%, 24% and 14%, respectively. The shift of rice to the northeast, wheat to Huang-Huai-Hai, and maize to the northwest were the main causes for the increase of the total WSF, accounting for 65%, 21% and 16%, respectively. This illustrates that the current distribution of grain crops has become substantially less sustainable than in 1980, which has exacerbated China's water scarcity.

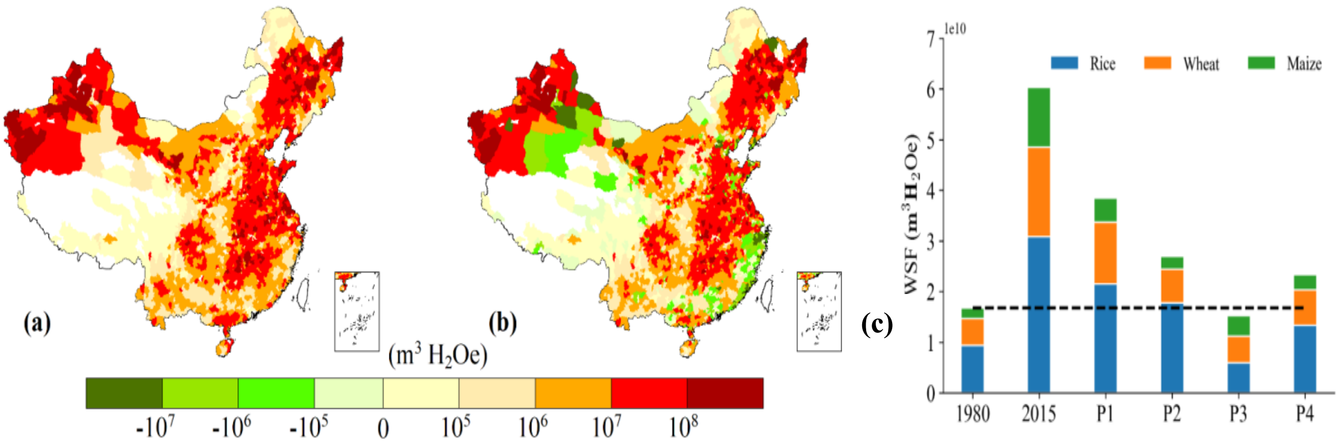

Fig. 1. Water-scarcity footprint (WSF) of the three crops (a) in 2015, (b) the net change between 1980 and 2015, and (c) sensitivity analysis of the WSF. P1-4: please refer to the section of Material and methods.

To reach the sustainable limit (WSI = 0.5), China must reduce the irrigation water consumption in hotspot regions by 2.4×10^{10} m^3, which is 18% of the national irrigation for the three crops in 2015. The major hotspot regions were in Huang-Huai-Hai, the northwest, and northeast, which required 46%, 31% and 7% of the total irrigation reduction target, respectively. The water-rich regions, which had relatively lower WSIs (< 0.5), had a potential to increase irrigation by 2.2×10^{12} m^3, which is far more than the reduction target for the hotspot regions. These regions are mainly located in the south but also in the northeast, accounting for 78% and 19% of the total potential increase of irrigation water. Consequently, there is no absolute national irrigation water shortage for grain production within the water boundary. The reduction of irrigation in the hotspot regions implies that the associated grain production would also be decreased. Based on the current crop yields, the total grain loss in the hotspot regions was estimated as 1.3×10^{11} kg, 21% of national production in 2015. However, the potential increase of irrigation in water-rich regions makes it also possible to increase grain production there. By considering both the irrigation water availability and crop yield potential, we find that the possible increase of grain production in water-rich regions can compensate 56–65% of the loss when yield gaps are closed to 75–80% of the potential yield (Fig.2). Thus, the total grain loss would be reduced from 21% to only 8–9% of the national grain production in 2015.

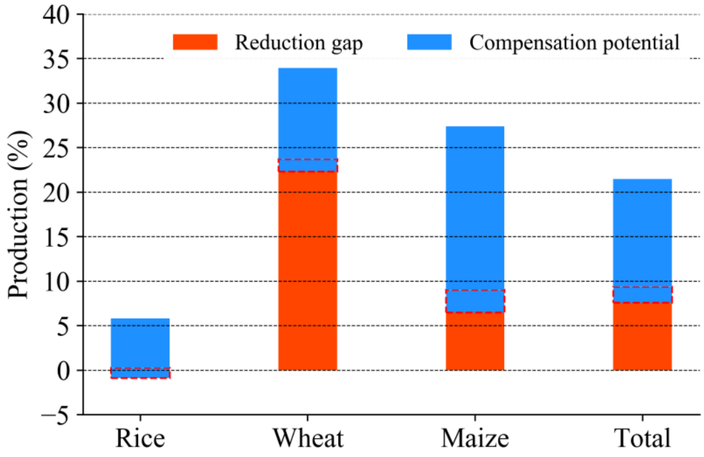

Fig.2. Loss of grain production (whole bars) to meet the downscaled planetary water boundary in hotspot regions and potential for compensation (blue bars) by closing yield gaps in water-rich regions. The red dashed frames indicate the additional compensation potential by closing the yield gaps from 75% to 80% of the potential yield.

Discussion and conclusions

We identify that China's historical shift of grain production has exacerbated national water scarcity and illustrate the potential to achieve grain production goals within freshwater boundaries. The results lead to several strategic implications for China's grain production. First, the spatial water consumption pattern rather than the absolute shortage requires more political attention. The pressure which land-use change puts on China's freshwater arises from the current pattern of water consumption, which often occurs in highly water-scarce regions. Second, China must reverse its grain production shift towards water-scarce regions. There is high potential to balance national grain production by just closing yield gaps in water-rich regions while meeting a downscaled water boundary. Third, national crop redistribution can also be combined with existing technologies and knowledge. However, priorities should be given to the hotspot regions to satisfy the more urgent needs and obtain a higher positive impact. By integrating food production and a water boundary, we illustrate the broader value of the safe and just operating space approach for sustainable development. Future work needs to further assess the results with detailed spatial information. Especially, it requires to elaborate the exact amount of freshwater dominated by some regions located in cross border areas sharing the same aquifers with their neighbouring countries.

Acknowledgements

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Abstract code: 60

Assessing ecosystem services to address blind spots in farm LCAs

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Abstract

Purpose: Environmental performance of farming systems needs to be assessed to decrease the loss of biodiversity, for example using frameworks such as life cycle assessment (LCA) and ecosystem services (ES) assessment. How to combine these two methods to assess environmental performance more precisely remains a research question. We analyze parallel use of the LCA method ReCiPe and the Ecological Focus Area (EFA) calculator, both of which can assess ES supplied by EFAs, to evaluate how to address blind spots of LCA with an ES assessment tool.

Methods: ReCiPe assesses impact on four ES categories, and eleven additional ES categories could be integrated into it, four of which have a high priority according to their monetary value. However, doing so would not resolve two blind spots of LCA: (i) a vision oriented toward negative impacts of agricultural production on ES supply, without considering potential benefits of certain practices or farm management on ES supply, and (ii) not considering non-productive farm areas (i.e. semi-natural areas) in assessments. We analyze the potential of the EFA calculator to address blind spots of the LCA method ReCiPe and advantages that combining the two methods can provide for assessing environmental performance of farming systems, especially by considering the influence of both land cover and the intensity of practices on ES supply.

Results and discussion: We do not yet have empirical results for use of the two methods. We assume that they will consist of (i) LCA results, (ii) ES assessment results and (iii) common interpretation of them, with reflection on how they can be used to assess dynamics of ES on farms. Adding impacts of farm production on other ES to ReCiPe and applying the EFA calculator to grassland and cropland could increase the precision by benefiting from the complementarity between the two methods (assessing the same ES on the same areas). An overview of other LCA and ES assessment methods is necessary to highlight advantages and disadvantages of combining ReCiPe and the EFA calculator.

Conclusion: Combining them could allow all farm area (productive and semi-natural areas) to be considered when expanding beyond the negative-impact-oriented vision of LCA, to provide an overall assessment of environmental performance. Combining LCA and ES assessment tools could be a useful way to show environmental benefits and lower environmental impacts in a single assessment for systems that base their production on biological processes and attempt to increase their environmental performance.

Keywords: *Environmental assessment; Life cycle assessment; Ecological focus area; Biodiversity; Agriculture.*

Introduction

Loss of biodiversity has been identified as a major impact of farming systems, which emphasizes the importance of redesigning them (Foley *et al.*, 2011). This requires assessing their wider environmental impacts and performances (Meier *et al.*, 2015), using frameworks such as life cycle assessment (LCA) (Huijbregts *et al.*, 2016) and ecosystem services (ES) assessment. Biodiversity, the biotic components of ecosystems, interacts with abiotic ecosystem components to furnish ecological processes from which ES flow (Tallis *et al.*, 2012). ES, which are contributions that ecosystems make to human well-being (Haines-Young and Potschin, 2018), are assessed by qualifying and quantifying (sometimes in a spatially explicit manner) their supply in a specific area

(Tzilivakis *et al.*, 2019). Currently, LCA methods do not consider ES. Alejandre *et al.* (2019) studied different LCA methods to develop an approach to assess impacts on ES supply in LCA. To do this, they noted that the LCA method ReCiPe (Huijbregts *et al.*, 2016) already assesses four ES categories, and eleven additional ES categories could be integrated into ReCiPe. However, their approach still does not resolve two blind spots of LCA: (i) a vision oriented toward negative impacts of agricultural production on ES supply without considering potential benefits of certain practices or farm management on ES supply and (ii) not considering non-productive farm areas (i.e. semi-natural areas) in assessments. Consequently, integrating ES assessment in LCA is not sufficient to assess the overall environmental performance of a farm.

After an initial evaluation of selected ES assessment tools, we focus our analysis on the potential of one of them, the Ecological Focus Area (EFA) calculator (Tzilivakis *et al.*, 2016; Tzilivakis *et al.*, 2019), to address blind spots of the LCA method ReCiPe. EFAs correspond to non-productive semi-natural areas of farms, such as hedges, fallows and isolated trees, which LCA does not consider. Further, we highlight the complementarity of the two methods for assessing the environmental performance of farming systems.

Material and methods

In an agricultural context, LCA usually focuses on a farm as a production system, considering almost exclusively its inputs, outputs and the processes that occur on its agriculturally productive area (Boone *et al.*, 2019). ReCiPe connects the life cycle inventory to 17 midpoint impact categories that can be aggregated into the three standard endpoint categories (Huijbregts *et al.*, 2016). ReCiPe has two advantages: (1) midpoints and endpoints are easily correlated using factors that remain constant for each impact category, because environmental mechanisms for each stressor are considered to be identical after the midpoint impact, and (2) characterization factors are adapted to a global scale rather than a continental scale (Huijbregts *et al.*, 2016).

Alejandre *et al.* (2019) used the ES classification of CICES V5.1 and found that the ReCiPe method can assess four ES categories (Fig. 1), which are represented by two provisioning ES (mineral/fossil energy scarcity, water provisioning) and two regulation and maintenance ES (carbon sequestration, protection from UV radiation). Among eleven other categories of ES that could be included in ReCiPe, they identified those with the highest priority. According to the monetary value of the ES in these categories, four of the categories can be represented in decreasing order by the most valuable ES in each (i.e. erosion prevention, waste treatment, recreation and pollination) by connecting them to midpoint impact categories (Fig. 1).

As mentioned, ReCiPe ignores potential environmental benefits of farming systems to ES supply. Alejandre *et al.* (2019) relate LCA impact categories to impact on ES supply, such as anthropogenic emissions that counteract carbon sequestration ES. LCA considers practices or farm management that could increase ES supply, but often considers only the emissions and extractions of resources for agricultural production that decrease it. Moreover, ReCiPe, like all LCA methods, generally focuses on the productive function of farming systems, considering livestock, crops, grasslands, equipment and infrastructure in the assessment (Fig. 2). It ignores the farm's semi-natural areas that play key roles in supplying ES in a farming landscape (Sabatier *et al.*, 2015).

To address the first blind spot, ES assessment tools can add a benefits-oriented vision to LCA's impact-oriented vision (Fig. 2). To address the second blind spot, ES assessment tools consider semi-natural areas (Tzilivakis *et al.*, 2019) and sometimes consider productive land areas as well (Fig. 2). It would therefore be useful to associate LCA with an ES assessment tool to have two complementary visions of environmental performance.

We propose using the EFA calculator (Tzilivakis *et al.*, 2019) in parallel with LCA. The calculator contains several models, each of which estimates an ES supplied by EFAs based on their types, locations, distance from productive areas and proportional areas on the farm. The EFA calculator estimates the supply of five ES considered important to include in LCA: carbon sequestration (already considered by ReCiPe), erosion prevention, pollination, aesthetic value (these three a priority for addition to ReCiPe (Alejandre *et al.*, 2019)) and pest control (not a priority for ReCiPe) (Fig. 1). The calculator uses land-cover characteristics of EFAs to estimate the supply of the ES, but those of grasslands and crops would also be interesting to include in the models. The calculator does not, however, consider the influence of management intensity on ES supply.

As mentioned, ReCiPe already considers four ES categories, and with the addition of new impact midpoint categories, other ES could be assessed, especially regulation and maintenance ES and their relation to land use (Alejandre *et al.*, 2019) and thus to the intensity of practices. Adopting these two methods would provide two ways to assess ES: based on land use (i.e. intensity of human management on an area) (ReCiPe) and based on land cover (i.e. type of physical material on an area, without quantifying the intensity of human management) (EFA calculator).

Using the EFA calculator along with ReCiPe requires identifying what additional data the calculator requires that are not collected for LCA. These data include each type of EFA, location, proportional area (or length, depending on the EFA) and boundaries with productive areas. Another advantage of using the EFA calculator is its ability to assess support for biodiversity by relating the variety of EFAs and their characteristics to potential habitats for genetic and species diversity.

Results

We do not yet have empirical results for the use of the two methods, but preliminary results will be forthcoming. We assume that they will consist of (i) LCA results, (ii) ES assessment results and (iii) common interpretation of them. We are currently planning how to interpret the results, such as comparing the two methods' estimates of ES supply and integrating the estimates into an overall vision of ES dynamics on the farm by considering their interactions with farm practices and land-cover types. We chose the EFA calculator rather than another tool because (i) we can apply it throughout Europe, (ii) it is already operational for many EFAs and (iii) it seems possible to add productive areas to it.

Discussion

Both the EFA calculator and ReCiPe (in its current version and with the addition of midpoint categories proposed by Alejandre *et al.* (2019) to assess high-priority ES) focus on a few ES, which raises questions about their ability to consider ES supply well in an assessment of overall environmental performance of a farm. According to Alejandre *et al.* (2019), pest control is not considered a high priority ES to include in ReCiPe, but it could be included, despite its lower monetary value. Doing so would allow ReCiPe to consider all ES assessed by the EFA calculator. Moreover, they prioritized ES based on their monetary value, and the regulation and maintenance ES (pollination, erosion prevention and carbon sequestration) are the most important. Since both methods can consider them, it could be sufficient to use these methods with their selection of ES.

The EFA calculator estimates ES supplied by EFAs, not by other types of land cover on the farm. As mentioned, it may be possible to adapt the calculator to consider the ES supplied by other types of land cover. Doing so would require adapting the equations in the models that estimate ES supply to consider crop area. Initial examination of these equations indicates that grassland would be easier to consider than crops, because grassland has more characteristics in common with EFAs.

In line with the definition of "land cover", the EFA calculator relates land cover to ES supply without considering farm practices. Since it focuses on EFAs, we assume that human activities on them influence ES supply less than other characteristics of these areas (type, location and proportional area) (Sabatier *et al.*, 2015). If we add grassland and crops to the EFA calculator, we will use the same parameters as those for the EFAs (type, location, absolute area and proportional area); however, the land use (i.e. practices such as grassland grazing or mowing, species of crop grown) of productive areas (i.e. grassland and crops) influences the impacts of productive land cover greatly (e.g.). Consequently, we will first need to relate these parameters to farm practices. When applying the two methods in parallel, ReCiPe will estimate the impact of land use on ES supply. It is important, however, not to double-count the environmental effects assessed by the two methods, especially for regulation and maintenance ES (e.g. water purification) and their inverse equivalents in LCA (e.g. pollutant emissions to water) (Alejandre *et al.*, 2019).

We are currently focusing on the ReCiPe and EFA calculator methods, but other methods could be used for LCA and especially for ES assessment. Other ES tools that can consider all land-cover types and not only EFAs may be interesting to use (Tallis *et al.*, 2012), but they appear to require more data and be more difficult to relate to LCA. Moreover, the EFA calculator could be useful for considering on-farm biodiversity along with environmental impacts and ES in an overall assessment of environmental performance of farming systems.

Conclusions

Combining the ReCiPe method and the EFA calculator could allow all farm area (productive and semi-natural areas) to be considered when expanding beyond the negative-impact-oriented vision of LCA to provide an overall assessment of environmental performance that considers environmental impacts and ES. Doing so, however requires considering factors that influence ES supply, particularly land use (related to the ReCiPe method) and land cover (related to the EFA calculator). Agricultural systems that attempt to increase their sustainability, such as agroecological systems, increase their use of ES to decrease their purchased inputs, which also decreases their environmental impacts (Dumont *et al.*, 2013; Therond *et al.*, 2017). Combining LCA and ES assessment tools could be a useful way to reveal greater environmental benefits and lower environmental impacts of such systems in a single assessment.

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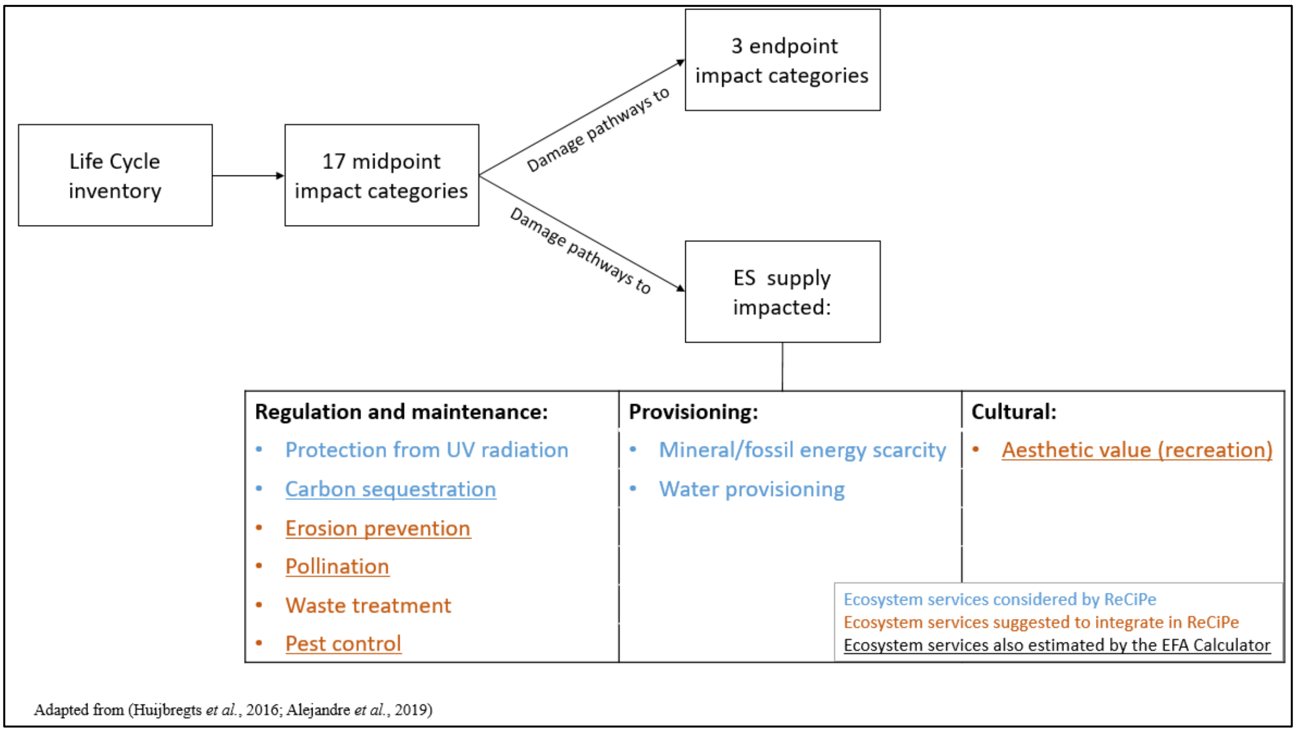

Figure 1. Ecosystem services (ES) in the LCA method ReCiPe and relations to ES estimated by the EFA calculator

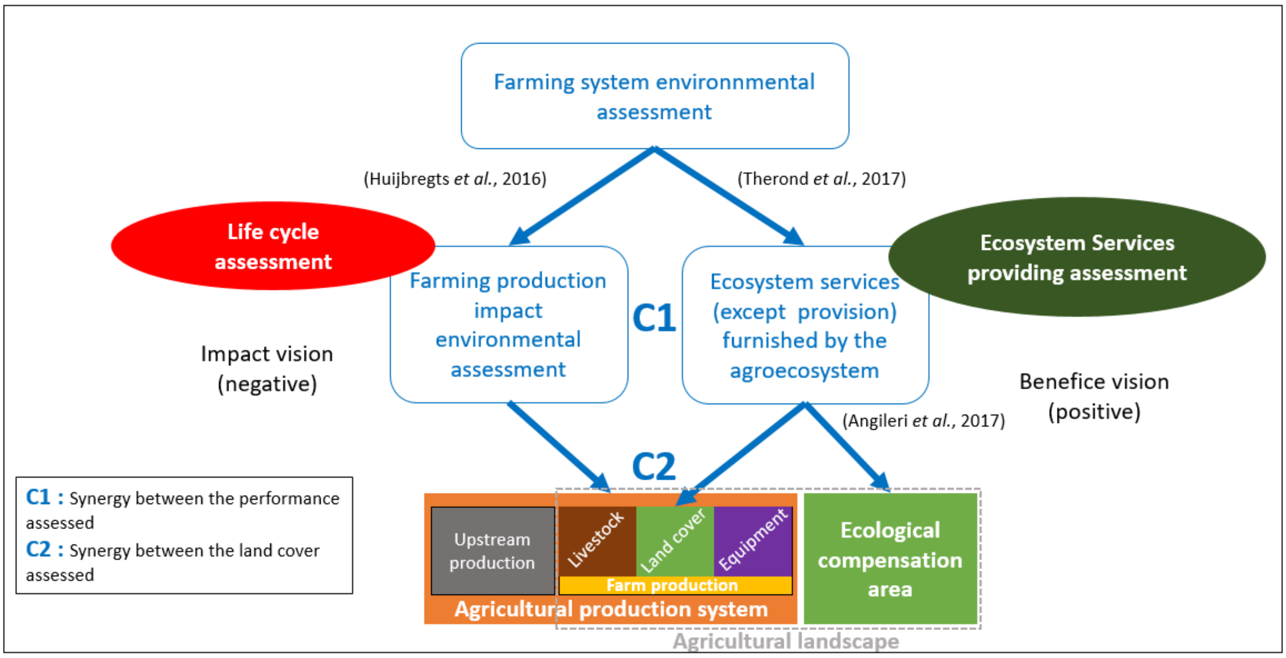

Figure 2. Complementarity between LCA and ecosystem services assessment methods

Abstract code: 342

Accounting for ecosystem services in life cycle assessment to fairly evaluate the environmental sustainability of organic and conventional farming systems

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Abstract

Purpose When evaluating the environmental performance of arable systems by LCA, the focus is put on the harvested product. Because the agricultural product involves actually a bundle of ecosystem services (ES), the impact should be allocated among the whole output. This study aims to develop and apply an allocation approach in order to fairly compare the resource footprint of products cultivated by organic and conventional arable farming systems.
Methods To compute allocation factors, we rely on the ecosystems services concept. First, a number of ES_{prov} (provisioning ES) and ES_{reg} (regulating ES) relevant to conventional and organic systems are selected. Second, scores are assigned to each of the ES, reflecting the capacity of the agro-ecosystem to supply a particular ES. Scores will be different for conventional and organic agro-ecosystems, because the capacity to supply ES is strongly influenced by farming practices which are different for both. For both steps, we relied on literature as well as expert knowledge. Data for the resource footprint are retrieved from life cycle inventory databases and the applied LCIA method is CEENE.
Results and discussion The environmental impact should be allocated among ES_{prov} and ES_{reg}. The allocation factor for ES_{prov} corresponds to the share of the average capacity to supply ES_{prov} by a particular system to the sum of the average capacities to supply ES_{prov} and ES_{reg}. Applying this to the selected and scored ES, two third of the input should be allocated to the ES_{prov} for a conventional system, while for an organic system, less than half of the inputs should be assigned to ES_{reg}, reflecting the focus of organic farming to deliver a range of ES_{reg} as well. Applying this approach demonstrates that for about half of the studied food products, organic products have clear environmental benefits in terms of resource consumption in comparison to conventionally cultivated products.
Conclusions In this study, we address the shortcoming that the multifunctional role of agricultural systems is often not integrated in LCA. The proposed allocation approach based on the capacity of agro-ecosystems to supply ES allows a more complete comparison of the environmental sustainability of organically and conventionally produced food and acknowledge the efforts made by farmers that not only aim to increase the productivity but also environmental sustainability.

Keywords: *Life cycle assessment, ecosystem services, agriculture, organic, arable farming*

Introduction

Today, there is an ongoing debate on the environmental sustainability of the products of organic farming. Life cycle assessment (LCA) can be used to compare the performance of conventional and organic arable farming systems in terms of environmental impact and productivity. Often, due to lower crop yields attained by organic systems, higher environmental burden might be found for organic products when evaluating the LCA results per product unit, despite the use of more environmental-friendly practices (Meier et al., 2015). However, these considerable differences in farm management affect the ecosystem services (ES) delivered by an agro-ecosystem (Sandhu et al., 2010). Though, in LCA the focus is traditionally put only on the (harvested) product, while the product provided by an agricultural system encompasses actually a bundle of ES (Meier et al., 2015; Schader et al., 2012).

In this study, we address the shortcoming that the multifunctional role of agricultural systems is often not considered in LCAs. Therefore, an allocation procedure is proposed based on the capacity of agro-ecosystems to supply different ES in order to divide the environmental impact over all agricultural outputs (i.e. provisioning and other ES). Allocation factors are developed for conventional and organic arable crop systems. These allocation factors are applied to calculate and compare the resource footprint of a range of crops cultivated by organic and conventional farming systems.

Material and methods

The recently updated Common International Classification of Ecosystem Services (CICES) distinguishes 'provisioning' (ES_{prov}), 'regulating and maintenance' (ES_{reg}) and 'cultural' ES (Haines-Young and Potschin, 2018). In this study, the focus has been put on ES_{prov} and ES_{reg}, being of main importance for arable farming systems.

First, relying on the CICES classification, a number of ES_{prov} and ES_{reg} relevant to European conventional and organic arable systems are selected. This selection happened based on literature research and expert judgement (national and international). For the two agro-ecosystems, the same ES are selected, to cover the largest group of ES relevant for both. However, the capacity of agro-ecosystems to provide ES is strongly influenced by farming practices such as tillage, fertilization or crop rotation, which are different for the two types of farming systems. Consequently, the supply of ES is different for organic and for conventional systems.

This forms the basis for the second step, namely scoring of the ES. To each ES, a score is assigned reflecting the capacity of the agro-ecosystem to supply this particular ES. This score will often be different for the organic and the conventional agro-ecosystem. Scoring happens according to the approach of Burkhard et al. (2012), an approach widely used for ES assessment. They evaluate several land cover classes according to their capacity to supply a specific bundle of ES within a given time period. They propose a scale ranging from 0 to 5, representing 'no' up to a 'very high' capacity. In this study, when possible, their scores are adopted. Supplemental scoring is based on literature research after which the scores are verified by experts from national and international research institutes.

In this study, both the selection of ES and the scores refer to regular conventional and organic agro-ecosystems, so representing a general case. However, a high degree of variability exists within both conventional and organic systems. Therefore, the number of selected ES might be different when focusing on a particular case study about which more specific information regarding farm management is available. Certain practices or decisions (e.g. greening measures) will vary (the focus of) the range of ES supplied by the farm system. Next, farmers need to make a range of choices regarding amongst others fertilization, crop rotation, etc. This will all influence the capacity to supply ES and, consequently, the scores assigned to the ES. Therefore, per case study, the values must be critically examined.

Production data of the studied food products are retrieved from the life cycle inventory databases Ecoinvent and Agribalyse (INRA, 2018; Koch and Salou, 2013; Swiss Centre for Life Cycle Inventories, 2015). The LCA method used to calculate the resource footprint (RF) of the production of food products is the resource accounting method CEENE (Cumulative Exergy Extraction from Natural Environment), which allows to express the natural resource consumption in terms of one single unit, i.e. joules exergy (J_{ex}) (Alvarenga et al., 2013; Dewulf et al., 2007).
The choice to retrieve data from life cycle inventory databases in this study corresponds to the choice made regarding the selection of ES as well as the scores assigned to them. Both are carried out from the viewpoint to represent regular conventional and organic agro-ecosystems, in general. So the data inventory and scores of ES are characterized by the same level of detail, both based on Western-European case studies and not representing any specific situation. It is therefore important to keep in mind that if selecting and scoring of ES is performed for a specific case study, also the data inventory (including yield) need to be changed accordingly in order to calculate the environmental impact.

Results and Discussion

Calculation allocation factors

The impact should be allocated among two groups of output: ES_{prov} and ES_{reg}. An allocation factor that indicates the fraction of the impact that is assigned to ES_{prov} (f_{prov}) is computed for each of the two farming systems. Consequently, the rest of the environmental impact is allocated to ES_{reg}, indicated by the allocation factor f_{reg}, as indicated in Eq. (1).

$$f_{prov} + f_{reg} = 1 \qquad (1)$$

Because the capacity to supply ES_{prov} and ES_{reg} is different for a conventional and organic system, the allocation factors will also be dissimilar, although the same procedure to compute the allocation factors is applied. First, relying on the scores assigned to the selected ES_{prov} and ES_{reg}, the average capacity to deliver ES_{prov}, called *(capacity to supply ES_{prov})$_{av}$*, for a conventional and organic system is computed by Eq. (2). n_{prov} refers to the number of ES_{prov} selected, which equals 4 in this study. The number of ES_{reg} selected is 10.

$$(capacity\ to\ supply\ ES_{prov})_{av} = \frac{\sum capacity\ to\ supply\ ES_{prov}}{n_{prov}} \qquad (2)$$

Applying Eq. (2), the average capacity to deliver ES_{prov} is 3.5 for a conventional and 2.75 for an organic system. Analogous, the average capacity to deliver ES_{reg} is calculated, being 1.60 and 2.90 for a conventional and organic system, respectively. Then, the allocation factor indicating the fraction of the environmental burden assigned to the ES_{prov} is calculated by Eq. (3). The factor f_{prov} corresponds to the share of the average capacity to supply ES_{prov} by a particular system to the sum of the average capacities to supply ES_{prov} and ES_{reg}. Consequently, the rest of the environmental impact is allocated to ES_{reg}.

$$f_{prov} = \frac{(capacity\ to\ supply\ ES_{prov})_{av}}{(capacity\ to\ supply\ ES_{prov})_{av} + (capacity\ to\ supply\ ES_{reg})_{av}} \qquad (3)$$

Applying this formula to the selected and scored ES, 69% of the input should be allocated to the ES_{prov} for a conventional system (f_{prov}=0.69). In contrast, for an organic system, 51% of the inputs should be assigned to ES_{reg} (f_{prov}=0.49, f_{reg}=0.51), reflecting the focus of organic farming to deliver a range of ES_{reg}. The allocation procedure is schematically presented in Fig. (1).

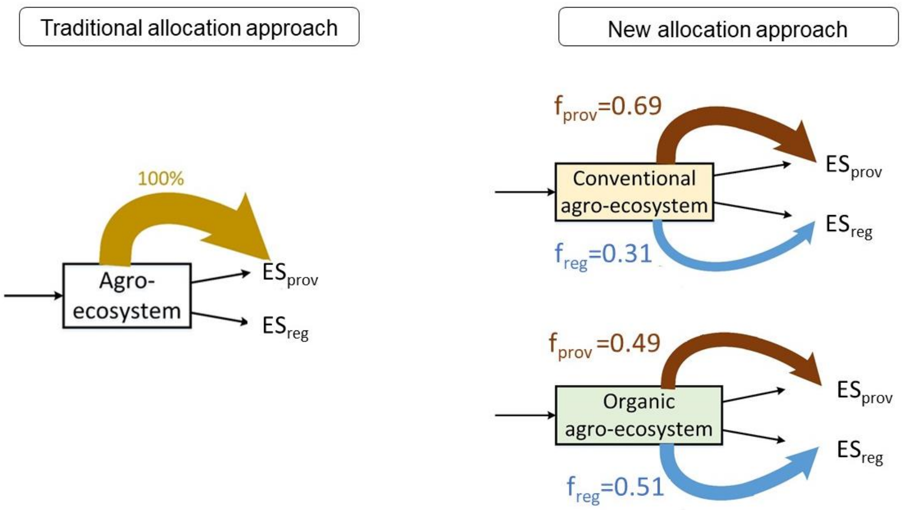

Figure 1: *Visualization of the allocation of the environmental impact to the output of an agro-ecosystem. The input includes provisioning (ES_{prov}) and regulating and maintenance (ES_{reg}) ecosystem services.*

In this study, we rely on the average capacity to deliver ES_{prov} and ES_{reg} in the allocation approach. In this sense, an equal weight is attached to ES_{prov} and ES_{reg} (both can get a maximum score of 5). Another option could be to use the ratio of the total capacity to supply ES_{prov} and the total capacity of ES delivered in order to compute f_{prov}. On the one hand, one could argue that the priorities are then clearly reflected in the allocation factors, but, on the other hand, the availability of ES_{reg} in CICES which can be associated with plant production systems, is higher than the number of biotic ES_{prov} relevant in the agricultural context. In addition, the number and the selection of ES depend on the choices made by the LCA practitioner. A second option could be to give a weight to the bundle of ES_{prov} and ES_{reg}, instead of using the averages. However, further research is needed to investigate this.

Calculation resource footprint

Relying on the allocation approach according to the ES theory, the new (allocated) RF (RF_a) of one agricultural product unit corresponds to the environmental impact assigned to ES_{prov} and is calculated by multiplying the RF of the a specific product cultivated under conventional or organic practices with the corresponding f_{prov}. This allocation approach has been applied to a range of food products. The ratio of the RF of a crop cultivated in an organic system ($RF_{a,org}$) to the RF of a crop cultivated under conventional practices ($RF_{a,con}$) can be calculated. In Table 1, both the ratios of the non-allocated and allocated RF regarding the ES_{prov} are presented. Important to highlight is that in this table, only the RF of crops corresponding to the ES_{prov} are presented, while also the RF corresponding to the ES_{reg} can be calculated. However, the focus on ES_{prov} corresponds to a provisional functional unit, and is often the only delivered agricultural product considered in LCA calculations.

For all crops discussed in this study except carrots, the standard RF of the provisional functional unit is higher for one kg of product produced by organic farming practices compared to production by conventional practices, due to the lower yield. The allocation approach allows a more complete comparison of the environmental sustainability of organically and conventionally produced food. So when applying the allocation factors, we demonstrate that for about half of the studied food products (including maize, potato), organic farming has clear environmental benefits in terms of resource consumption in comparison to conventional cultivation methods.

Table 1: *Ratio of the RF of organic to the RF of conventional food products, without and with allocation. Green colored cells are those for which organic systems have the lowest RF.*

Product	Ratio RF_{org}/RF_{con} (%)	Ratio $RF_{a,org}/RF_{a,con}$ (%)
Barley grain	154	109
Carrot	81	57
Faba bean	216	153
Maize grain	124	88
Maize silage	121	86
Potato	106	75
Protein pea	127	90
Rape seed	142	101
Rye grain	169	120
Triticale grain	185	131
Wheat grain	147	104

Because $f_{prov,org}$ is lower than $f_{prov,con}$, a higher reduction of the RF of organic products will be true. Consequently, the ratio of the $RF_{a,org}$ over $RF_{a,con}$, which gives an indication of the difference between RF of conventional and organic products, is smaller than the ratio of RF_{org} over RF_{con}. The smallest differences in RF between organic and conventional cultivation are noticed for carrot (RF_{org} 19% lower than RF_{con}) and potato (RF_{org} 6% higher than RF_{con}). In general, the difference between $RF_{a,org}$ and $RF_{a,con}$ is for most products rather small, even for 7 out of 11 products less than 20% (Table 1). Through ES based allocation, we can deduce that the difference in environmental impact of conventional and organic products is actually smaller than generally accepted. However, the allocation procedure does not result in the conclusion that organic farming is always favored in terms of environmental sustainability. The standard (unallocated) RF is lower for almost all crops cultivated under conventional farming than when organically produced. However, the RF_a is for almost half of the crops lower when produced by organic instead of conventional practices (Table 1). So although for many crops less inputs of agro-chemicals and fuel are associated with organic farming practices, the RF_a is not for all cases lower for organic practices, which emphasizes the important effect of the yield on the impact results and the importance of efficient use of land resource when assessing the environmental sustainability.

A closer look at the allocation approach

It should be kept in mind that the main goal of this study is to offer and test a methodology to account for ES in LCA in order to comprehensively compare the environmental sustainability of crops produced by conventional or organic farming. At first sight, the applied approach including a thorough literature review and expert judgement, seems to be adequate to define the scores needed in this research. For any particular case study, even when the same ES are selected, these values should always be checked critically and, if needed, adapted in order to calculate the allocation factors. Indeed, some measures or choices of farmers might change the capacity of the ecosystem to supply ES.

A valuable alternative option to the scoring approach of Burkhard et al. (2012), could be the use of response ratios used in meta-analyses. A response ratio is the ratio of the mean outcome to the one of the reference and indicates the effect size. These are not dependent on the opinion of experts but based on scientific measurements. However, up to now, the number of response ratios found for ES delivered by organic and conventional farming is limited. Furthermore, while it is emphasized throughout this chapter that local data should be applied when available, and that the scores assigned to the ES should then be adapted accordingly, this would not be possible when applying response ratios. Another option could be to rely on measured data of a specific case to develop scores. Further research on this is needed.

Conclusions

By making use of the proposed allocation approach, we stress the multifunctional role of agriculture and acknowledge the efforts made by farmers that not only aim to increase the productivity but also environmental sustainability (e.g., practices to maintain a good soil quality). Until now, allocation factors are only developed for arable land crops, but they can easily be determined for permanent grassland and permanent crops. Furthermore, research about how to integrate cultural services should be carried out as well.

Acknowledgements

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A biodiversity impact assessment method that embraces normativity

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Abstract

Addressing impacts on biodiversity in LCA is imperative. A peculiar challenge with regard to biodiversity is that any comprehensive description of biodiversity can only be a normative one.
Biodiversity is typically described through indicators like species richness or genetic variability. Such indicators are objective, but do not describe the entirety of biodiversity. It includes intra-species, inter-species, and ecosystem diversity. At each level, attributes like variability, quality & quantity, and distribution are distinguished. The scientific understanding of biodiversity and its links to human well-being is growing, but limited. The majority of species are yet unknown. Many cause-effect chains between biodiversity and ecosystem services are not completely understood.

The LCA community has agreed upon a land use impact assessment framework. It enables the inclusion of impacts of land use on biodiversity. Addressees and practitioners prefer a single indicator over many, so the one indicator should be as comprehensive as possible.

Given the contradiction between the inherent complexity of biodiversity and the demands of LCA practice, we see two challenges for including biodiversity in LCA:
First, a high level of aggregation is inevitably normative. The methodology used to develop a biodiversity indicator for LCA needs to explicitly address and embrace the normativity of aggregating biodiversity into a single point.
Second, knowledge gaps will have to be bridged with assumptions and non-codified knowledge in some cases. The methodology used to develop a biodiversity indicator for LCA should allow this.

With these challenges in mind, our methodology combines fuzzy modelling with a hemeroby approach in a three-tiered framework. The methodology has been presented in earlier iterations at other occasions, and we show the latest version at LCA Food 2020.

Our approach distinguishes four broad land use types, assigns a general biodiversity value interval to each of them, and assigns a specific value within the interval according to the specific land use practice. On the global level, impacts of land-using processes are weighted depending on the ecoregions in which the processes are located.

The approach is exemplified with a food product. However, the methodology is applicable to most types of land use. Other case studies are in preparation.

Keywords:*Biodiversity, Land Use, Hemeroby, Fuzzy Modelling*

Introduction

Biodiversity as a safeguard subject is both highly relevant and very complex. It contributes to human well-being and the functioning of ecosystems (Cardinale et al. 2012, Hautier et al. 2015). The complexity arises from the many organization layers (cells, organisms, populations, communities) and spatial scales (from square centimeters to continents) at which biodiversity exhibits a multitude of attributes (variability, quality & quantity, distribution) (see also United Nations 1992, Millennium Ecosystem Assessment 2005).

Life Cycle Assessment practitioners and developers strive to address all relevant environmental aspects along any product's value chain. While it has long been understood that this difficult safeguard subject needs to be addressed in LCA, it is not yet common to find a biodiversity indicator alongside others in the typical everyday study. One problem is that LCA addressees (and, by extension, practitioners) demand simple indicators that are easily understood by laypersons (e.g. board members of companies, average consumers). Addressees are also limited in the number of individual indicators they can process.

On the other hand, a number of companies actively address biodiversity in their management schemes and they want their efforts reflected in LCA results referring to their products. At the local level, this is doable, but if the local results are supposed to be aggregated with other less detailed results, they need to be comparable. The challenge for developers of impact assessment methods for LCA is to provide practitioners with a method that is both simple and complex.

Material and methods

We present an attempt to solve the contradiction between the complexity of biodiversity and the demanded simplicity of its representation. Our method relates to the land use framework recommended by the Life Cycle Initiative (Milà i Canals et al. 2007, Koellner et al. 2013) by quantifying the quality of a given plot of terrestrial surface, defining "quality" as "biodiversity value". The biodiversity value is assumed to be "the value that human societies ascribe to biodiversity rather than biodiversity as the subject of empirical study central to natural sciences" (citation from Lindner et al. 2019). How societies formulate their valuation of biodiversity relates to the scientific study of biodiversity, but it is not the same.

We use the hemeroby scale proposed by Fehrenbach et al. (2015) as a proxy for the biodiversity value. This scale effectively quantifies the naturalness of a given plot, with the highest value posited as the most natural state. This is not universally agreed, as there are examples of highly valued ecosystems that can exist only under constant management (see e.g. Batary et al. 2015). It is, however, a good default assumption where explicit definitions of aggregated values are lacking. In many world regions, conservation prioritizes naturalness, especially in those regions where biodiversity loss is mostly caused by encroachment of human environments into pristine ecosystems. Within the hemeroby scale, land use types are distinguished (e.g. forest, pasture, arable, mining). A value interval for each of the types is defined, limiting each land use type to a minimum and maximum achievable value. For example, even an intensively managed forestry plot is valued higher than a typical mining site (see Figure 1, taken from Lindner et al. 2019).

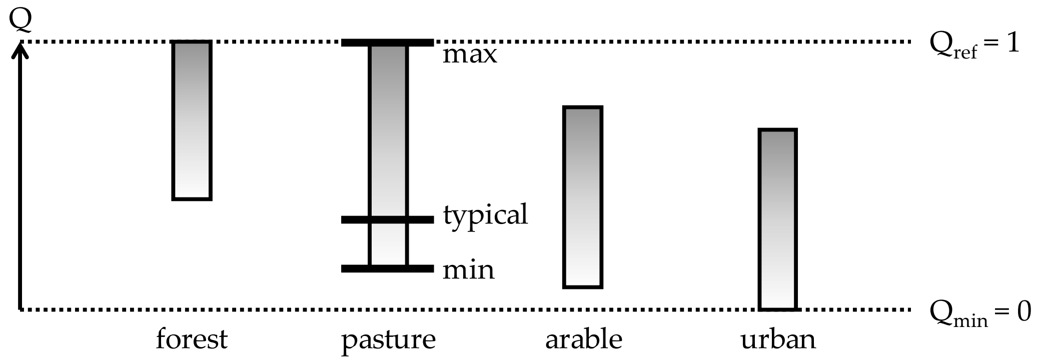

Figure 1: Land use types and biodiversity value intervals, taken from Lindner et al. (2019) under CC BY license

For a finer differentiation within the hemeroby scale, we use the valuation framework proposed by Lindner et al. (2012), defined by Lindner (2016), tested by Lindqvist et al. (2016) and operationalized at the regional level by Perennes (2017). Based on fuzzy modelling, this approach allows the formulation of a biodiversity value depending on land management and the landscape context of a specific plot. Each input parameter is transformed into an individual biodiversity contribution. Biodiversity contributions of related parameters are combined via logical AND/OR operators. All contributions are linearly aggregated into the biodiversity value of the plot. The calculation is much finer-grained than the hemeroby scale defined by Fehrenbach et al. (2015), but it does not prescribe a value system. Combining the two approaches yields a method that allows detailed calculations where there is a demand for them, but uses plausible default assumptions where a coarser analysis is wanted.

Our method also includes weighting factors for comparing impacts in different ecoregions. Such factors have been proposed e.g. by Brethauer (2012), Lindner (2016) and Lindner et al. (2019). What they have in common is the underlying assumption that a loss of biodiversity value of identical magnitude at the regional level would not be identical at the global level. In other words, 50% of the biodiversity value of an agricultural plot in the Brazilian Cerrado is not perceived as equal to 50% of the biodiversity value of an agricultural plot in the U.S. Midwest or Eastern Europe.

The elements mentioned above – individual parameters for land management, value intervals per land use type, ecoregion weighting factors – are unified in a framework very similar to the one proposed by Maier et al. (2019). For a given plot, fuzzy modelling is used at the local level to determine the biodiversity value relative to what is achievable within the respective land use type. The value intervals per land use type refer to the hemeroby scale and yield the biodiversity value at the regional level. Ecoregion weighting factors make impacts comparable and at the global level and allow aggregation of impacts across value chains.

Results

The focus of this article is method development, so the main results are LCIA models for various land use types. A common pizza consisting of wheat-based dough, tomato paste, pork salami and cheese, baked in a wood-fired oven, serves as an illustrative example of the rather abstract calculation framework (the same example as previously published by Lindner et al. 2019). The product system consists of four land-using processes:

Wheat and soy production are agricultural processes for which the biodiversity value is calculated from their respective management parameters. In this example, the wheat is produced in southwestern Germany and the soy in Brazil's Cerrado. While the management can be classified as "intensive" in both cases, the understanding of "intensive" differs between the two regions.

Tomatoes production is assumed to happen in fully enclosed greenhouses in southern Spain. For this case, we assumed a biodiversity value of zero, because the area is sealed and entirely artificial.

Wood is provided from a forest in southwestern Germany, assuming typical management for the region. This means no clear-cutting, but a rather homogenous composition of tree species and age classes.

The total biodiversity impact of the product can be dissected into impacts from the individual components. For the pizza example, Figure 2 (taken from Lindner et al. 2019) shows that the animal products make up the vast majority of the total impact.

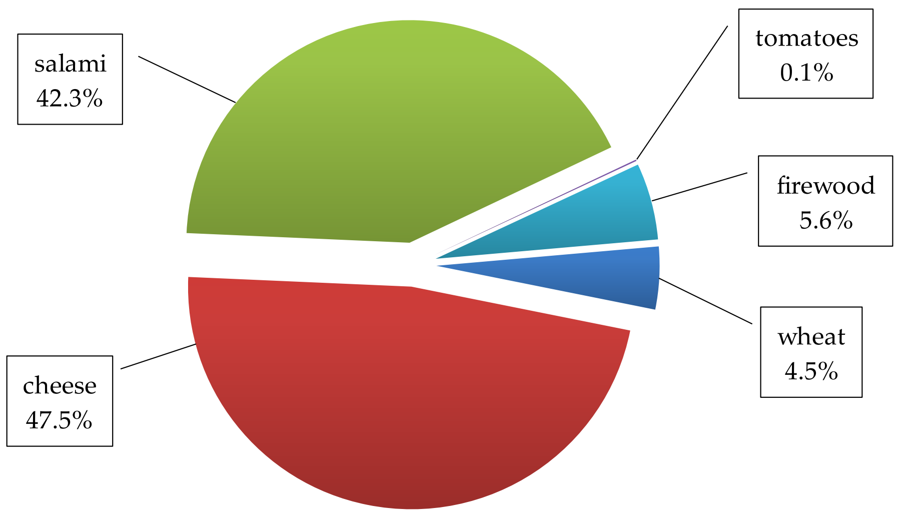

Figure 2: Fractions of biodiversity impact of a pizza related to its components, taken from Lindner et al. (2019) under CC BY license

Those processes whose impacts have been calculated in detail (all but the tomato production), it is even possible to break down the biodiversity contribution by parameter groups. Such a breakdown is illustrated in Figure 3 (taken from Lindner et al. 2019) for the wheat production in the pizza product system. It shows both the potential biodiversity value and the achieved value of the managed area (actual), indicating the distance from the reference state (potential).

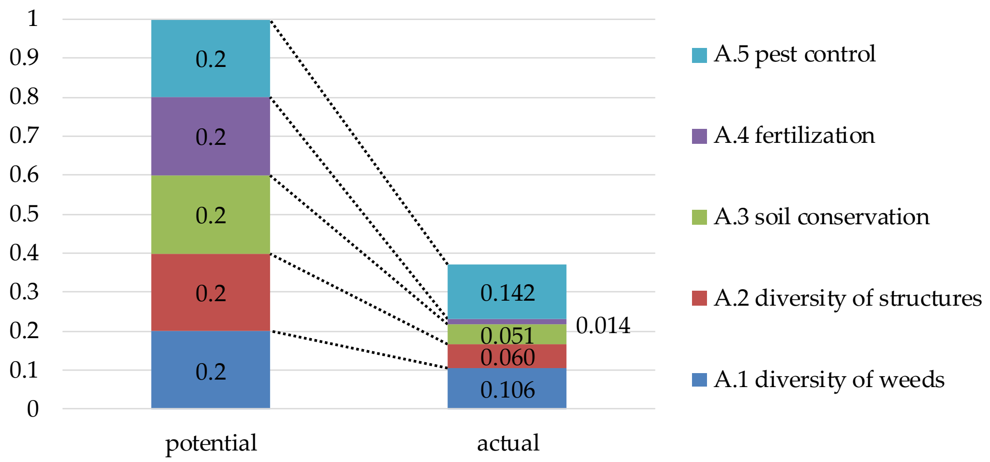

Figure 3: Biodiversity value contribution at local level by parameter groups, taken from Lindner et al. (2019) under CC BY license

The parameter groups A.1 to A.5 in Figure 3 are value-contributing aspects of arable land use. Each parameter group could contribute 1/5 to the biodiversity value in the reference state, but doesn't in the actual state, indicating the trade-off that LCA is meant to quantify: Having a product (actual state, diminished value) or not having it (reference state, no impact).

All impacts, regardless of the calculation granularity, can be aggregated at the level of product system. The biodiversity impact of the exemplary pizza, calculated as the sum of the impacts of its components, is 0.54 BVI, or biodiversity value increments. BVI is a synthetic unit, indicating the abstract nature of the quantified object.

Discussion

The method generally seems to achieve the above-mentioned goal, to unify both fine and coarse assessments under a common yet flexible value system that allows meaningful aggregation of biodiversity impacts. It is arguably more holistic than methods referring to singular quantities (e.g. species richness), yet it is possible to analyze impacts on biodiversity at the local, regional and global level, with high or low level of detail, and impacts can be aggregated across value chains.

However, normative contents cannot be provided with scientific objectivity. There is a relatively good consensus for "naturalness", but with caveats. Firstly, the naturalness reference is not given in every world region. Secondly, naturalness may be interpreted differently across world regions; it might mean "untouched/unspoiled" in some regions and "supporting natural ecosystem dynamics" in others. While there is a solid body of literature relating to hemeroby, it is not as expansive as it would have to be to be immediately globally applicable.

It is the understanding of the authors that using the hemeroby scale is a good default and a practical starting point so the method can be applied in case studies of various products under various conditions. Stakeholders (government agencies, NGOs, academic institutions, companies) can now engage in the discussion about the normative contents of aggregated biodiversity assessment. This discussion should include questions about e.g. which anthropogenic habitats to value as high as natural habitats, which land use practices to value higher/lower than others (and how much higher/lower), and how much inherent biodiversity value should be ascribed to ecoregions (relative to each other).

Conclusions

The method presented here allows the analysis of land use impacts on biodiversity at the local, regional and global level, with high or low level of detail, as well as aggregation across value chains. The authors plan to continue the work, focusing on clarifying the normative assumptions and providing characterization factors for relevant land use processes, with the broader goal of improving the integration with the land use framework of the Life Cycle Initiative.

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Integration of biodiversity assessment into LCA in agriculture: the AgBalance® approach

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Abstract

Intensive agriculture can cause a sharp decline in biodiversity in a given landscape. Sustainable agriculture therefore requires assessment methods in order to predict potential impacts of agricultural management practices on farmland biodiversity. Based on the principles of Life Cycle Assessment (LCA), BASF has developed AgBalance® to enable farmers analyzing and improving the sustainability of their farming operation. AgBalance® is based on the Product Environmental Footprint Category Rules Guidance (PEFCR) by the European Commission (2017), which includes most of the relevant impact categories for agriculture, like climate change, acidification, eutrophication, etc. but misses a biodiversity impact category. To close this gap, a new methodological approach called "Biodiversity Calculator" was developed, by using the characterization model of Chaudhary and Brooks (2018) and combining it with a set of interventions previously identified as effective in terms of positive impacts on biodiversity by the "Conservation Evidence" meta-analysis (Sutherland et al., 2019). The results from the "Biodiversity Calculator" are incorporated into AgBalance® using an adapted normalization and weighting scheme of the Product Environmental Footprint method of the EU commission (PEF). The resulting "Biodiversity Calculator" comprises a versatile tool that complements the AgBalance® methodology and informs farmers on how to adapt their agri-environmental strategies to mitigate their impact on biodiversity.

Keywords: *biodiversity; sustainable agriculture; LCIA; AgBalance®*

1. Introduction

It has been described by various authors that agriculture is the main threat for 87 % of globally threatened bird species (IUCN, 2016) and other taxa (Macdonald et al., 2015). Thus, preventing further biodiversity loss in agricultural production systems comprises a pre-requisite for their sustainability (Benton et al. 2003), underlining the importance of assessing biodiversity on farm.

BASF has been using AgBalance® since 2012 for LCA-based sustainability assessment of various farming practices. AgBalance® contributes to an adequate assessment of sustainable agriculture, by incorporating state-of-the-art scientific methods for LCA analysis in agriculture, including the impact categories recommended by Product Environmental Footprint (PEF) method (European Commission, 2017), like climate change, eutrophication, etc. However, the PEF method does not include a biodiversity impact category. Even though the necessary integration of biodiversity as an impact category is recognized by the European Commission (2017), the inclusion of biodiversity in LCA-based environmental methods imposes difficulties to the methodological framework of LCA itself (Curran et al., 2011). Moreover, site-specific data are necessary to accurately assess biodiversity loss at regional and local scale (Teixeira et al. 2016). Lastly, species richness has been considered a useful basis for these models, but it must be complemented with land use intensity-based indicators (Teixeira et al., 2016).

The objective of this research was to develop an action-based, LCA-compatible biodiversity assessment, which can be integrated into the AgBalance® methodology. The so-called "Biodiversity Calculator" is a software tool developed for agricultural systems to estimate the impact of specific farming practices and to develop scenarios on how to improve biodiversity on-farm, through a management-driven approach.

Of the already existing methodological approaches, the UNEP-SETAC working group endorses the model proposed by Chaudhary et al. (2015) and Chaudhary and Brooks (2018) as most suitable to assess the land use driven impacts on biodiversity (Frischknecht et al., 2016). In order to derive information on the biodiversity on farm, action-based approaches take into account interventions and farm management (Sutherland et al., 2019) to assess the impact of farming on biodiversity. The most comprehensive evidence base for the effectiveness of such measures comprises the meta-analysis "Conservation Evidence" (Sutherland et al., 2019). By focusing on interventions that positively impact the biodiversity potential, this meta-analysis can support the operationalization of interventions for farming as a building block of sustainable agriculture (Shackelford et al., 2017).

2. Material and methods

Technically, the "Biodiversity Calculator" includes the characterization factors from Chaudhary and Brooks (2018) and allows users to adjust them with so called "interventions", i.e. factors that describe farmers' management practices. These factors were calculated based on the information extracted from "Conservation Evidence" (Sutherland et al., 2019). The "Biodiversity Calculator" was developed with the scientific advice of the Fraunhofer Institute for Building Physics. In detail the methodological background of the "Biodiversity Calculator" and its integration in the AgBalance® methodology can be summarized as follows:

2.1. Modelling with regional and country specific characterization factors

To capture the predicted species loss due to land use, the characterization model of Chaudhary and Brooks (2018) was used. The model provides mean global characterization factors (CF) for land occupation and transformation of 804 ecoregions and 245 countries and islands, for five land use types and three levels of intensity each. For the "Biodiversity Calculator," these CFs were extracted for all ecoregions, countries and islands, covering the relevant land use types for AgBalance®: cropland, pasture and plantation forests[1].

2.2. Selection of agricultural interventions with impact on biodiversity

Data for the impact of management practices on biodiversity was extracted from the meta-analysis "Conservation Evidence" (Sutherland et al., 2019). In "Conservation Evidence," the interventions had been assessed by an expert panel in terms of effectiveness (effectiveness score in percentage) and

[1] In the "Biodiversity Calculator," permanent crops were assigned to the land use type of plantation forests. However, Chaudhary (2018) included permanent crops in the cropland land use type.

strength of the evidence (certainty score in percentage). Furthermore, the interventions were classified in several overall effectiveness categories, ranking from "beneficial" to "harmful" (Sutherland et al., 2019). A total of 39 interventions from the conservation categories "Farmland Conservation" and "Mediterranean Farmland"[2] with evidence classified as "beneficial" or "likely to be beneficial," were chosen as a basis for the Biodiversity Calculator, to provide farmers with measures that mitigate their biodiversity impact due to land use intensity as demonstrated by Chaudhary and Brooks (2018). The choice was narrowed down to 29 interventions, after 10 redundant interventions were excluded in order to avoid double-counting of interventions in the calculation of action scores (see section 2.3).

2.3. Calculation of action scores

To rank these interventions, the effectiveness (EC_i) and certainty components (CC_i) of each intervention *i* were multiplied to yield a single action score AS_i (see Eq. 1).

$$AS_i = \frac{(EC_i \cdot CC_i)}{100} \qquad [\%] \qquad \text{Eq. 1}$$

The single action score of each intervention *i* was divided by the total sum of action scores of all applicable interventions of land use type *j*, to obtain a scaled action score ($SAS_{i,j}$) that ranges between 0 % and 100 % (see Eq. 2). The applicability of each intervention *i* for land use type *j* is provided in the respective synopsis in "Conservation Evidence". In the calculator, the number of applicable interventions *n* varies for each land use type: out of 29 interventions, 21 apply to cropland management, 24 to pasture and 8 to plantation forests.

$$SAS_{i,j} = \left[\frac{EC_{i,j} \cdot CC_{i,j}}{\sum_{i=1}^{n} EC_{i,j} \cdot CC_{i,j}}\right] \cdot 100 \qquad [\%] \qquad \text{Eq. 2}$$

Action scores of selected interventions were summed into a total action score of the farm (AS_{farm}) as shown in Eq. **3**, where higher values are considered better for biodiversity. The binary variable s_i equals 1 if the intervention *i* is selected, otherwise it equals 0.

$$AS_{farm} = \sum SAS_{i,j} \cdot s_i \qquad [\%] \qquad \text{Eq. 3}$$

2.4. Effect of action scores on the characterization factors

The characterization factors (CF) for minimal and intense use of each land use type and ecoregion or country were fitted in linear regressions as a function of the action score of the farm. A linear function was assumed, as the exact cause-and-effect relationships between the interventions and biodiversity remain largely unknown. Accordingly, it was assumed that the action score of 0 % corresponds to the CF of intense use as a starting point, and the action score of 100 % corresponds to the CF of minimal use, the CF values for action scores between 0% and 100% are derived by interpolation as follows.

Eq. **4** and Eq. **5** represent the linear regressions that estimate the characterization factor of potential species loss on the farm due to land occupation ($CF_{occ,j,k}$) and transformation ($CF_{trans,j,k}$) respectively, as a function of the action score of the farm, given a land use type *j* and country or region *k*. The characterization factors of minimum and intense use are different for each land use type, country and

[2] The conservation categories "Farmland Conservation" and "Mediterranean Farmland" refer to the effect on biodiversity of farmland wildlife and human dominated landscapes that add economic and ecological value. Effects of these interventions were assessed for northern and western Europe and Mediterranean climates (Dicks et al., 2013) (Shackelford et al., 2017).

ecoregion, so the slopes $m_{occ,j,k}$ and intercepts $b_{occ,j,k}$ of the linear regression will also vary accordingly. Subsequently, the $CF_{occ,j,k}$ and $CF_{trans,j,k}$ are multiplied with the area of land occupation and transformation respectively to obtain the species loss per functional unit, which is the result of the LCA-based biodiversity assessment.

$$CF_{occ,j,k} = m_{occ,j,k}(AS_{farm}) + b_{occ,j,k} \quad \text{[species loss/m}^2\text{]} \quad \text{Eq. 4}$$

$$CF_{trans,j,k} = m_{trans,j,k}(AS_{farm}) + b_{trans,j,k} \quad \text{[species loss·year/m}^2\text{]} \quad \text{Eq. 5}$$

2.5. Integration of biodiversity assessment into AgBalance® methodology

The results of the biodiversity assessment are incorporated into the AgBalance® methodology using an adapted normalization and weighting scheme of the PEF method of the European Commission (2017). As normalization factor for the biodiversity impact, an annual average of number of species gone extinct is used, based on the data from IUCN database of species gone extinct in the last 100 years (IUCN, 2019) of the same taxa covered by Chaudhary and Brooks (2018). The AgBalance® weighting scheme is based on the PEF methodology for the development of a weighting approach for the Environmental Footprint by Sala et al. (2018). Therefore, to include the biodiversity impact category, a weighting factor and a robustness factor were derived by determining the importance of the topic and the robustness of the assessment tool. According to the concept of the Planetary Boundaries, climate change and biodiversity rank on the same level of importance for life on earth (Steffen, et al., 2015). Therefore, the weighting factor of biodiversity was allocated equivalent to that of climate change in the AgBalance® methodology. Twelve experts of two fields of expertise (experts in method development and experts in biodiversity) provided their assessment of the robustness of the methodology implemented in the "Biodiversity Calculator," as defined by Sala et al. (2018). Subsequently, a mean value of the assessment of the experts was calculated to obtain a robustness factor for the biodiversity impact category. With the robustness factors and corresponding weighting factors of each impact categories of the AgBalance® methodology, a weighting scheme including a biodiversity assessment for sustainability analysis of farming practices was implemented.

3. Results and discussion

The "Biodiversity Calculator" was initially developed as an Excel tool and a web-based interface was created to facilitate the usability. For assessments using the "Biodiversity Calculator," the first step is the selection of the country or ecoregion where the farm is located in the section "Region definition" (see Figure 1), followed by the land use type to be assessed in the pre-selection of interventions. An optional feature enables the customization of the tool through the application of filters, allowing users to select subsets of interventions that correspond to their farm management conditions. As a next step, the interventions to be applied at the farm or in the farmland can be selected to predict the impact on species loss. The numerical outcome of the Biodiversity Calculator comprises three values: i) the action score of the farm (AS_{farm}), an index from 0 % to 100 %, ii) a CF for land occupation of the farm expressed in potential global species loss per square meter and iii) a CF for land transformation expressed in potential global species loss per square meter times regeneration years. While the CFs are relevant for LCA applications, the results are graphically displayed, showing the Action score as well as the change in species loss due to the implemented interventions. Figure 1 shows a partial view of the interface of the "Biodiversity Calculator" and the graphic with the results, where higher action scores reduce the potential species loss. A calibration and validation of the tool is anticipated for next year, using field monitoring data on changes in the abundance and diversity of different species in response to the implementation of the interventions included in the calculator.

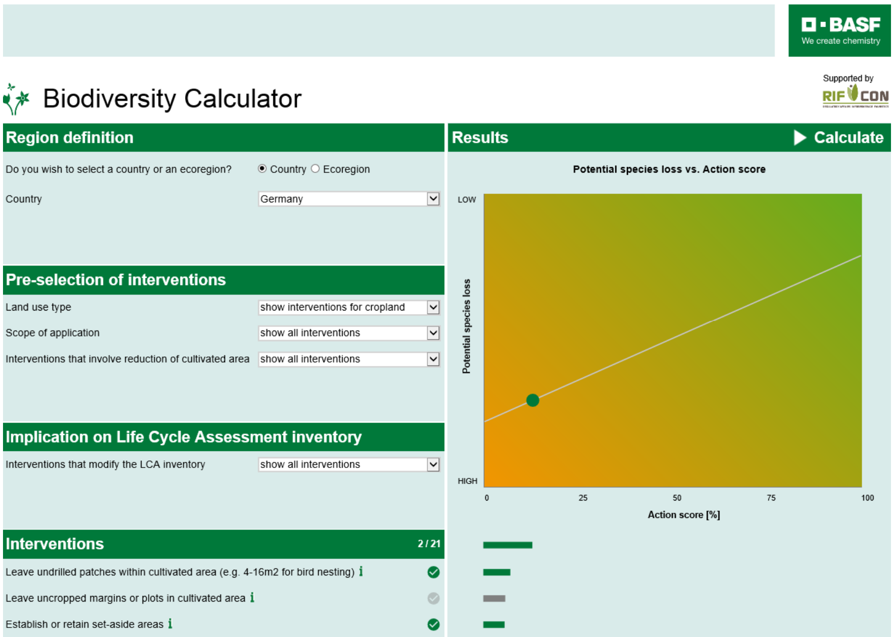

Figure 1: Partial view of the interface of the "Biodiversity Calculator"

4. Conclusions

The "Biodiversity Calculator" comprises a versatile tool to support decisions about how to maintain and restore biodiversity on the farm and an LCA-compatible assessment method, with a focus on cropland, pasture and (to a lesser extent) permanent crops. This method is seamlessly integrated into the existing AgBalance® framework and allows for a site-specific biodiversity impact assessment based on the location of the farm, land use type and the management strategies chosen by farmers. It can also be easily integrated into other LCA frameworks as well.

Limitations due to simplifications for the sake of practicality are known. Furthermore, customization and expansion of the tool is required for case studies focused on permanent crops. Additionally, the evidence base of "Conservation Evidence" is restricted to regions with Mediterranean climates and to northern and western Europe. Improvements like adaptation of interventions to different geographies and the extension to permanent crops are currently discussed. Further development is necessary to account for the decline in biodiversity, as well as its interrelations with other impact categories leading to an endpoint-oriented damage category.

5. Acknowledgements

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Understanding the interrelations between food consumption and the preservation of natural resources in urban food systems

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Abstract

We evaluated the environmental sustainability of local agricultural production within two urban food systems comprising two medium-sized cities in Southern Germany by considering the susceptibility of the local ecosystem and compared supply from local agriculture under different production intensities with demand in the two cities.

We took the nitrogen (N) surplus target per hectare of agricultural land from the German Sustainable Development Strategy, which builds on the UN Sustainable Development Goals, as a measure for ecosystem carrying capacity to derive a scenario for a site-adapted local agricultural production intensity. Using life cycle assessment, we calculated environmental impacts for the prevalent commodities produced within agriculture surrounding the cities of the studied urban food systems. Impacts were related to kg of protein from the overall agricultural output. Further we related protein supply from local agriculture within the urban food systems under the different production intensities to protein demand in the cities based on available consumption data.

Adopting local agricultural production intensity towards the N surplus target within the defined regions around the cities substantially reduced environmental impacts per kg of protein from local agriculture for all impact categories compared to the present production intensity. Under a site-adapted production intensity local agriculture would still be able to supply protein demand in the cities of the urban food systems. However, a shift from an animal protein-based to a more plant protein-based diet would be required to make the urban food systems overall more sustainable.

Keywords: *urban food system, site-adapted production intensity, ecosystem carrying capacity, nitrogen surplus target.*

Introduction

The increase of local food supply and demand is seen as an important strategy to make food systems more sustainable (Wiskerke 2009) especially in the context of urban food systems. City food flow analysis as outlined by Moschitz and Frick (2020) provide the necessary information about the situation of urban food provisioning as the basis to discuss changes in the food system and to develop alternatives. As sustainability of the urban food system is not determined solely by the origin of the food, food flow analyses need to be combined with sustainability assessments.

For the evaluation of environmental sustainability life cycle assessment (LCA) is the method of choice to analyze the environmental impact of a given food system. However, current product based agricultural LCAs allow for limited conclusions only on their environmental sustainability. As environmental impacts per product unit indicate how eco-efficient a food system is, no information is provided if the agricultural production intensity within a given spatial context overexploits local natural resources.

Therefore, in order to make informed decisions on the environmental sustainability of food systems targets are needed that define a safe operating space that allow to assess which diets and food production systems help to achieve the UN Sustainable Development Goals (SDGs) of the 2030 Agenda as proposed by the EAT Lancet Commission (Willett et al. 2019). Whereas the EAT Lancet Commission has defined these targets on global level they need to be broken down to local or regional level and indicators need to be identified that express local ecosystem susceptibility and can be combined with LCAs.
The capacities of regional ecosystem resources are exceeded in many places throughout Europe as a result of over-intensive agriculture (Sutton et al. 2014; Westhoek et al. 2014), although there may be considerable regional differences. An important indicator of agricultural production intensity is the nitrogen (N) input on agricultural land (UAA) (Herzog et al. 2006) and thus also the N surplus on UAA, which correlates with the N input. High nitrogen inputs lead to eutrophication of aquatic and terrestrial ecosystems, change the composition of plant communities, increase the risk of nitrate leaching into groundwater and contribute to global warming.
The German Sustainable Development Strategy, which builds on the SDGs, defines a nitrogen (N) surplus target of 70 kg per hectare of UAA in the annual average from 2028 to 2032 (The Federal Government 2016). This target value allows the definition of a limit for the production intensity in agriculture as it can be taken as average Germany-wide upper boundary still allowing regeneration of natural resources affected by reactive N emissions. On this basis, model calculations can be made for agriculture at the regional level on how agriculture should be equipped under regional conditions in order to be better adapted to local environmental resources and thus meet environmental objectives.
This study was carried out within the KERNiG project[1], which analyzed the governance of urban food systems (UFS) in two cities in Southern Germany, Leutkirch and Waldkirch with about 20'000 inhabitants each. As defined in Moschitz and Frick (2020) the UFS of the city of Leutkirch comprised seven administrative districts (region A) and the UFS of the city of Waldkirch 11 administrative districts (region B) potentially relevant for the local food supply. The aim was to evaluate the environmental sustainability of the local agricultural production within the region of the two UFS considering the susceptibility of the local ecosystem and to compare supply from local agriculture under different production intensities with demand in the two cities.

Material and methods

Using LCA environmental impacts of local agricultural production within the regions of the two UFS were calculated up to farm gate on midpoint-level under the present production intensity and compared with the impacts under a production intensity approaching the annual N surplus target of 70 kg per hectare of UAA. The agricultural production potential for the two UFS under the present farming intensity was taken from Moschitz and Frick (2020). However, environmental impact assessment was restricted to agricultural commodities with an annual production volume of 10'000 tons and more per region, which covered 98 and 99%, respectively of the total production potential. The functional unit was kg of protein from total local agricultural production output in the region of each UFS and for each production intensity.
The N surplus in the region of each UFS was calculated as the difference between N added to the agricultural system and N removed from the system. The input side considered fertilizer N input, feed produced externally, bought-in seeds, N fixation through the cultivation of legumes and the average annual N deposition (7 kg N/ha*a^{-1}). The output side represents the N leaving the farming system via products. To determine the N surplus under the present farming intensity N surplus was calculated for crop commodities per hectare first considering local agricultural practices and yields. The surplus per ha was multiplied by the production area of the respective crop within the region of each UFS. For animal commodities N surplus was calculated per head based on data on regional animal

[1] http://www.envgov.uni-freiburg.de/de/prof-envgov/forschung/kernig-projekt/kernig-verbundprojekt

productions systems (Gamer and Bahrs 2010) and multiplied with the number of heads in the region of each UFS. The sum of the N surpluses of each crop and animal commodity was then divided by the total UAA in the region of each UFS resulting in the average annual N surplus per hectare of UAA.

As the analysis of the N surplus of the present farming intensity revealed that animal production is the driving factor in the regions of both UFS contributing to more than 95% to the N surplus, milk and beef cattle stocking density was adapted to the available amount of permanent grassland. Pig stocking density, which in the present state was assumed to rely on external feed inputs of at least 30% was adjusted to the available amount of whey resulting from the dairy production of the milk produced. This allowed to maintain a closer N cycle between milk and pig production. Overall, these adjustments led to a reduction of cattle beef numbers between 10 and 50% and a reduction of pig stocking density of 70%. Through the shift to mainly grassland-based cattle production arable land used for feed production became available for crop production entering the channel for direct human consumption. For these areas of arable land within the region of the two UFS under the reduced production intensity it was assumed that bread wheat is cultivated.

Food supply from local agricultural production under the different production intensities was compared with the present food consumption in the two cities as quantified for relevant food products in Moschitz and Frick (2018). For this, total agricultural output as tons of proteins produced in the regions surrounding the cities was attributed proportionally to the number of inhabitants in the cities. From this share of the total agricultural output for the cities amounts of the same food products as assessed in the consumption survey were determined.

Results

Under the present agricultural production intensity in the regions of the two UFS annual N surplus resulted in 140 kg N/ha UAA for region A and in 87 kg N/ha for region B. After adapting cattle production to the available grassland resources and linking pig with milk production through the exploitation of whey, annual N surplus dropped down to 81 kg N/ha for region A and to 79 kg N/ha for region B approaching the target of annual 70 kg per ha of UAA according to the German Sustainable Development Strategy.

For both UFS, adopting local agricultural production intensity towards the N surplus target within the defined regions around the cities substantially reduced environmental impacts per kg of protein from local agriculture for all impact categories compared to the present production intensity (Fig. 1). For most impact categories environmental impacts related to the overall agricultural output in the regions of the two UFS was reduced by 40 to 60% per kg of protein.

According to our model results, present protein demand in the two cities could be supplied by local agricultural production even under a reduced production intensity (Fig. 2). In fact, for both UFS a higher amount of protein would be available under a site-adapted production intensity. However, the shift in production intensity towards the N surplus target would lead to a shift in protein supply from animal to plant food products (Fig 2).

Discussion

Combining LCAs of agricultural products with indicators for ecosystem carrying capacity allow to assess scenarios for agriculture with a site-adapted production intensity. In this combination they provide additional insight into the sustainability of food systems, particularly urban food systems aiming at enhancing supply and demand of food from local agricultural production.

The chosen indicator, i.e. the N surplus target of 70 kg per ha of UAA according to the German Sustainable Development Strategy, is only a rough measure for local ecosystem carrying capacity as it represents the average across the whole of Germany. This means that depending on the susceptibly of the local ecosystem context the annual N surplus from agriculture may need to be even lower than the 70 kg per hectare of UAA in some areas, but it might also be higher in other areas with less

susceptible ecosystems.
To adapt intensity of local agricultural production surrounding the cities in the two studied UFS we took the available permanent grassland as the limiting natural resource for cattle production and we linked milk and pig production by exploiting whey as a protein rich by-product from dairy in pig fattening to further reduce the N surplus. The adaptations still lead to an N surplus being 17% (UFS A) and 13% respectively (UFS B) above the German N surplus target. However, environmental impacts per output unit from agricultural production were reduced substantially and as we linked the impact assessment to an indicator for ecosystem carrying capacity, we can conclude for sure that agriculture surrounding the cities in the two studied UFS would become more sustainable under a site-adapted production intensity.
Reducing production intensity has of course implications on the agricultural output. However, in the agricultural production surrounding the two cities, reducing production intensity would not lead to an overall lower food production. In fact, overall agricultural output in terms of proteins or calories produced turned out to be higher in the model under a site-adapted production intensity. However, the composition of the agricultural output changed shifting from a dominant animal protein-based production to a more plant-based production in the case of UFS A still being able to supply animal protein demand in the city. Also, in UFS B adapting local agricultural production intensity lead to a shift from animal to plant protein production. However, this shift was less pronounced. Further already under the present production intensity local agriculture is not able to supply the present animal protein demand in city B. Nevertheless, there would be enough overall protein output to supply the cities demand. However, it would afford a stronger shift from an animal to a plant-based diet in order to nourish the city from local agricultural production. Synergies with a healthy diet

Conclusions

Adapting local agricultural production intensity within the surrounding region of the studied UFS towards a level that allows for regeneration of natural resources reduces the overall environmental impact of local food production while still providing enough proteins and calories for human nutrition. However, without a change in consumption from animal based to more plant-based diets the overall environmental impact of urban food consumption will not be reduced. Rather, food related environmental impacts will be shifted from local level to other regions.

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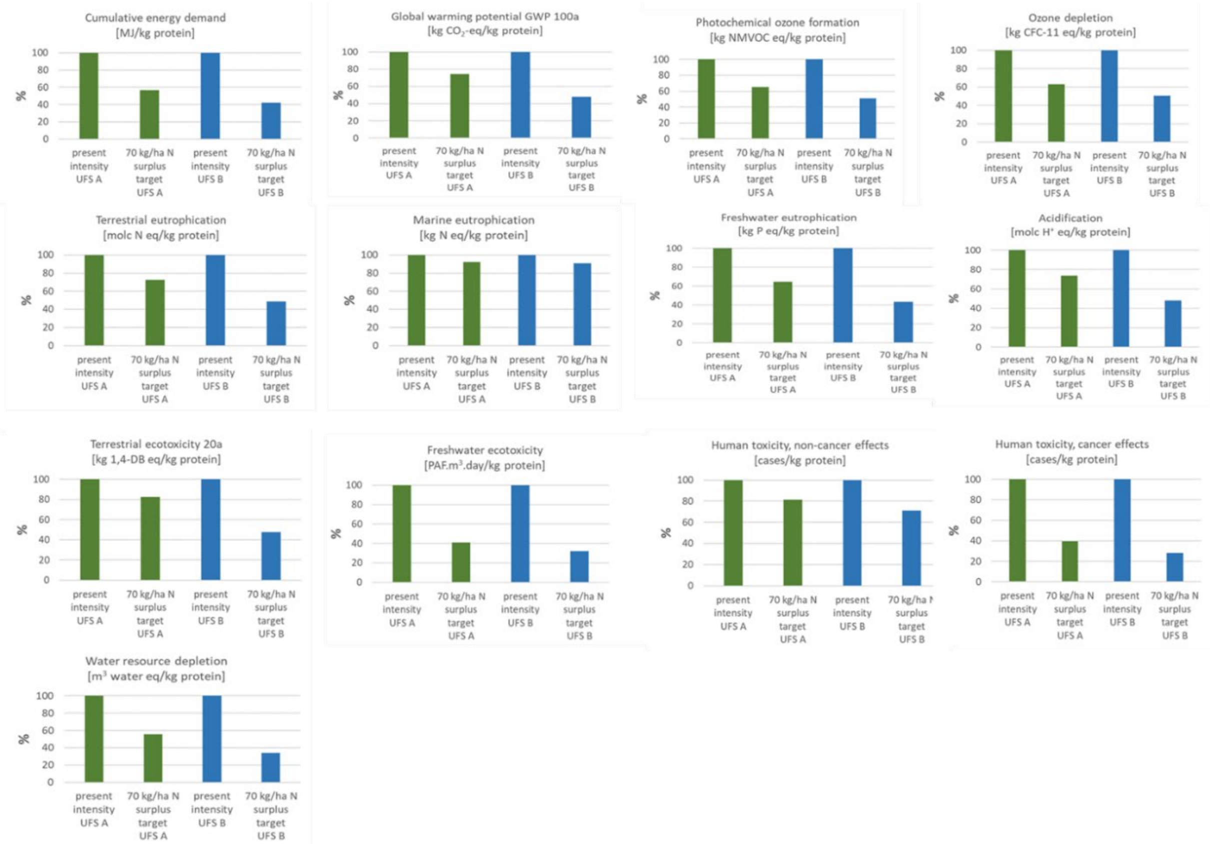

Figure 1. Relative difference of impacts per kg of protein across the total agricultural output between present local production intensity and intensity approaching the N surplus target in the regions (A & B) of the two studied UFS.

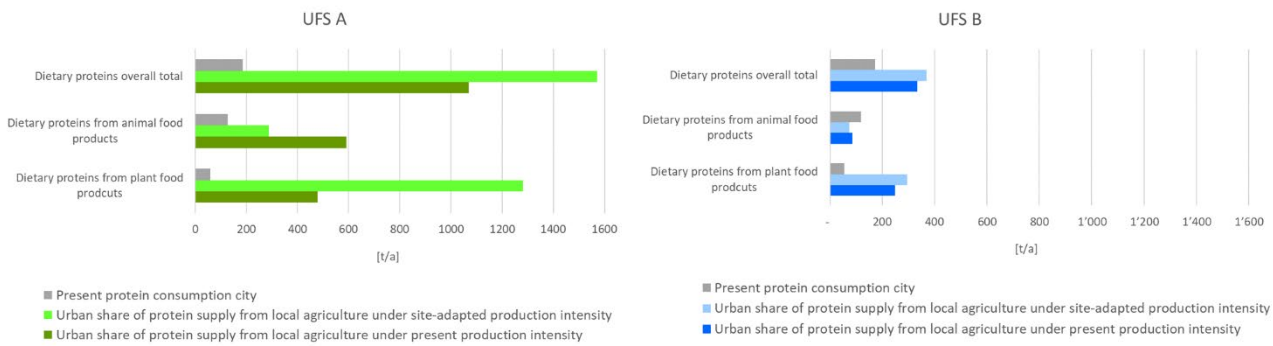

Figure 2. Local agricultural protein supply under different production intensities in relation to present protein consumption in the cities as determined by Moschitz and Frick (2018).

Abstract code: 140

POtential Ecosystem Services and Impacts Evaluation (PoESIE) method: Application to French pond systems

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Abstract

Pond fish farming is a declining activity in France. The diversity of its roles raises the question of whether the framework of ecosystem services (ES) could give a better visibility of the assets of this activity. The aim of this study is to propose a method called "Potential Ecosystem Services and Impacts Evaluation" (PoESIE)" to evaluate ES to clarify the ES provided by ponds in France. PoESIE is based on the combination of LCA and Emergy Accounting (EA) to assess jointly ES and environmental impacts, highlighting trade off associated to management practices in fish ponds. The PoESIE framework is based on the four steps of LCA: (i) *Goal and scope* consists of defining boundaries of the ecosystem of interest, the technosphere and the ecosphere that support it. Functional unit is defined as "to occupy and value a surface by supplying ES" (ha); (ii) *Ecosystem inventory* consists of quantifying the capture and emission of matter by the ecosystem and the technosphere, as well as the emergy value of each of these flows; (iii) *Assessment step* covers two stages. First, each material or energy flow is linked to an ES. Then, characterization factors are defined based on LCA impact categories to assess each ES. The emergy value of each flow is aggregated according to ES. Finally, each ES is assessed through two metrics: potential biophysical value and potential environmental work done to produce an ES. Environmental impacts assessment is performed by an attributional LCA; (iv) *Interpretation* follows the classic LCA step. The two metrics of each ES are compared and synergies and trade-offs among ES are analyzed. PoESIE was applied on 135 ponds grouped into five management classes. The main results show that each management class has his own impact and service pattern. The method shows trade-offs. For instance, intensive and semi-intensive managed ponds provide the best level of ES, and have moderate environmental impacts, but EA show poor sustainability performances. The proposed PoESIE method has shown its applicability to a slight anthropised system at the interface between the natural and the productive environment. Pond aquaculture can provide a good level of ES, mainly when ponds are managed in order to produce fish.

Keywords: *ecosystem services; life cycle assessment; emergy accounting; fishpond; sustainability.*

Introduction

Ecosystem services (ES) became an active field of research after publication of the Millennium Ecosystem Assessment (MEA, 2005). Following a proliferation of conceptual frameworks and typologies for ES (Braat, 2018; Haines-Young & Potschin, 2012), several methods were developed to quantify ES (Bennett & Isaacs, 2014; Othoniel et al., 2016). Two sets of scientific fields were used to develop assessment methods: (i) economics and sociology, to assess economic values and the perception of ES (Farber et al., 2002); and (ii) ecology, agronomy and environmental sciences, whose biophysical approaches were used to assess ES characteristics directly or indirectly (Zhang et al., 2010). The ES provided by natural ecosystems are now extrapolated to agro-ecosystems to broaden assessment of agricultural activities. Among livestock systems, fishponds have some specific characteristics. Since they are ecosystems managed by fish farmers, they produce finfish as food, but also provide a range of ES (Willot et al., 2019). Nonetheless, they also have negative impacts on the environment, which can be assessed by LCA. Therefore, developing a consistent framework that can assess and balance ES and impacts is a relevant goal for agricultural systems, especially fishponds. Our study consisted of developing a method to assess ES and environmental impacts, based on existing environmental assessment frameworks, and applying it fishponds in France to highlight trade-offs associated with their management practices.

Material and methods

1/ Framework

We developed the "Potential Ecosystem Services and Impacts Evaluation" (PoESIE) method based on the combination of Life Cycle Assessment (LCA) and Emergy Accounting (EA) (Odum, 2002) to assess both ES and environmental impacts. LCA estimates potential environmental impacts due to resource consumption and pollutant emissions, while EA estimates cumulative energy via the flow of natural resources and social and manufactured inputs, which go through the system.

In the first step, the ES considered were those directly connected to the material flows: provisioning and regulating ES (Haines-Young & Potschin, 2012). LCA was adapted to assess them according to the approach developed by Kuittinen et al. (2016). The EA part of the method consists of calculating emergy using LCIA characterization methods modified from their original use. Since EA and LCA have similar steps (Rugani & Benetto 2012), the PoESIE framework is based on LCA steps (Fig. 1).

(i) The goal and scope consists of defining the boundaries of the ecosystem of interest and the technosphere and ecosphere that support it. Within the system boundaries, the material flows of the ecosystem are modeled and "linked" to the ecosphere and technosphere. The assessment of ES is only applied to the local ecosystem boundaries.

In attributional LCA, functions refer to the performance characteristics of the system assessed (ISO, 2006). In LCA studies of managed ecosystems, the main functions are to provide food if the system is agriculture or aquaculture. An alternative function of ecosystems in LCA is to occupy an area (Henriksson et al., 2012a). In an ES context, emphasis is placed on the land used by ecosystems and comparison of types of management for a given ecosystem (Bennett and Isaacs, 2014). The functional unit must reflect the multifunctionality of ecosystems and the area occupied. Thus, the function of all types of ecosystems in the PoESIE method is to occupy and add value to an area of ecosystem by supplying ES. The related functional unit is a unit of area (e.g. ha, km2). The ES supplied by the ecosystem are then identified, as are potential environmental impacts associated with their supply.

(ii) The ecosystem inventory consists of quantifying the capture and emission of matter by the ecosystem (for ES assessment and LCA) and the technosphere (for LCA only), as well as the emergy value of each of these flows (for EA). The quantification must remain consistent with the modeling assumptions made during the first step. Biophysical processes, biophysical elements and managed elements are identified, listed and quantified. During the ecosystem element and flow inventory, like for attributional LCA, all relevant flows of raw materials, energy and matter are listed for each unit process of the technosphere (Chomkhamsri et al., 2011). The environmental work inventory leads to the construction of an emergy table (Rugani and Benetto, 2012), which includes all inputs of the ecosystem (ecosphere and technosphere) and their Unit Emergy Values (UEV).

(iii) The assessment step covers two stages. First, each material or energy flow is linked to an ES. Then, characterization factors are defined based on LCA impact categories to assess each ES (using ReCiPe midpoint method for water consumption, global warming potential, CML method for eutrophication and land competition, and TCED method for total cumulative energy demand as implemented in Simapro v8.3). The emergy values of each flow are aggregated by ES. Finally, each ES is assessed using two metrics: potential biophysical value and potential environmental work done to produce an ES. Environmental impacts are assessed by attributional LCA.

(iv) Interpretation follows the classic LCA step. The two metrics of each ES are interpreted and then compared. Synergies and trade-offs among ES, for both metrics, are analyzed.

2/ Application

This method was applied to 135 freshwater fishponds in the Dombes of France. To build a typology of the practices, we performed Hierarchical Multiple Factor Analysis followed by Hierarchical Clustering on Principal Components (HCPC) using R software. The parameters selected for the

HCPC were the mean concentrations of total i) carbon, ii) calcium, iii) chlorophyll a, iv) nitrogen and v) phosphorus; vi) water pH; vii) macrophyte cover; viii) species richness of macrophytes, ix) phytoplankton, x) and invertebrates (specifically dragonflies); xi) fishing yield and xii) pond area and depth. To these data were added quantitative values associated with management practices, such as liming, fertilizing and feeding. The ponds were grouped into five management classes: i) "Intensive" ponds (30 ind.) with high levels of inputs, mean fish yield of 445 kg/ha, and a mean area of 10 ha; high concentrations of carbon, nitrogen, and phosphorus in water and the lowest level of biodiversity; ii) "Semi-intensive" ponds (21 ind.) with high levels of inputs , mean fish yield of 397 kg/ha and a mean area of 11ha, high concentrations of carbon, nitrogen, and phosphorus in water and the lowest level of biodiversity; iii) "Semi-extensive" ponds (64 ind.) with low levels of inputs, mean fish yield of 321 kg/ha, mean area of 10 ha, high biodiversity and mixed management that depended on fish farmers' choices; iv) "Extensive" ponds (15 ind.) with no human activities (e.g. fertilizing) during the empty period and few during the filled period, mean fish yield of 240 kg/ha, high biodiversity and a mean area of 22 ha; and v) "Recreational" ponds (5 ind.) with mean fish yield of 222 kg/ha, low nutrient concentrations in water, high biodiversity and a mean area of 45 ha.
We selected two provisioning ES (i) animals from in situ aquaculture (AFISA), which corresponds to fish production, and (ii) materials for agricultural uses (MFAU), which corresponds to the use of pond sediment (applied to crops in the Dombes region to decrease fertilizer applications) and three regulating ES (i) hydrological cycle and water flow maintenance (HCFM), which corresponds to water flows exchanges and stocking; (ii) global climate regulation (GCR), covering carbon sequestration and methane emissions; and (iii) water quality regulation (WQR), because freshwater fishponds are considered to influence river eutrophication strongly, which influences human well-being. Finally, five impact categories global warming (GWP), eutrophication (EUT), water consumption (WC), energy use (TCED) and land competition(LC) - and two emergy indicators - UEV and the percentage of renewable energy stemming from nature and artificial sources (%R) were estimated. To simplify interpretation, indicator values were transformed into four qualitative classes: good, moderately good, moderately poor, and poor.

Results

Each management class had a unique pattern of impacts and ES (Figure 2). All ES except water quality regulation were correlated with intensification of practices, and animals from in situ aquaculture and global climate regulation positively so. Intensive and semi-intensive ponds supplied four ES at the highest level, while semi-extensive ponds supplied three ES at the highest level. Intensive and semi-intensive ponds differed in their supply of materials for agricultural uses and water quality regulation; the former supplied the highest water quality regulation but lower materials for agricultural uses U, while the latter supplied the highest materials for agricultural uses but the lowest water quality regulation.
Environmental work showed a similar pattern for animals from in situ aquaculture and hydrological cycle and water flow maintenance and for materials for agricultural uses and global climate regulation. Recreational ponds had the best environmental work profiles. %R differed significantly among ES, it ranked the same for all pond classes. Thus, intensification of practices influences the indicators but does not change the sustainability greatly. Intensive practices seem to be the best way to manage ponds to supply ES, although special effort should be made to manage the ecosystem functions underlying materials for agricultural uses supply.
Environmental impacts also seemed to be sensitive to intensification of practices, except for WC and LC, which were related to physical components of fishponds. EUT was low in intensive classes. GWP was much lower than global climate regulation, and the more intensive the pond class was, the less GHGs were emitted to the atmosphere, due to higher concentration of phytoplankton fixing CO_2. TCED differed only for recreational ponds, for which it was higher.
The method shows trade-offs between ES and environmental impacts. For instance, intensive and

semi-intensive managed ponds provide the highest level of ES and have moderate environmental impacts, but the EA shows that they have poor sustainability performances.

Discussion

The three metrics show different aspects of anthropised ecosystems and their sustainability. Given their relatively low productivity and few management practices, freshwater ponds in France are considered as semi-natural ecosystems that provide several ES. From an aquacultural viewpoint, it is important to note that the classification of management practices in the Dombes region is not adapted to other contexts. The "intensive" practices that produce fish yields of 445 kg/ha/year are far less intense than those that yield tens of thousands kg/ha/year in southern Asia.

Most of these ES (animals from in situ aquaculture, materials for agricultural uses and water quality regulation) depended on intensifying management. In contrast, global climate regulation did not, and was considered as a disservice due to the emission of GHGs. hydrological cycle and water flow maintenance varied little among levels of intensification because the water cycle is connected more to physical flows (rain, evaporation). Environmental impacts and environmental work of the freshwater ponds were strongly correlated with the intensification of practices. EA provides information that relates environmental impacts to the ES.

Conclusions

The PoESIE method is a step toward valuation of ES, their associated impacts and their sustainability level. However, the PoESIE method does not consider cultural ES, mainly because it is based on an environmental assessment method and related biophysical measurements. Incorporating cultural ES and social aspects into environmental assessment remains a great challenge.

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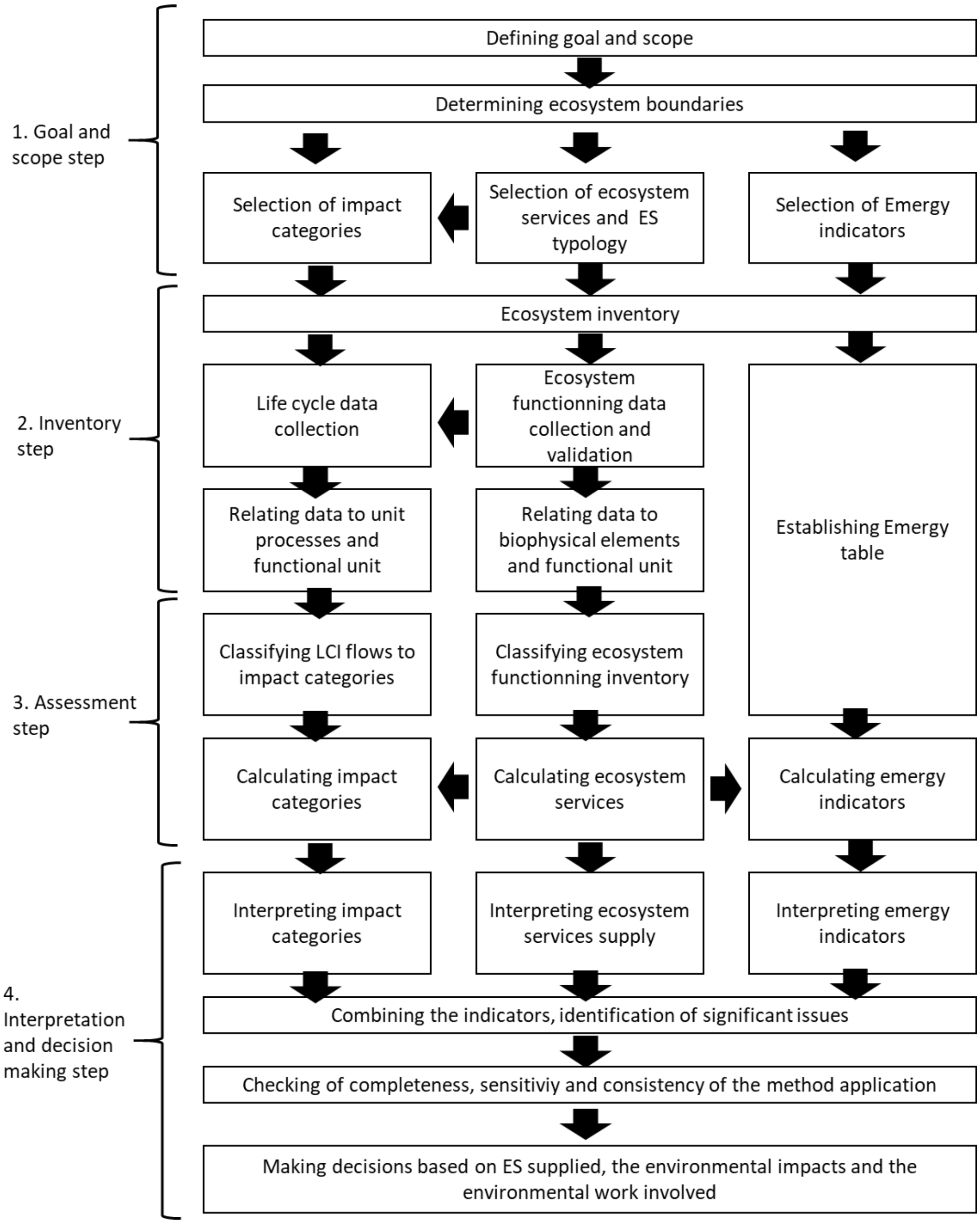

Figure 1. General procedure for applying the PoESIE method

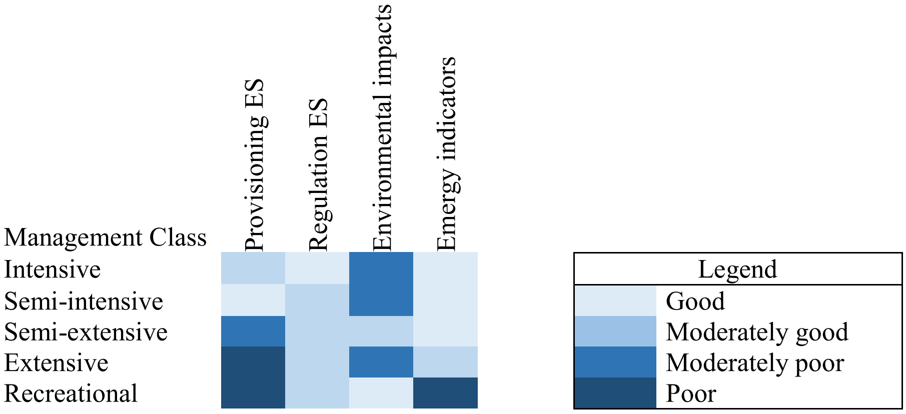

Figure 2. Summary of assessment of ES, environmental impacts and environmental work as a function of fishpond class

Abstract code: ID 328

Assessing biodiversity along global value chains – a multi-scale approach

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Abstract

Purpose Land use for agriculture is one of the main drivers of biodiversity loss. While there are valuable LCIA methods for biodiversity, they do not take account for impacts at different spatial scales and face challenges in software and database integration. This study reports on a new Biodiversity Multi-scale Assessment (BioMAss) method. Goal is to describe the calculation procedure and to show the methodological approach exemplarily for the land use type cropland.

Methods The BioMAss method accounts for the global, regional and local scales. For the analysis of global and local biodiversity risks, this method builds upon the approach of Maier et al. (2019). For the analysis of regional impacts, local biodiversity risks are scaled up to a broader landscape context. Herein, all land use types and their intensities that are part of the landscape are considered. Therefore, a landscape development index (LDI) is calculated in a GIS environment to derive the biodiversity risks at the landscape level. The LDI contains the shares of the individual land use types in the landscape as well as their land use intensities and the associated effects on biological diversity.

Results and discussion The calculation procedure of the method is described. Exemplary results are presented for the global and regional scale for cropland. The importance of a multi-scale method is highlighted since different recommendations for LCA end users are derived. At the global scale it is important to use resources from areas that are outside of global biodiversity risk areas. At the regional scale the landscape composition is decisive. Herein, it is advisable to keep landscapes with a higher share of primary and secondary habitats and/or with a higher share of extensive land use types. At the local scale the individual management parameters are decisive since they directly impact the local biodiversity. The multi-scale approach also allows the creation of characterization factors in line with current land use modelling in LCA databases and the impact assessment framework LANCA.

Conclusions Activities for food production have a disruptive impact on biodiversity on different spatial scales, e.g. through the design of global supply chains, field management and landscape planning. Therefore, the development of a multi-scale method that provides decision support for each of the scales is of high socio-economic and ecological relevance. While the method is compliant with existing LCI models, it also allows addressing the specific land use requirements in a comprehensive way.

Keywords: *Biodiversity; LCIA; scale; GIS, landscape; LANCA*

Introduction

Land use for food production is among the main causes of the continuing loss of biodiversity. Here, LCA is the most widely used tool to measure such impacts. Although there are valuable methods for life cycle impact assessments (LCIA) on biodiversity, they do not account for the impacts at global, regional (e.g. landscape) and local (patch or field) scale within one framework including the consideration of land management parameters (Maier et al. 2019; Lindner et al. 2019). This study reports on a newly developed multi-scale method for analyzing biodiversity impacts in life cycle assessment (LCA), applicable to primary information or background data for the supply chain.

Material and methods

This method builds on the framework of Maier et al. (2019) by facilitating the assessment for the landscape scale. The aim of this paper is to describe the calculation procedure and to exemplify the methodological approach for the land use type cropland. Results are shown for the global and regional scale. On a global scale biodiversity risks maps are made comparable. Therefore, existing nature conservation schemes are harmonized within a uniform biodiversity risk (UBR) map, depicting all critical biodiversity areas identified to date (Maier et al. 2019). The global land use model of Hurtt et al. (2011) is used to calculate a global risk factor per each type of land use. This factor quantifies the probability that a type of land use is located within a biodiversity conservation area (Eq 1).

$$BR\_globe = AreaLU[i]/AreaUBR[i] \qquad (1)$$

where
BR_globe : Global biodiversity risks at location [i]
AreaLU: Area under land use cropland [i]
AreaUBR: Area on UBR map as proposed by (Maier et al. 2019)

On a local scale the impacts on biodiversity in the field are assessed. Data of Newbold et al. (2015); Newbold et al. (2016) from the PREDICTS database (Hudson et al. 2014) are used. These datasets provide an impact interval for each land use type indicating the scope for land users to influence their impact on biodiversity in the field. Quality intervals are calculated according to the UNEP SETAC framework (Koellner et al. 2013b) by comparing the biodiversity quality of the specific land use type, with the reference situation of primary vegetation under minimal use as an average of the biodiversity metrics species richness, rarefied species richness and abundance for a diverse range of taxa (from invertebrates to vertebrates and plants) (Maier et al. 2019; Newbold et al. 2015). This step yields characterization factors for the local scale and is calculated as

$$CFOcc_{LU1} = (Q_{ref} - Q_{LU1}) \qquad (2a)$$

$$CFTrans_{LU1 \rightarrow LU2} = (Q_{ref} - Q_{LU1}) - (Q_{ref} - Q_{LU2}) \qquad (2b)$$

where
$CFOcc_{LU}$: Characterization factor for occupation for the specific land use type
$CFTrans_{LU\text{->}LU}$: Characterization factor for permanent transformation
Q_{ref}: Quality value of biodiversity (species richness and abundance) of reference situation (primary vegetation)
Q_{LU}: Quality value of biodiversity (species richness and abundance) under land use type

Herein, the actual impact of the characterization factor depends directly on the intensity of land use. Therefore, the method calculates global land use intensity indices (LUIs) based on the approach of (Herzog et al. 2006; Erb et al. 2013; Kuemmerle et al. 2013). These indices result from individual management parameters that are specific for each type of land use and have proven effects on biodiversity.

$$LUI_{cropland\ [i]} = \frac{PI[i]}{PI[MTI]} + \frac{PII[i]}{PII[MTI]} + \frac{PIII[i]}{PIII[MTI]} + \frac{PIV[i]}{PIV[MTI]} + \frac{Pn[i]}{Pn[MTI]} \qquad (3)$$

where
$LUI_{Land\ use\ type\ [i]}$: Land Use Intensity Index of a specific land use type at location [i]
P: specific management parameter (I to n parameters)
MTI: maximum tolerable intensity of specific management parameter P calculated after (Sattler et al. 2007) per global agro-ecological zone

The values of the LUI are translated into the biodiversity quality and into characterization factor values assuming that the biodiversity quality decreases proportionately to the rate of increase in human influenced land use similar to the approaches of Arunyawat & Shrestha (2016) and McKinney (2002) for habitat quality. In line with their approaches, linear and unimodal decay functions are tested:

$$BR\_LUI_i=(a*LUI_i^2+b*LUI_i+c) \quad \text{if unimodal} \quad (4)$$

$$BR\_LUI_i=(a*LUI_i+b) \quad \text{if linear} \quad (5)$$

where
BR_LUI_i: specific biodiversity risk based on the LUI
LUI_i: LUI of the land use cropland i
a, b, c: set of land use type specific coefficients derived from PREDICTS from (Newbold et al. 2015)

The LUI for cropland production is calculated using the following datasets, based on the suggestions of (Maier et al. 2019), who also suggests datasets for the calculation of the LUI of the other land use types:

- Fertilizer (kg nitrogen ha−1·year−1) (Hurtt et al. 2011)
- Pesticide (kg per ha) (FAO 2019)
- Mechanization (No of tractor ha−1·year−1) (FAO Statistics Division 2010)
- Set-aside areas (Ratio Field size/buffer zone size [%])
- Crop rotation (Share crop rotation per field [%]) (Hurtt et al. 2011)
- Global cropland production sites (Area of cropland production [km²]) (Hurtt et al. 2011)

For the assessment at the regional scale, the results of the local biodiversity risks are scaled to a broader landscape context, considering all land use types occurring within the landscape. Thus, biodiversity risks derived from a landscape development index (LDI) are calculated. The LDI, adopted from Brown and Vivas (2005), contains the shares of the individual land use types in the landscape (landscape composition), derived from the dataset of Hurtt et al. (2011) as well as the herein calculated LUIs and associated biodiversity impacts. The regional biodiversity risks based on the LDI are calculated as follows, excluding bare areas and desserts where no land use activity is taking place:

$$BR\_regLDI_{total}=\sum \% LU_i*BRI\_LUI_i \quad (6)$$

where
BR_regLDI_{total}: Biodiversity risk at landscape level
$\% LU_i$: percent of the total area of influence in land use i
BR_LUI_i: Biodiversity risk for land use i depending on the land use intensity index

Results and discussion

With regard to global risks, there are some countries that have an especially high share of cropland production in biodiversity risk areas (see table 1). For consumers and producers it would be advisable to produce or buy their products from countries where the biodiversity risks would be lower. For landowners and farmers in these high-risk countries it is especially advisable to decrease their land use intensity in order to mitigate the local impacts.

With regard to the land use intensities and local biodiversity impacts especially the areas that are under high land use intensity that show e.g. high application rates of pesticides or fertilizer, have a greater impact on the local biodiversity. A reduction of fertilizer and pesticide application will result in a lower land use intensity and therefore in a higher biodiversity quality.

With regard to the regional biodiversity impacts, the landscapes with a larger share of land use types under high land use intensity show the greatest impacts on biodiversity. Regions that still have a large share of native primary or secondary vegetation or landscapes with a large share of low land use intensity have a lower impact on regional biodiversity. As can be seen in Figure 1, these regions are found in the areas of the Amazon forest, the Congo Basin, the Western part of the USA, Canada or New Guinea. For these countries, it is advisable to keep their low landscape development index and keep protecting the remaining habitats. For the regions with a higher LDI and associated higher biodiversity risks, such as in Europe or Central Asia it is advisable to set aside more area for biodiversity or to increase their proportion of land use types under extensive management in order to reduce the biodiversity risks in the landscape. Thus, the biodiversity risks of the LDI contribute directly to the debate on land sharing versus land sparing by including both conservation strategies.

To make the calculated biodiversity risk values available as characterization factors in LCA databases and tools, they have to comply with the existing Life Cycle Inventories (LCI). Thus, the factors have to follow the currently applied land use framework by Koellner et al. and the elementary flows on country average level (Koellner et al. 2013b; Koellner et al. 2013a). As the presented method allows to address different spatial levels, it also allows for the calculation of country average values and their integration in the LCIA frameworks such as LANCA® (Bos et al. 2016). Furthermore, the native integration of management parameters allows to fully addressing the available flow list. Compliance with existing LCI databases and LCA software is a requirement for any new biodiversity method to be integrated in LCA. The presented method allows for a full coverage of existing LCI models. As those models are expected to advance, the method provides the consideration of location and type of activity in a seamless, flexible approach, and thus to adequately address the specific aspects of land use activities (Winter et al. 2017; Canals et al. 2016; Verones et al. 2019) .

Conclusions

Since socio-economic activities on different spatial scales have a disruptive impact on biodiversity, e.g. through the design of global supply chains, field management and landscape planning, the development of a multi-scale method for assessing the impact on biodiversity in LCA is of high relevance. However, the methods used so far in LCA could not provide sufficient decision support. The BioMAss method addresses this research gap by enabling the identification and comparison of more biodiversity-friendly alternatives on different scales. Thus, the method provides a coherent framework for companies, producers, consumers and landowners to assess the impact on biodiversity and thus contribute to mitigate negative impacts. While it can be integrated into current land use assessment methods and frameworks, the structure presented could also indicate an overall approach for the further development of land use assessment practice in LCA.

Table and Figures

Table 1: Global biodiversity risks of cropland production exemplarily for some high risk countries

Country	Share of cropland production in biodiversity risk areas
Namibia	0.762
Samoa	0.712
Bolivia	0.661
Gabon	0.591
Peru	0.577

Somalia	0.573
Congo	0.563
Brazil	0.557
Indonesia	0.545

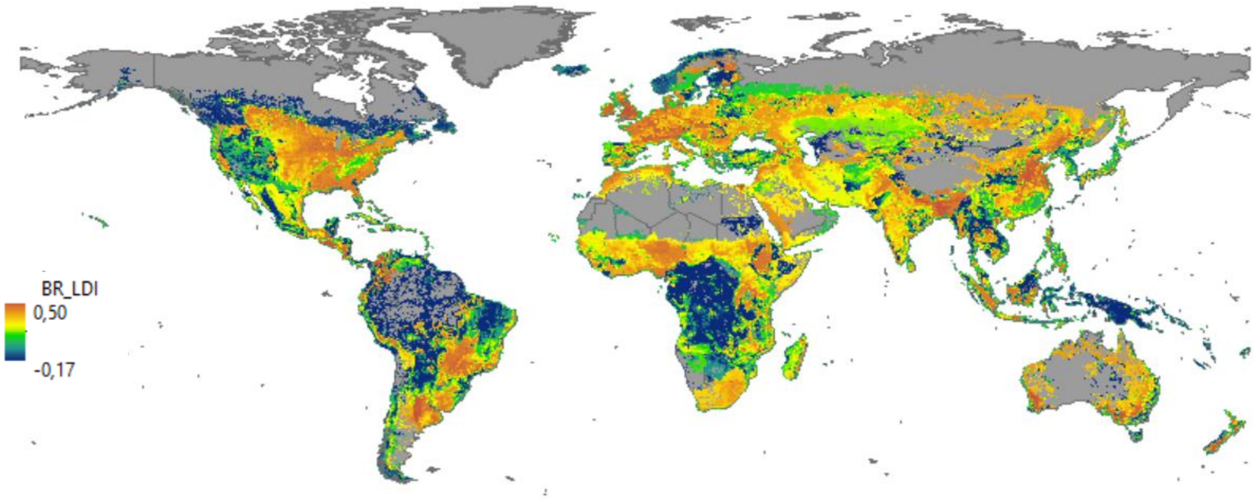

Figure 1: Biodiversity risks derived from a landscape development index for cropland production

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Topic 2:

Livestock Production:

Beef and Dairy

Abstract code: 46

Environmental impact assessment of beef production in a semi-intensive in Paraguay

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Abstract

A Paraguayan cattle farm was evaluated to explore the environmental performance of beef production in a semi-intensive system. The LCA method was applied with a "cradle-to-farm gate" perspective and 1 kg of Live Weight as the functional unit selected. Primary data referring to cropping and livestock systems' inputs and outputs for the three-years from 2016 to 2018 were collected on site. Twelve different impact categories were evaluated. Cattle farming confirmed to be responsible for intensive GHG emissions (24.8 kg CO_2 eq/kg LW), especially when it occurs predominantly on pasture. A trade-off has been identified between impact categories strongly affected by animal-related emissions (including climate change, acidification potential and eutrophication), occurring mostly on pasture, and others (toxicity-related categories, ozone and resources depletion) by feed production, despite its limited inclusion in the overall rearing cycle, almost exclusively during the finishing feedlot phase.

Keywords: *beef cattle, Paraguay, life cycle assessment, grazing systems*

Introduction

Beef production has notable environmental implications on a global scale, mostly connected to the agricultural production phase (LEAP, 2015). Paraguay contributes greatly to the international market for this commodity. In 2018 bovine population was estimated to be 13.6 million heads (SENACSA, 2020) and beef production around 560 thousand metric tons of carcass weight equivalent, of which ca. 365 thousand metric tons were exported (USDA, 2019). Paraguayan beef farming is characterized by being developed mostly on pastures or grasslands. However, as is increasingly happening in South America, the rearing system may also include a finishing phase with animals confined to feedlots (USDA, 2019). In this context, this contribution reports the preliminary results deriving from a study on the environmental performance of a semi-intensive beef cattle production system, which involves both a grazing phase and one confined in feedlots.

Material and methods

This study focuses on a farm located in Alto Paraná Department (SE Paraguay). The farm's agricultural land is destined for pasture for raising beef cattle (about 950 ha) and crop production. A part of crop production is intended for internal cattle consumption, namely oats to produce hay and maize to produce silage, consumed during the finishing phase. The rearing system of the farm, intended exclusively for beef production, is a cow-calf closed-cycle. After the weaning at 7 months, the fattening cycle is divided into two phases: an initial 15-month period of rotational grazing and a finishing 3-month period confined to feedlots. The latter involves the use of feeds, which are either produced internally (e.g. maize silage) or purchased (e.g. protein concentrates). In the three-year period 2016-2018, the farm sold 243 animals per year at an average live weight (LW) of 465 kg, represented by both young animals (steers and heifers) from fattening and culled cows from the mother herd of cows (and replacing heifers) deputed to reproduction and nursing new calves.

To carry out the environmental analysis, the Life Cycle Assessment (LCA) approach was adopted in a cradle-to-farm gate perspective and 1 kg of live weight (LW) was selected as functional unit (FU), in accordance with LEAP guidelines (LEAP, 2015). System boundaries include the extraction of raw materials; the manufacture and supply of the productive factors consumed, and the emissions related to their use and consumption, as well as emissions related to enteric fermentations and animal manure. The latter is entirely left on the ground as it is, both in pastures and feedlots, and do not undergo any type of handling (removal, storage, distribution, etc.).

Since farm land use has remained constant for a period above 20 years, soil organic carbon was assumed to be in a steady-state (IPCC, 2019). Therefore, no direct land use changes (dLUC) were considered on-farm. In contrast, dLUCs related to off-farm feed production, soybean-derived products in particular, has been included. Indirect LUC has been excluded from the assessment.

Primary inventory data, collected through questionnaires and interviews with farmers and staff, refer to the 2016-2018 three-year period and concern the consumption of production factors and generated outputs. Table 1 shows, by way of example, the inventory data relating to maize silage production.

Table 1. Inventory data for maize silage production (yield: 34.27 ton·ha^{-1}, fresh mass, with 33% dry matter)

Field Operation	**N.**	**Tractor (power and mass)**		**Operative Machine**		**Diesel Consumption**	**Inputs**		**Working Time**
		kW	**ton**	**Type**	**ton**	**kg·ha^{-1}**	**Product**	**Amount (·ha^{-1})**	**h·ha^{-1}**
Soil tillage (sporadic)	1 every 5 years	65	3.8	Chisel	0.8	15.50	-	-	1.43
		55	3.0	Lime spreader	1.0	5.29	Lime fertilizer	2000 kg	0.18
		65	3.8	Disc harrow	0.8	4.90	-	-	0.45
No-till seeding	1	105	5.4	Precision seed drill	4.0	9.60	Seed	30 kg	0.57
							$N-P_2O_5-K_2O$ fertilizer (10-15-15)	220 kg	
Spray of agrochemicals	4	-	-	Self-propelled Sprayer (94 kW)	6.6	1.25	Herbicides	2.23 L	0.043
							Insecticides	0.70 L	
							Fungicides	0.37 L	
Chopping	1	-	-	Forage harvester + tractor and trailer	5.0 + 4.5	52.80	-	-	0.35
Internal transport	-	55	3.0	Trailer	1500	0.044 (kg·km^{-1})	-	-	-

The same data were collected for the cultivation of oat and pastures, entirely sown in *Brachiaria spp.* and renewed on a ten-year rotation. Both as regards the production of oat hay and maize silage, no N_2O emissions from crop residues were considered, being two crop productions that involve the

removal of the entire aboveground biomass. For the livestock subsystem, primary data included animal flows and rearing cycle phases, their duration and entry/exit body weights of animals, as well as consumption of feed and supplements and main herd productive parameters.
Secondary data were used in order to account for data gaps or background information of the production systems. In particular, models were used for computing emissions from lime and fertilizers application (Brentrup et al., 2000; Prahsun, 2006), as well as those related to animals (enteric fermentations and manure management) (IPCC, 2019).
Background data for inputs manufacture and supply (e.g. seeds, lime, fertilizers, fuels, tractors and agricultural machinery, purchased supplements and feeds, including possible related LUC) were taken from the Ecoinvent® v.3.5 database (Weidema et al., 2013). Due to the scarcity of data referring specifically to Paraguay in the database, data referring to the global market and, where available, to Brazil have been used.
The impact assessment was performed using the ILCD 2011 Midpoint + V1.10 method, taking into consideration 12 midpoint impact categories.

Results and Discussion
As shown in Table 2, animal-related emissions (both from enteric fermentations and from manure) are the main causes (≥70%, up to 98% for ME) of the impact for 7 of the 12 evaluated impact categories. Feed production (both on- and off-farm) greatly contributes (from 37% to 78%) to the impact in toxicity-related categories, and ozone and resources depletion, due to energy and machinery use and the field application of lime, fertilizers and pesticides. The same impact categories are also significantly affected by pasture management, which refers to the ten-year renewal of pastures (soil tillage and sowing), as well as to production and supply of the mineral salt intended as supplement for grazing animal.

Table 2. Environmental impact for the selected FU (1 kg of LW leaving the farm) in absolute terms and divided by the relative contributors.

Impact category	Unit	Score	Relative contribution (%)					
			CH_4, enteric	CH_4 & N_2O, manure	Other N compounds & PO_4^{3-}, manure	On-farm feed	Off-farm feed	Pasture management
Climate Change	kg CO2 eq	24.84	85.5	11.6	-	0.8	0.7	1.4
Ozone Depletion	kg CFC-11 eq	$1.24 \cdot 10^{-7}$	-	-	-	20.4	17.0	62.6
Human Toxicity, non-cancer effects	CTUh	$4.53 \cdot 10^{-7}$	-	-	-	44.9	19.7	35.5
Human Toxicity, cancer effects	CTUh	$4.74 \cdot 10^{-8}$	-	-	-	21.5	26.4	52.1
Particulate Matter formation	g PM2.5 eq	4.68	-	-	89.3	2.8	3.3	4.7
Photochemical Oxidant Formation	g NMVOC eq	14.09	61.4	0.7	7.5	8.7	6.4	15.4
Terrestrial Acidification	molc H+ eq	0.19	-	-	96.5	0.8	1.4	1.2
Terrestrial Eutrophication	molc N eq	0.87	-	-	96.9	0.7	1.4	1.0
Freshwater Eutrophication	kg P eq	2.88	-	-	89.2	5.1	2.1	3.6
Marine Eutrophication	kg N eq	0.15	-	-	97.7	0.4	1.3	0.7
Freshwater Ecotoxicity	CTUe	8.32	-	-	-	48.4	23.7	27.9
Mineral, Fossil & Renewable Resources Depletion	kg Sb eq	$6.52 \cdot 10^{-5}$	-	-	-	58.5	19.3	22.2

As for climate change, results are in line in terms of absolute values and hotspots with those reported by other studies relating to South American beef systems (e.g. *Becoña et al.* (2014) in Uruguay and *Florindo et al.* (2017), *Ruviaro et al.* (2015) and *Kamali et al.* (2016) in Brazil), suggesting similar practices in beef cattle farming across the continent, which translate into common productive and environmental issues. As regards the other impact categories considered apart from climate change, comparisons with existing literature are limited by the fact that (i) not all studies have the same impact coverage, (ii) not all studies use the same factors characterization by categories such as acidification and eutrophication (iii) some categories have a localized impact, greatly influenced by soil and climate conditions, and comparisons between different geographical contexts can be misleading (De Vries & De Boer, 2010). At the same time, it is necessary to carry out studies that include a broad spectrum of impact categories to highlight any environmental trade-offs and to avoid that mitigation strategies aimed, for example, at tackling climate change may result in a burden shifting towards other impact categories at the inside of the studied system.
A better efficiency in resources use (both in the livestock rearing system and in internal crop production) and herd management would have positive effects from an environmental (lower impact per kg of product, for all impact categories) and economic (higher productivity) point of view, and ample room for improvement is possible in this regard.
It should also be stressed that in other production chains where the grazing phase is shorter, or even not foreseen, the observed climate change values appear regularly lower (LEAP, 2015). This suggests that a system intensification could be an option for mitigating GHG emissions. On the other hand, it has been highlighted how feed production, the demand for which would be greater in the case of a system with limited grazing, may influence other impact categories instead. A careful evaluation of the trade-offs is therefore required to obtain the best mitigation option.

Conclusions

Beef cattle rearing in the system under study is responsible for intense greenhouse gas emissions, methane in particular, especially due to the long duration of the fattening cycle and the prolonged period of grazing. This determines a high carbon footprint of the beef cattle ready for slaughter, equal to 24.8 kg CO_2eq/kg LW leaving the farm, and confirms beef as a high-range impactful food product mainly because of the agricultural phase. Also, particulate matter formation, acidification and eutrophication potentials are also strongly influenced by emissions related to animals, in particular to manure deposited in the pasture. Feed production, despite a limited inclusion in the overall rearing cycle, greatly influences the impact categories related to toxicity, and ozone and resources depletion. Future studies should first deepen the impact subdivision between pasture and feedlot stages, as well as between the different animal categories and breeding phases, in order to search for targeted mitigation strategies. Further improvements should concern the evaluation of the robustness of the results through sensitivity analysis of some key factors of the modeling of the inventory, among which certainly those that have resulted as hotspots, as animal-related emissions estimate. Linking the results with the country's environmental policies could also be addressed in future studies.

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Utilization of Dry Aged Beef Trimmings to reduce the Environmental Impact of Raw Fermented Sausages

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Abstract

Purpose: In this study, usually discarded trimmings of one of the most environmentally impacting meat products, dry aged beef (DAB), and their incorporation into raw fermented sausages as a substitute for fresh beef were investigated by means of life cycle assessment (LCA). As demand is increasing steadily worldwide, trimmings arise evermore. Thus, a further use while considering technological, microbiological, economic and environmental feasibility is necessary. To maintain microbiological safety, DAB trimmings were treated with high pressure processing (HPP).

Methods: Dry aged trimmings were pasteurized by HPP (600 MPa, 3 min hold) to reduce the bacterial load, achieving a 3-log reduction. Pasteurized dry aged beef trimmings were then incorporated into raw fermented sausages, consisting of pork and beef.

With attributional LCA, environmental hotspots of DAB production and mass and economic allocation of impacts between coproduction schemes were estimated. Functional unit was 1 kg DAB-trimmings. In a cradle-to-gate analysis, infrastructure, machinery and equipment installation were not considered, but waste treatments for all materials were included. Ecoinvent 3.1 database was used for background processes and energy calculation for HPP according to Aganovic et al. (2017). Effects of material transformation and processes from life cycle impact were analyzed with SimaPro 8.0.1 and IMPACT 2002+ for a combined midpoint-end point damage-oriented approach (Humbert et al. 2012), summarizing impacts in midpoint categories which relate to damage categories.

Results and discussion: Consequently, the higher the amount of substituted beef, the earlier the necessary weight reduction due to water loss is achieved. Using HPP, microbiota on DAB trimmings is reduced allowing 50 % substitution in raw fermented sausages. Caused by substitution, less weight was lost during ripening, since control initially had 12 % more water than DAB sausage.

LCA defined benefits of DAB trimmings utilization, since an overall reduction of environmental impact was observed for major impacting categories (~5 %) (Fig. 1). This impact reduction is associated mostly with the reallocation of environmental impact from the main product to the by-product (DAB trimmings). Application of DAB trimmings in raw fermented sausages resulted in ripening time reduction, resulting in a reduction of environmental impact (20 %) (Fig. 2), mostly in respiratory inorganics (~15 %), land occupation (21 %), global warming potential (23 %) and nonrenewable energy (23 %).

Conclusions: Utilization of DAB trimmings for raw fermented sausages improved the environmental impact of DAB in the range of 5 % and of raw fermented sausages overall of 20 %.

Keywords: *life cycle assessment (LCA); by-product; Dry aged beef trimmings (DAB); high pressure processing (HPP); raw fermented sausages; sustainability*

Introduction

With world population increasing, the demand for high-quality protein is rising. Protein from meat, especially beef, is associated with many environmental problems (Henchion et al. 2017). Dry aged beef (DAB) with significant moisture loss, processing time and trimmings waste has become one of the most environmentally impacting meats. A potential solution could be in the improvement of processing and use of by-product (DAB trimmings) for a new product (Park et al. 2018). However, the feasibility of such use should be confirmed from technical, processing, microbial, economic and environmental perspectives. Dry aged beef has reemerged over several years as a well-established upper-priced product with a large consumer acceptance (Ponnampalam et al. 2019). During the traditional dry aging process, beef cuts are aged without oxygen-protective wrapping for 21 – 90 days at a controlled relative humidity (70 – 80 %) and temperature (0 – 3 °C) (Savell 2008; Ponnampalam et al. 2019). Compared to wet aging in a vacuum bag, dry aging is more expensive due to a greater loss caused by evaporation, trimming of the dry surface and, therefore, higher operating costs (Kim et al. 2018). Dry aged beef has a more intense flavor, described as 'beefier and more brown/roasted,' caused by enzymatic and biochemical processes (Warren and Kastner 1992). Consumers are willing to pay for this unique flavor profile (Sitz et al. 2006; Baird 2008) and, since demand for this high-quality beef product has been increasing steadily worldwide (Sinha and Prasannan 2017), evermore dry, usually discarded trimmings arise (Ahnström et al. 2006).

No studies on the environmental impact of dry aged beef and neither any studies of the potential of the application of the usually discarded trimmings for the design of a potentially more sustainable production and product is available. Since raw fermented sausages are dried anyway, the low water content of trimmings is a great benefit to reduce ripening time and thereby minimize overall economic and environmental costs. The objective of the LCA was to define the feasibility of dry aged beef trimmings utilization as a component for existing or new product. The aim was first to define if utilization of trimmings would be beneficial for the main dry aged beef product and second what would be the environmental impact of such trimmings' decontamination and application as an ingredient for a new product development (raw fermented sausage).

Material and methods

2.1 High-pressure processing of DAB trimmings

The dry aging process took 21 – 28 days at 0.5 °C and 75 % relative humidity and was conducted at the industrial plant of EDEKA Südwest (Rheinstetten, Germany) from about 50 sirloins from heifers with a high intramuscular fat content and high fat cover (fat grade 3 – 4). The DAB trimmings were divided into three batches and cut into 3 cm cubes. The HPP was carried out with a Wave 6000/55 from Hiperbaric S.A. (Burgos, Spain) at 600 MPa and a holding time of 3 min.

2.2 Sausage manufacture

The raw fermented sausage (type: *Mettwurst;* medium grained, uncut storable without cooling; (BMEL 2019)) consisted of 60 % pork and 40 % beef (purchased from a local meat producer), 2.8 % curing salt with 0.5 % $NaNO_2$, 0.85 % raw fermented sausage ripening combination (Pacovis, Stetten, Switzerland) and 0.02 % bacteriocin-producing starter culture (Lyocarni VBY 81, SACCO, Cadorago, Italy). The sausage batter was filled into fibrous casings. The production process was repeated three times. Raw fermented sausages were analyzed on day 0, 2, 5, 7 and 9 regarding water (n = 3) (ASU L06.00-3) and weight loss (n = 15). Based on the absolute beef content, 50 % DAB was substituted and analyzed by means of LCA.

2.3 Life Cycle Assessment (LCA)

2.3.1 Goal and scope of the LCA

The objective of the LCA was to define the feasibility of utilizing DAB trimmings as a component in existing or new products. The aim was, firstly, to define whether the utilization of trimmings would be beneficial for the main DAB product and, secondly, what would be the environmental impact of the decontamination and application of such trimmings as an ingredient for a new product development (raw fermented sausage).

2.3.2 Type of LCA

The current study relied on attributional LCA, which allowed for the estimation of environmental hotspots of DAB production and the allocation of impacts between coproduction schemes. The study relied on mass and economic allocation (between the main DAB and trimmings) for the allocation of impacts. The expansion and consequential modelling were not applied, as it was not possible to define a reference product on the market. Trimmings are currently treated as waste.

2.3.3 Functional unit

The functional unit in the study relied on the mass and was defined as 1 kg of DAB (21 days of aging) with trimmings utilized as waste and as a coproduct to define the scope of environmental improvement for such a product. Application of trimmings for raw fermented sausage production was also defined on a 1 kg basis, as products were comparable in quality. Only relevant products were compared (DAB was not compared to raw fermented sausage).

2.3.4 System boundaries

A cradle-to-gate analysis was conducted regarding the processing, including the packaging required for intermediate products, and the processing and utilization of waste materials. The infrastructure, machinery and equipment installation were not considered, but waste treatments for all the materials consumed were included. Furthermore, a comparison with other products took place, for which these factors were not considered either. The study was performed for the conditions of Germany as the data were retrieved from German companies and pilot production areas. The study relied on the ecoinvent 3.1 database for background processes (e.g. electricity, water, washing agents).

2.3.5 Data sources

The study relied on industrial and experimental data. Industrial and pilot industrial data on DAB and raw fermented sausage production was acquired from a relevant industrial partner, EDEKA Südwest (Rheinstetten, Germany), and is presented in this study in paragraph '*2.2 Sausage manufacture*.' Processing parameters of HPP and raw fermented sausage ripening were derived from pilot industrial scale equipment during the trials at the German Institute of Food Technologies (DIL e.V., Quakenbrück, Germany). Energy calculation for the HPP was performed according to the procedure defined in a previous study (Aganovic et al. 2017).

2.3.6 Life cycle impact assessment methodology

The effects of the material transformation and processes from the life cycle impact were analyzed via SimaPro 8.0.1 software (PRè Consultants, Amersfoort, The Netherlands, 2010) using different characterization factors. The impact assessment method IMPACT 2002+ (V 2.11) was used for

comparisons (Jolliet et al. 2003), selected for a combined midpoint-end point damage-oriented approach (Humbert et al. 2012). It summarizes impacts in midpoint categories which, in turn, relate to one or several of the damage categories: Human health, ecosystem quality, climate change and resource consumption.
The results were presented in 'points' – units normalized according to the impact within a damage category and weighted according to the annual impact of an average European citizen – for aggregated endpoint scores. A single score is then 'calculated as the total yearly damage score due to emissions and extractions in Europe divided by the total European population' (Humbert et al. 2012).

Results and Discussion

3.1 DAB trimmings in raw fermented sausages

Using HPP, microbiota on DAB trimmings is reduced to an extent that allows incorporation into a product. Thus, raw fermented sausages with 50 % substitution of fresh beef with HPP-treated DAB trimmings have been produced. By substitution, less weight is lost during ripening. The control sausage needs to lose 12 % weight, respectively, water, to have the same water content as sausages with 50 % substitution on day 0.

3.2 Life Cycle Assessment

The LCA conducted defined the potential benefits of the application of DAB trimmings for both the DAB processing and the application of trimmings as a component of raw fermented sausage. The results indicated the minor beneficial role of the application of DAB trimmings for DAB production. An overall reduction of the environmental impact in the range of ~5 % was observed for major impacting categories (Fig. 1). Such an impact reduction is associated mostly with the reallocation of environmental impact from the main product to the by-product (DAB trimmings).
Application of DAB trimmings as a component of raw fermented sausages resulted not only in the substitution of premium beef but also in the reduction of ripening time. Such a cumulative impact resulted in a reduction of environmental impact in the range of 20 % (Fig. 2). Reduction was observed mostly in the categories of respiratory inorganics (~15 %), land occupation (21 %), global warming potential (23 %) and nonrenewable energy (23 %).

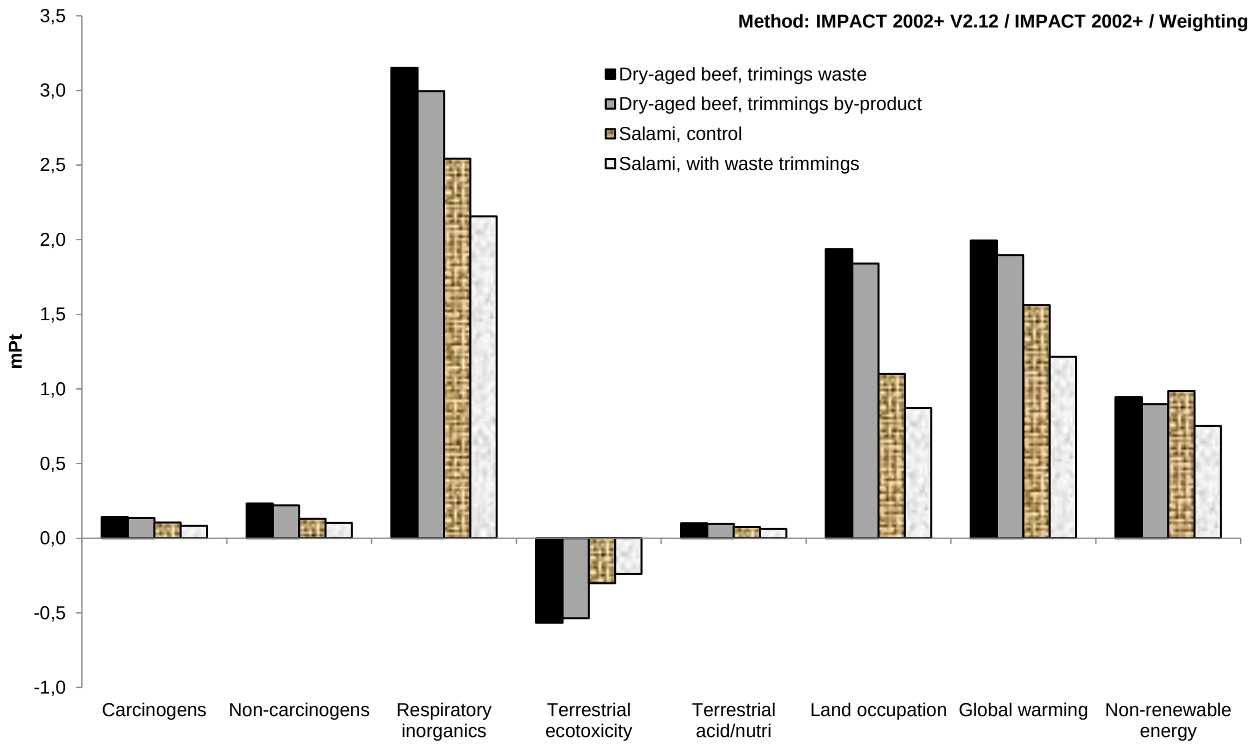

Fig. 1: Environmental impact of products in midpoint impact categories (weighted according to the significance of impact; mPt - miliecopoints, 1 kPt equal to the annual impact of one European person on the environment; Functional unit – 1 kg of product; categories with low impacts are excluded from the graph for a better representation).

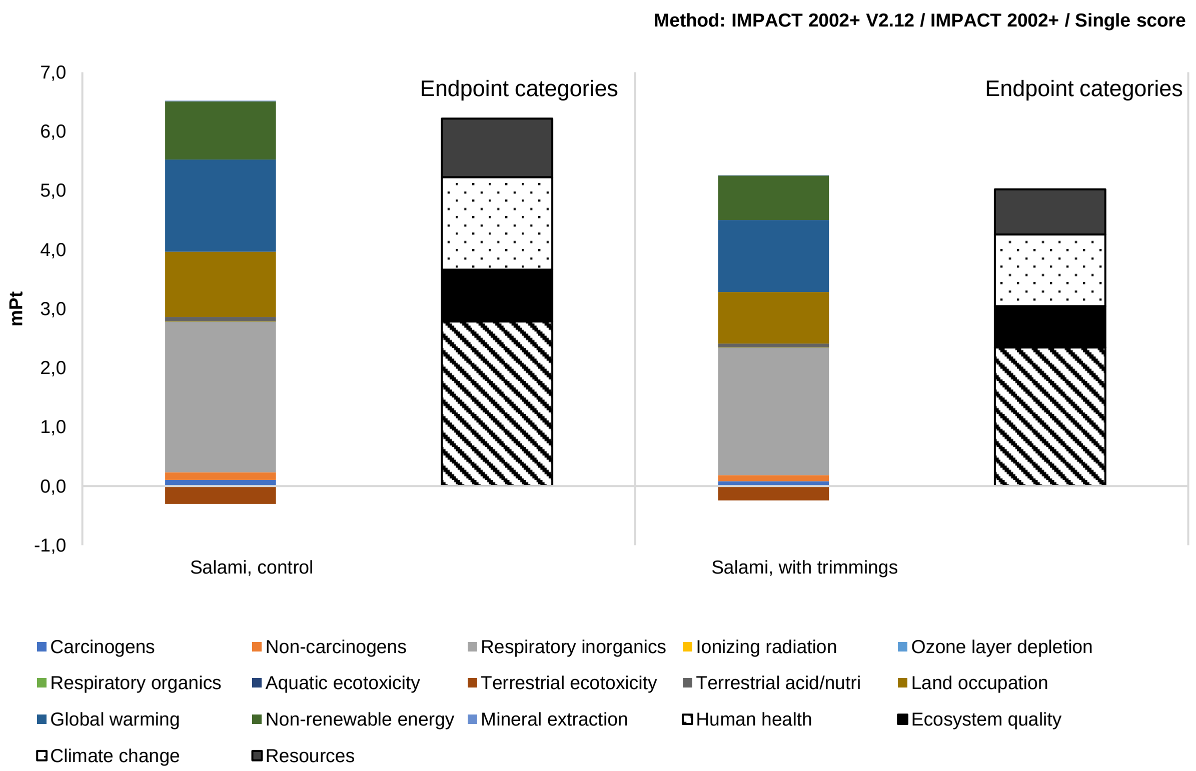

Fig. 2: Integrated environmental impact of raw fermented sausages (left column – midpoint impact categories; right column – endpoint impact categories; mPt - miliecopoints, 1 kPt equal to the annual impact of one European person on the environment; Functional unit – 1 kg of product).

Conclusions

The initial hypothesis that trimmings of DAB are microbiologically stabilized after HPP treatment is correct. Both, the water content of the raw fermented sausages and the total production time, are reduced due to the substitution. The utilization of DAB trimmings for raw fermented sausages improved the environmental impact of DAB in the range of 5 % and of raw fermented sausages overall of 20 % for a 50 % substitution.

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Tool for determination of climate change related to milk production

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Purpose

To achieve a sustainable supply of animal origin food, farmers need to identify strategies, that promote the best use of available resources and minimize the potential environmental impact. With this regard, a tool for the evaluation of Climate Change related to the production of cow's milk was developed. The tool enables farmers to have findings quickly, by providing a method that is easily applicable on a field scale, without the need for tabulated data or empirical formula.

Methods

Statistical analysis was performed using SAS 9.4 software (SAS Institute, 2012). The first step was performed through a principal component analysis (PCA; PROC PRINCOMP) to study the relationships among total environmental impacts per kilogram of fat and protein corrected milk (estimated trough LCA approach) and several quantitative variables related to farm management on 200 dairy farms. Starting from the most significant variables, a general linear model (GLM) procedure was performed to build an equation suitable to estimate Climate Change (CC) for the production of 1 kg of fat and protein corrected milk (FPCM).

Results and Discussion

The 200 dairy farms involved in the study resulted different for Utilized Agricultural Area (UAA), 68.4±96.7 ha; arable land was 54.8±30.1% of UAA. Average herd size was 150±145 cows with a milk production of 27.3±4.88 kg FPCM/head/day. CC resulted to be 1.44±0.30 kg CO_2 eq/kg FPCM. From the statistical analyses the best equation, suitable to estimate CC for the production of 1 kg of FPCM, included the following variables: Herd size (number of lactating and dry cow); Dry matter intake (DMI; kg/head/d); Milk production (kg FPCM/head/d); Feed self-sufficiency (%). DMI was positively related to CC, while herd size, milk production and feed self-sufficiency were negatively related to the dependent variable.

Conclusions

The development of this tool can influence the management choice at farm and can improve the chance of mitigation of CC of milk production.

Keywords: *tool, climate change, milk production, dairy farm*

Introduction

Livestock contribute for 14.5% to human-induced greenhouse gas emissions that contribute to climate change (CC) but it concurs to global food security and poverty reduction, providing regular income to producers (FAO 2011). To produce milk in an environmentally sustainable way, farmers need to identify appropriate strategies, in terms of management and feeding of livestock, forage systems and production practices for livestock feed, which allow the best use of the available resources and minimize the potential environmental impact, as underlined by Famiglietti et al. (2019). To this aim, a tool has been developed for the simplified assessment of Greenhouse Gas (GHG) emissions associated with the production of cow's milk. The tool allows farmers to quickly obtain results by providing an easily applicable method on a field scale, starting from a limited number of inputs, without the need of tabulated data or complex calculations. This tool can be used easily by farmers, to help identify and evaluate strategies at farm, for reducing CC of milk production.

Material and methods

The estimation of Climate Change (kg CO_2 eq.) for the production of 1 kg of fat and protein corrected milk (FPCM) was performed using the Life Cycle Assessment method. An attributional approach, from cradle to farm gate, was adopted. Allocation between milk and meat was calculated through a physical method (IDF 2015), based on the use of feed energy by the dairy animals and the physiological feed requirements of the animals to produce milk and meat. All the inputs (e.g. off farm feeds and bedding, machinery, fuel, lubricants, electricity, organic and mineral fertilizers, pesticides, plastics and water) and outputs (i.e. emissions to the air, soil and water, milk and meat) involved in the productive process were considered within the system boundaries. In order to collect information about the management practices, the farmers were interviewed directly about several aspects of their farming system as cropping system, herd composition, manure management, feed rations, purchased feed, milk production and composition.The background data for the production of seeds, raw materials, diesel fuel, fertilizers, pesticides, tractors and agricultural machines (equipment and self-propelled machines), as well as for transport, were obtained from the Ecoinvent Database V.3 (Ecoinvent 2015) and Agri-footprint Database (Blonk Consultants, 2014). Gas emissions from animals, manure and fertilizer spreading were estimated as reported in Guerci et al. (2013) and Bava et al. (2014). Information about crop management systems were collected and used to create specific process in the software used for GWP estimation (SimaPro V 8.3 software).

Statistical analysis was performed using SAS 9.4 software (SAS Institute 2012). The first step was performed through a principal component analysis (PCA; PROC PRINCOMP) to study the relationships among GWP and several quantitative variables related to farm management on 200 dairy farms.

Starting from the most significant variables, a GLM procedure was performed to build an equation suitable to estimate GHG emissions, expressed as GWP (kg CO_2 eq./kg FPCM).

Results and Discussion

The most of 200 dairy farms involved in the study were intensive with all cows kept in permanent confinement without pasture. The Utilized Agricultural Area (UAA; 68.4±96.7 ha) and the percentage of arable land (54.8±30.1% of UAA) resulted different among farms. Average herd size was 150±145 adult cows with an average milk production of 27.3±4.88 kg FPCM/head/day. Average GWP was 1.44±0.30 kg CO_2 eq/kg FPCM, which was higher than the results found by Bava et al. (2014) in the same area. This result can be influenced also by the increasing load given to Land Use Change for soybean meal used in cow feeding calculated in the last year and implemented in Simapro database.

From the statistical analyses the best equation, suitable to estimate GWP for the production of 1 kg of FPCM, included the following variables (Table 1):

Table 1. Results from GLM analyses, estimate coefficients for equation parameters

Parameter	Estimate	Standard Error	Probability
Intercept	1.7559	0.2065	<.0001
DMI, kg/head per day	0.0345	0.0095	0.0004
Maize silage, % DMI	0.0031	0.0013	0.0172
Grasshay, % DMI	-0.0040	0.0017	0.0226
Grassland, % UAA	0.0017	0.0007	0.0193
Herd size, no. lactating and dry cows	-0.0004	0.0001	0.0032
FPCM, kg/head per day	-0.0391	0.0042	<.0001

Where: DMI=Dry Matter Intake; UAA= Utilized Agricutural Area; FPCM= Fat and Protein Corrected Milk

The developed equation is:
GWP milk (kg CO_2 eq./kg FPCM) = 1.7559 + 0.0345 DMI + 0.0031 Maizesilage % - 0.0040 Grasshay % +0.0017 Grassland % - 0.0004 Herdsize – 0.0391 FPCM

The relationship between the estimates of GWP obtained from primary data and the predicted values from the equation showed R^2=0.337.

Milk production per cow and herd size were inversely related to the impact per kg of product. The mitigation effect of enhancing individual milk production is due to the fact that emissions are spread over more units of milk, thus the emissions related to the maintenance requirements of the animals are diluted (Capper et al. 2009). Secondly, productivity gains are usually achieved through improved practices and technologies which also contribute to increase efficiency in feed conversion ratio and consequently to emissions reduction, such as high quality feed and high performance animal genetics. Enhanced productivity is generally achieved through herd management, animal health and reproduction practices that increase the proportion of resources utilized for productive purposes rather than simply being used to maintain the animals. The relationship between predicted GWP per kg FPCM and milk production expressed as kg FPCM/head per day resulted quite good (R^2=0.3915).
On the contrary, DMI was positively related to GHG emissions. It is well known that higher DMI means higher daily CH_4 enteric emission (Boadi et al. 2004; Gislon et al. 2020), that is by far the main contributor to GWP of milk production, since higher DMI is usually related to a more fibrous diet involving higher methane production.
Among the factors influencing GWP of milk production, dairy efficiency (kg FPCM per kg DMI) is one of the most important (Bava et al. 2014). The parameter expresses the efficiency of feed conversion to milk. Figure 1 shows the relationship between predicted GWP (kg CO_2 eq/kg FPCM) and dairy efficiency (kg FPCM/kg DMI).

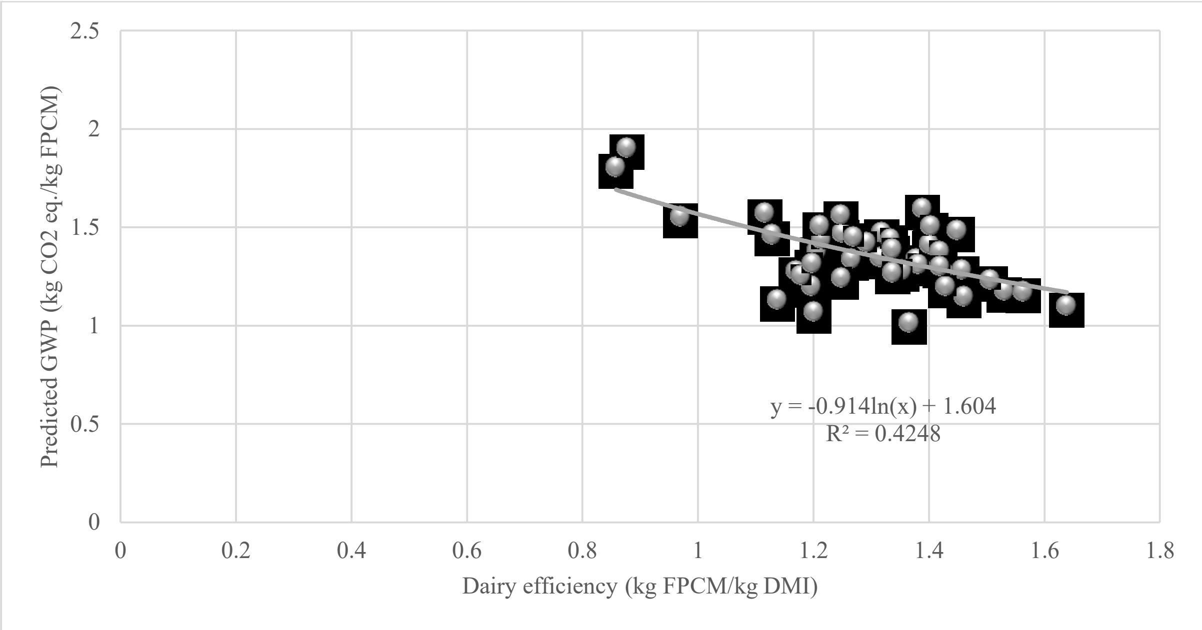

Figure 1 - Relationship between predicted GWP (kg CO_2 eq/kg FPCM) and dairy efficiency (kg FPCM/kg DMI).

The developed equation was implemented in an Excel sheet to allow the simplified estimation of the GWP per kg FPCM of a given dairy cattle farm on the basis of the following input variables:

- Herd size (no. lactating and dry cows)
- Total land (UAA, ha)
- Average daily dry matter intake (DMI, kg/day)
- Maize silage percentage on dry matter intake (Maizesilage % DMI)
- Grass hay percentage on dry matter intake (Grasshay, % DMI)
- Grassland percentage on total Utilized Agricultural Area (Grassland, % land)
- Average daily milk production (kg per head)
- Milk fat (%)
- Milk protein (%)

The equation has the strenght to be based on a low number of variables and parameters easy to be collected by the farmers as milk quality analyses, feed ration characteristics and land use choices.

Conclusions

In the equation, resulted from a large database, variables related to cow ration characteristics and land management choices were included, this means that, in order to mitigate environmental impact, is necessary to have a holistic approach, improving at the same time feeding management, milk production level, crop production practices. The tool is suitable for intensive systems, with animals kept in permanent confinement without pasture.
The tool allows to obtain the Predicted Global Warming Potential of milk production of a given farm, the comparison of the environmental performance of the farm with a benchmark and a number of indicators as Fat and Protein Corrected Milk, Dairy efficiency, Stocking Density.

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Longitudinal observation to assess greenhouse gas emissions from smallholder dairy farms in Indonesia: the more the merrier?

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Abstract

Purpose: The present study aimed to develop a data collection procedure to assess greenhouse gas emissions (GHG) on smallholder dairy farms in Indonesia. To do this, we first evaluated seasonal differences in GHG per kg of fat and protein corrected milk (FPCM), and second, we evaluated the number of observations within the season to assess seasonal estimate of GHG. **Methods:** We conducted LCA at 32 smallholder dairy farms in Lembang, Indonesia. Data were collected bimonthly from October 2017 to October 2018 through 6 farm visits (FVs) to gather information about inputs, outputs, and farm activities, such as milking, feeding, and manure management. FV1, FV2, FV3 were conducted in the rainy season, and FV4, FV5, FV6 in the dry season. The quantification of GHG was based on IPCC Tier 2 (2019). We presented GHG per unit of FPCM at each season. The Wilcoxon signed-rank test was used to evaluate the difference in GHG between seasons. Within each season, correlations were analysed between the estimate of GHG, milk yield, GHG from different processes based on 3 observations and based on 1 or 2 observations. **Results and discussion:** The GHG in dry season was lower than in the rainy season (1.07 vs. 1.37 kg CO_2-eq/kg FPCM). The major contributor, enteric CH_4 emissions, was reduced in the dry season, and it was most likely associated with the change of feed composition that led to better digestibility. The estimated GHG based on 3 observations had lower correlation with the estimated GHG based on 1 observation than with 2 observations in both seasons. These results indicated that 1 observation did not capture the variation of on-farm activities related to the estimates of GHG from manure management, forage cultivation, and purchased feeds within each season. **Conclusions:** Our finding suggested to assess GHG from smallholder dairy farms in Indonesia at least once in each season. When multiple observations within each season are infeasible, we recommend conducting at least 2 observations to estimate GHG from manure management, forage cultivation, and purchased feeds.

Keywords: *greenhouse gas emissions, longitudinal study, smallholder dairy farm, Indonesia.*

Introduction

The tropical climate in Indonesia is characterised with rainy and dry seasons. Due to the seasonality, smallholder dairy farms in Indonesia adapt their practices to cope with resource availability. The farmers change practices such as adjusting feed composition, frequency of feeding, the proportion of collected manure and applied manure to land at each season (De Vries and Wouters 2017). These changes affect GHG from the farms associated with ruminal digestion and manure management (Gerber et al. 2013). To assess GHG, life cycle assessment (LCA) is suitable approach, but conducting LCA on smallholder farms is challenging due to the lack of data availability (Rosenstock et al. 2013). Often, LCA studies are done through cross-sectional survey which does not consider changes of practices between seasons. To gain insight into changing practices, we opted for longitudinal observations on smallholder dairy farms in Indonesia. The present study aimed to develop a data collection procedure to assess greenhouse gas emissions (GHG) on smallholder dairy farms in Indonesia. To do this, we first evaluated seasonal differences in GHG per kg of fat and protein corrected milk (FPCM), and second, we evaluated the number of observations within the seasons to assess seasonal estimate of GHG.

Material and methods

System description and life cycle inventories

The scope of LCA on smallholder dairy farms in Indonesia is from production of inputs at upstream level to on-farm gate. The farms' inputs are purchased feeds (concentrates, tofu by-product, cassava pomace, and rice straw), synthetic fertiliser, and fuel. The outputs of the farms are milk and sold animals. The on-farm activities include dairy herd, forage cultivation, and manure management. We classified the manure management into four different practices: discharged manure, sold manure, applied manure for forage cultivation, and used manure in bio-digester.

The calculation of GHG was the multiplication of activity data that release emissions at a certain stage from the upstream level to on-farm gate and emission factors. The activity data at the upstream level were identified through interviews and literature, whereas the activity data on farm was obtained through direct measurement and interview. The emission factors were based on literature.

We selected 32 out of 300 smallholder dairy farms from the study of De Vries and Wouters (2017) in Lembang, West Java, Indonesia. We visited the farms every two months throughout one year. The FVs from December 2017 to April 2018 (FV1 to FV3) were during rainy season, whereas the FVs from June 2018 to October 2018 were during dry season. At each FV, we conducted direct measurement to record daily feed intake, daily milk yield, and body weight of dairy cattle. In addition, we asked the farmers about the herd (age of animal, last calving date and lactation period of the cows, purchased and sold animals) and proportion of collected manure. We used this information to estimate on-farm GHG from enteric methane (CH_4) fermentation and nitrous oxide (N_2O) and CH_4 from manure management. The emission factors for these on-farm processes were based IPCC Tier 2 (IPCC 2019).

During one of FVs in every season, we asked the farmers about the purchased feeds, synthetic fertiliser. and fuel. According to on-farm interview, we selected relevant literature to obtain emission factors to produce ingredients of the concentrate (Vellinga et al. 2013; FAO 2015), tofu by-product (Zannah 2017), cassava pomace (Suroso 2011), and rice straw (Agatha 2016). To estimate GHG from transportation of the purchased feeds, we estimated the distance from producer to the farms and used emission factors for specific mode of transportation (Wernet et al. 2016; Liu et al. 2017). The emission factors of synthetic fertiliser and fuel were based on Ecoinvent 3 (Wernet et al. 2016).

Allocation

We applied economic allocation for GHG from crop cultivation and feed processing at the upstream level because these systems have multiple outputs (main product and by-product). The allocation was related to the economic value of the outputs. We did not apply economic allocation for GHG from on-farm activities into milk and sold animals because the farmers did not sell animals every two months. We allocated GHG from the adult cows to represent "milk", whereas GHG from other animal classes were allocated to "sold animal" outputs. To obtain GHG intensity, GHG from adult cows were divided by the amount of milk in FPCM.

Impact assessment and statistical analysis

The different GHG from upstream to on-farm level was aggregated in carbon dioxide equivalent (CO_2-eq) by weighing factors (Myhre et al. 2013). We presented the results as GHG intensity per unit of fat and protein corrected milk (FPCM) that was the summation of GHG (numerator) and divided by FPCM (denominator) at each season. The FPCM was based on IDF (2015). The Wilcoxon signed-rank test compared means of GHG from different seasons and means of GHG from different processes.

We performed Pearson correlation analyses between the estimate of GHG, milk yield, GHG from different processes based on 3 observations and 1 or 2 observations at each season to understand the relationship between the number of observations.

Results and Discussion

Table 1 shows that GHG intensity in the dry season (1.07 kg CO_2-eq/kg FPCM) was lower than in the rainy season (1.37 CO_2-eq/kg FPCM). The most important contributor to GHG was enteric CH_4 emissions that were also reduced in the dry season. Because feed digestibility is associated with enteric CH_4 emissions (Johnson and Johnson 1995), this result indicated that feed composition in the farms during the dry season was more favorable to reduce emissions. The GHG in present study was lower than previous study on smallholder dairy farms (Garg et al. 2016; Taufiq et al. 2016) because our study calculated gross energy intake through direct measurement of feed instead of the estimate based on animal requirement as IPCC Tier 2 (2019) advised. The estimate based on animal requirement overestimates gross energy intake due to the assumption of ad libitum feeding, while the farmers offered a restricted amount of feeds for dairy cattle.

Table 1. Greenhouse gas emissions (GHG) per unit of fat and protein corrected milk (FPCM) at Indonesian smallholder dairy farms and contribution of different processes in the rainy and dry season.

Items	Rainy season*	Dry season*
GHG per FPCM (kg CO_2-eq/kg FPCM)	1.37^a (0.70)	1.07^b (0.52)
GHG from different processed (kg CO_2-eq/kg FPCM):		
Enteric fermentation	0.75^a (0.42)	0.64^b (0.29)
Manure management	0.24^a (0.20)	0.16^b (0.15)
Forage cultivation	0.15^a (0.18)	0.03^b (0.10)
Purchased feeds	0.23 (0.18)	0.25 (0.17)

*value between the brackets presents standard deviation (n = 32); superscripts show significant difference (*P*-value < 0.05)

Seasonal GHG based on 3 observations had stronger correlation with seasonal GHG based on 2 observations than with seasonal GHG based on 1 observation in both seasons (Table 1). These results were in accordance with the correlation between different observations to estimate GHG from manure management, purchased feeds, and forage cultivation. The estimated GHG from those three processes based on 3 observation had higher correlation with the estimates on 2 observations than with 1 observation (Table 2). The low relationship between the estimates based on 3 observations and the estimates based on 1 observation indicated that variation of on-farm activities to estimate GHGE from those three processes existed within each season. The variation of on-farm activities can be explained by changing the proportion of collected manure and the amount of purchased feeds and the unreliable information about input and yield of forage throughout the years. Because conducting multiple observations are most likely infeasible, our results suggested at least 2 observations to capture the variation of on-farm activities to estimate GHG from those three processes at each season. In addition, single observation to estimate seasonal milk yield and GHG from enteric CH_4 emissions at each season was sufficient.

Table 2. Correlation between the seasonal estimates based on 3 observations and 1 or 2 observations for greenhouse gas emissions (GHG) per unit of fat and protein corrected milk (FPCM), milk yield, and greenhouse gas emissions from different processes at each season

	Seasonal estimates based on 1 or 2 observations					
Rainy season	FV1	FV2	FV3	FV1&FV2	FV1& FV3	FV2&FV3
Seasonal estimates based on 3-observations:						
GHG per FPCM	0.26	0.71	0.65	0.68	0.85	0.92

milk yield	0.93	0.95	0.96	0.96	0.95	0.85
Enteric CH_4 fermentation	0.93	0.97	0.98	0.99	0.99	0.99
GHG from manure management	0.59	0.99	0.98	0.98	0.99	0.99
GHG from purchased feeds	0.81	0.98	0.98	0.99	0.98	0.99
GHG from forage cultivation	0.74	0.99	0.95	0.97	0.99	0.98
	Seasonal estimates based on 1 or 2 observations					
Dry season	FV4	FV5	FV6	FV4&FV5	FV4&FV6	FV5&FV6
Seasonal estimates based on 3-observations:						
GHG per FPCM	0.47	0.79	0.37	0.88	0.65	0.82
milk yield	0.94	0.97	0.93	0.99	0.99	0.98
Enteric CH_4 fermentation	0.99	0.90	0.97	0.99	0.99	0.97
GHG from manure management	0.90	0.61	0.89	0.99	0.98	0.86
GHG from purchased feeds	0.95	0.85	0.96	0.98	0.99	0.97
GHG from forage cultivation	0.89	0.83	0.92	0.96	0.99	0.95

Conclusions

The GHG per FPCM produced by Indonesian smallholder dairy farms in the dry season was lower than in the rainy season. Our finding suggested to assess GHG from smallholder dairy farms in Indonesia at least once in each season. The correlation between different number of observations to estimate GHG per FPCM showed that single observation was insufficient to capture variation of on-farm activities within each season in relation with estimate of GHG from manure management, forage cultivation, and purchased feed.

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Carbon footprint of milk produced in Indonesian smallholder dairy farms: greenhouse gas emissions associated with different manure management systems

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Abstract

Purpose

The increase in the dairy cattle population in Indonesia results in large amounts of manure that has major environmental impacts, including climate change induced by greenhouse gas emissions (GHGE). Improving manure management is potentially a way to reduce GHGE from dairy production in developing countries. The objective of this study was to analyze GHGE associated with different manure management systems (MMSs) taking a cradle-to-farm-gate approach.

Methods

This LCA study was performed to assess dairy activities at 32 smallholder dairy farms in the Lembang district, West Java, Indonesia. Farms were surveyed six times on a bimonthly basis from December 2017 till October 2018 to collect information about farm and manure management characteristics, and milk production. The 32 farming systems were classified based on four different MMSs: applied manure without manure treatment to forage cultivation area (DLA), sold manure to manure traders (SEL), used manure as a substrate for anaerobic digestion (ADS) and discharged manure to the environment (DIS). The life cycle inventory for GHGE included upstream and on-farm processes. The means of GHGE per unit of milk produced of the four different MMSs were compared by the Kruskal-Wallis and Dunn's posthoc test.

Results and discussion

GHGE from milk produced in smallholder dairy farms ranged from 1.00 to 1.31 kg CO_2-eq/kg FPCM (fat and protein corrected milk). On average, the contribution to total GHGE was 57% for enteric fermentation, 26% for feed production, 16% for manure management, and 1% for fertilizer production. Total GHGE differed between manure management systems. DIS had the lowest GHGE (0.07 kg CO_2-eq/kg FPCM) and differed significantly from DLA (0.15 kg CO_2-eq/kg FPCM), SEL (0.40 kg CO_2-eq/kg FPCM), and ADS (0.20 kg CO_2-eq/kg FPCM). The GHGE of DIS was relatively low because we used the methane correction factor (MCF) and N_2O emission factor of the IPCC-category of *daily spread*, which has a low emission factor for N_2O and CH_4.

Conclusions

We assessed four different MMSs in this study and found that MMS has important impacts on GHGE. Although the practice of discharging manure results in the lowest GHGE of the four MMSs assessed in this study, the nutrient losses of this system are high. The yield of biogas was not used optimally, leading to additional methane losses. To draw conclusions, environmental impact assessment related to manure management systems in smallholder dairy farms should also consider other environmental impacts.

Keywords: *smallholder dairy farms, GHGE, manure management*

Introduction

The dairy cattle population in Indonesia increased rapidly as a response to the increase in national milk demand. Milk consumption in Indonesia increased from 11 kg per capita in 2010 to 14 kg per capita in 2018 and is expected to continue to increase over the years (Livestock statistic 2019). The higher demand for milk occurs as an effect of two major driving factors: (1) higher middle-class income and (2) the rise of awareness of the Indonesian population to consume milk. The increase of the dairy cattle population, mainly in West Java province, generated huge amounts of manure production and, consequently, impacted the environment, among others by the emissions of greenhouse gases (GHGE).

Life cycle assessment (LCA) is a widely acknowledged method to assess GHGE at dairy farms. This method measures all the GHGE along the production chain of milk, mostly up to the farm-gate. In the calculation of GHGE using LCA in the dairy sector, three main sources of emissions are distinguished: enteric fermentation (methane), manure management (nitrous oxide and methane), and feed production including cultivation, processing and transporting (carbon dioxide and nitrous oxide) (FAO 2018).

Manure management is one important contributor to GHGE related to dairy production. In smallholder dairy farms, a large variation of manure management systems exists (De Vries et al. 2019). The four most common manure management systems (MMSs) are: the practices of applied manure with or without treatment to the forage cultivation area, sold manure to the manure traders, used manure as a substrate for anaerobic digestion and discharged manure to the environment. In the case of smallholder dairy farms, in which vast amounts of manure is being produced, it is important to consider different MMSs in the calculation of GHGE. In addition, improving manure management can be a potential solution to reduce GHGE. Therefore, this study aimed to analyze GHGE associated with different manure management systems (MMSs) in smallholder dairy farms in Indonesia based on a cradle-to-farm gate approach.

Material and methods

The LCA study was performed at 32 smallholder dairy farms in the Lembang district, West Java, Indonesia. This district is the second-largest milk producing district in Indonesia, by producing 23% of national milk supply. We conducted farm surveys six times on a bimonthly basis from December 2017 till October 2018, to collect information about farm and manure management characteristics, and milk production. The 32 smallholder dairy farms were selected from the 300 dairy farmers that participated in the study of De Vries et al. (2017). To understand the association between manure management systems (MMSs) and GHGE, we first classified the 300 dairy farmers into one of the following MMSs: applied manure without manure treatment to forage cultivation area (DLA), sold manure to manure traders (SEL), used manure as a substrate for anaerobic digestion (ADS) and discharged manure to the environment (DIS).

The MMSs classification was based on the management of solid manure (i.e., when at least 40% of solid manure being collected), we classified the farm into one of the MMSs. The classification was based on solid manure only because the urine fraction is being discharged by all dairy farmers. We selected eight dairy farmers randomly per MMS from the long list of the 300 dairy farmers. After the start of the assessment, some farms changed the practices of MMS. Therefore, we ended up with an unequal number of dairy farmers per MMSs (DLA = 6, SEL=7, ADS = 10, DIS =9).

Following this, we collected the information related to the upstream and on-farm processes. The upstream processes included the production (cultivation and processing) and transportation of purchased feed, and production and transport of inorganic fertilizer including the energy used. Inventory data from upstream processes formation was collected from the interview with the dairy farmers and the dairy cooperative, and from literature. The on-farm processes included the enteric fermentation, manure management, and inorganic fertilizer application. Such information collected from direct measurement at each farm visit (i.e., feed intake of the animals and bodyweight of the animals), interview with the dairy farmers and literature. Specific questions related to manure management on farms were asked (i.e., the size of manure storage, proportion manure being collected, being used for land application, used for bio-digester, sold, and discharged). We also measured milk yield on-farm from each lactating animal at each farm visit. In addition, we collected feed and milk samples to determine the nutrient composition (DM, ash, protein, fat, and carbohydrate). The emission factors related to enteric fermentation and manure management were based on IPCC (2006). In the case of applied manure for forage cultivation, discharged manure, including discharged bio-digestate (the by-product of bio-digester), methane conversion factor (MCF) of the IPCC-category *daily spread* was used. For the used manure of bio-digester, MCF of the IPCC-category *anaerobic digester* was used. For sold manure, MCF of the IPCC-category *dry lot* was used. The estimate of CH_4 emissions from bio-digester also included biogas loss that is not used for cooking in households. The biogas loss was calculated by subtracting the biogas used for cooking from the biogas yield. The biogas yield was calculated based on the IRENA guideline (2016). Foregone emissions related to the production and combustion of LPG replaced by the biogas were subtracted from the total GHGE. In case of sold manure, we didn't correct for foregone emissions related to (inorganic) fertilizer application as in practice, (crop) farmers do currently not adapt their fertilization plan when manure is added. The emission factors for feed and inorganic fertilizer production were derived from the LEAP database (FAO, 2015). GHGE were summed based on the conversion factors, 1 for CO_2, 28 for CH_4, and 265 for N_2O. The functional unit used in this study is kg CO_2-eq per kg fat and protein corrected milk (FPCM), which expressed the greenhouse gas emission (GHGE) per kg FPCM. We compared the total GHGE and contribution of different processes to GHGE of four different MMSs by the Kruskal-Wallis and Dunn's posthoc test.

Results

The GHGE at Indonesian smallholder dairy farms ranged from 1.00 to 1.31 kg CO_2-eq/kg FPCM and differed between manure management systems (Table 1). DIS had the lowest GHGE compared to DLA, SEL and ADS. GHGE from enteric fermentation was on average 0.66 kg CO_2-eq/kg FPCM, from manure management 0.21 kg CO_2-eq/kg FPCM, from feed production 0.31 kg CO_2-eq/kg FPCM and from artificial fertilizer 0.01 kg CO_2-eq/kg FPCM. We compared contribution of different processes to GHGE and found that the contribution of manure management differed among manure management systems. DIS had the lowest GHGE (0.07 kg CO_2-eq/kg FPCM) and differed significantly from DLA (0.15 kg CO_2-eq/kg FPCM), SEL (0.40 kg CO_2-eq/kg FPCM), and ADS (0.20 kg CO_2-eq/kg FPCM). No significant different found between GHGE of MMS and other processes and no interaction found.

Table 1. Greenhouse gas emissions from milk production (GHGE) and the contribution of different processes (kg CO_2-eq/kg FPCM) at Indonesian smallholder dairy farms with four different manure management systems (MMSs) (means, SE).

MMSs	GHGE from different process				Total GHGE
	Enteric fermentation	Manure management	Feed production	Artificial fertilizer	
DLA	0.70 (0.03)	0.15b (0.01)	0.37 (0.01)	0.01 (0.002)	1.22a (0.12)
SEL	0.64 (0.01)	0.40c (0.01)	0.26 (0.03)	0.01 (0.003)	1.31b (0.11)
ADS	0.70 (0.06)	0.20b (0.03)	0.33 (0.04)	0.01 (0.002)	1.24ab (0.12)
DIS	0.62 (0.04)	0.07a (0.01)	0.26(0.03)	0.01(0.001)	1.00a (0.09)

DLA (applied manure without manure treatment to forage cultivation area), SEL (sold manure to manure traders), ADS (used manure as a substrate for anaerobic digestion, DIS (discharged manure to the environment)

Figure 1 shows the proportion of different processes to the total GHGE. On average, the contribution of the process to total GHGE was 57 % for enteric fermentation, 26% for feed production, 16 % for manure management processes, and 1% for fertilizer production.

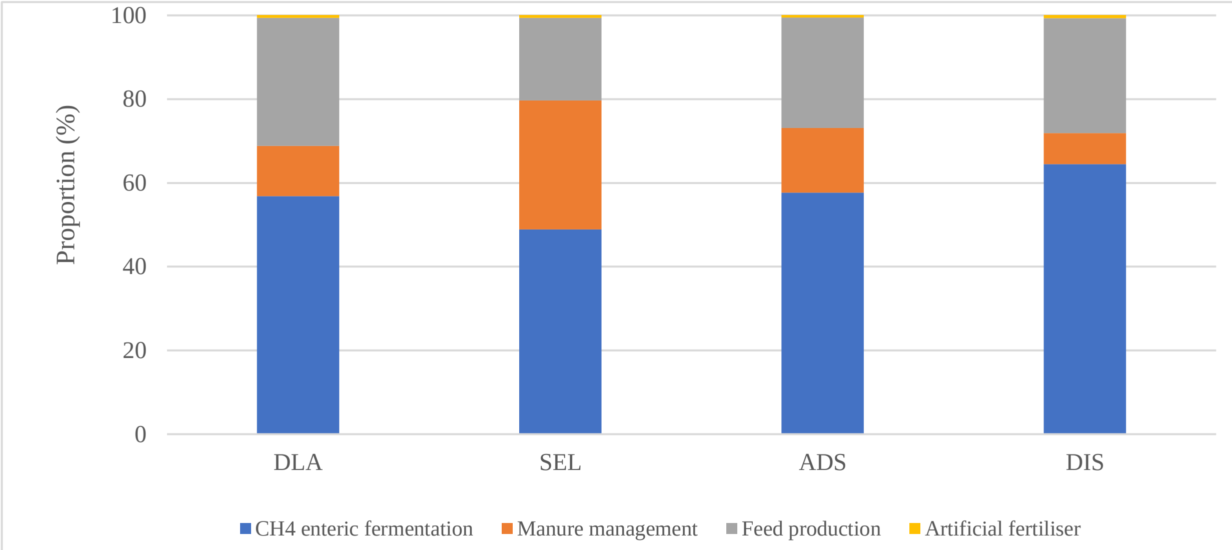

Figure 1. The proportion of different contributor to the GHGE.

Discussion

The GHGE in our study was lower than found in the study of de Vries et al. (2019), which was 1.5 CO_2-eq/FPCM, and lower than the GHGE of milk produced by smallholders in Southeast Asia, which was 2.4 kg CO_2-eq/FPCM (Opio et al. 2016). The difference was explained by differences in method of data collection (longitudinal vs cross sectional observations) and emission factors for manure management. The total GHGE differed among farming systems and the difference was associated with a difference in the contribution of manure management, showing the importance of MMSs to reduce GHGE. Improving manure management can be a potential strategy to reduce GHGE.

The relatively high emission of manure management processes in case of SEL results from the high emissions during manure storage systems at these farms. As manure is not used optimally, the replacement of (inorganic) fertilizer is negligible which offers room for improvement in terms of both nutrient use and GHGE. GHGE of ADS was relatively low because in this system manure is used as a source for anaerobic digestion in the bio-digester. However, 28% of the methane produced was lost from the digesters because production exceeded the energy requirements of farm households. The GHGE of the DIS system was relatively low because we used the MCF and N_2O emission factor of the IPCC-category of *daily spread*, which has a low emission factor for N_2O and CH_4. The selection of IPCC-category of *daily spread* is because the specific emission factor for discharged manure is not available. Although discharging manure results in the lowest GHGE, the nutrient losses of this system are high, causing N and P pollution at the regional level.

Conclusions

In this study we analyzed the association of GHGE with different manure management systems (MMSs) at 32 smallholder dairy farms. We found that the total GHGE differed among MMSs and DIS has the lowest GHGE compared to other systems. We concluded the importance of MMSs to reduce GHGE and improving manure management can be a potential strategy to reduce GHGE.

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Huge variation of environmental performance on dairy farms in Central Norway

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Abstract

The aim of this work was to calculate farm specific LCAs for milk-production on 200 dairy farms in Central Norway, where 185 farmed conventional and 15 according to organic standards. We assume that there are variations in environmental emission drivers between farms and therefore also variation in indicators. We think that information can be utilized to find management improvements on individual farms.

Farm specific data on inputs and production for the calendar years 2014 to 2016 were used. The LCAs were calculated for purchased products and on farm-emissions, including atmospheric deposition, biological nitrogen fixation, use of fertilizer and manure. The enteric methane emission from digestion was calculated for different animal groups. The functional unit was one kg energy-corrected milk (ECM) delivered at farm-gate.

For the 200 dairy farms there were huge variations of farm characteristics, environmental performance and economic outcome. On average, the organic farms produced milk with a lower carbon footprint (1.2 kg CO_2 eq./kg ECM) than the conventional ones (1.4 kg CO_2 eq./kg ECM). The organic farms had also a lower energy intensity (3.1 MJ/kg ECM) and nitrogen intensity (5.0 kg N/kg N) than their conventional colleagues (4.1 MJ/kg ECM and 6.9 kg N/kg N respectively). The contribution margin was better on the organic farms with 6.6 NOK/kg ECM compared to the conventional with 5.9 NOK/kg ECM. The average levels of the environmental indicators were comparable but slightly higher than findings in other international studies.

The current study proved that the FARMnor model allows to calculate LCAs for large number of individual farms. The results show that the environmental performance and economic outcome vary between farms. We recommend that farm specific LCA-results are used to unveil what needs to be changed for improving a farm's environmental performance.

Keywords: *LCA; greenhouse gas; sustainable farming; economic performance; organic farming; conventional farming*

Introduction

Values for different environmental impact categories of dairy milk and meat production can be found in databases or as results from LCA studies. Based on the study of 20 Norwegian dairy farms by Schueler er al. (2018), it can be expected that there is a huge variation in environmental indicators, such as GHG emission, among dairy farms. Based on ecoinvent 3.5 (Weidema et al. 2013), to produce 1 kg of fat and protein corrected milk (FPCM), 1.1 kg CO_2-eq. are emitted, 4.3 MJ energy needed (of this, 3.4 MJ non-renewable energy sources) and 1.7 m^2 agricultural area occupied. For modelled, representative dairy farms in Norway, Roer et al. (2013), calculated values of 1.5 kg CO_2-eq., 4.2 MJ non-renewable energy sources and 1.9 m^2 per kg energy corrected milk

(ECM). Despite average GWP-values for Norwegian milk production, variation between dairy farms within a country can be expected. Out of 29 LCA-studies for milk production, reviewed by Baldini et al. (2017), only five considered a large number of farms. To "support the objective of reducing the carbon intensity of the dairy and beef sectors of Irish agriculture" (Murphy et al. 2013, p. 427), a decision support tool, named "Carbon Navigator", was developed. To be able to calculate LCAs for many different farms, it is necessary to have access to farm data and to ease the process of data inventory, farm modelling and impact calculation. This is enabled in the Carbon Navigator tool by being available as online tool including the connected databases. Thus, farmers and their advisors, can calculate the actual environmental impact and look for improvements for reduced emissions and improved financial performance. Comparable to this approach, we updated the FARMnor model (Schueler 2019), to be able to conduct LCAs for some hundred dairy farms in Norway.
The objective of the current study was to calculate farm specific LCAs for milk-production on 200 dairy farms in Central Norway. We assumed that the variation in environmental performance on Norwegian Dairy farms is high and can differ considerably from the ecoinvent or the average value found by Roer et al. (2013). Farm-specific data are more useful to identify parts than needs improvement on a farm than analysis based on standardised data.

Material and methods

The environmental performance of 200 farms in Central Norway were calculated for milk and meat delivered at farm gate, using the FARMnor model (Schueler 2019) to conduct a Life Cycle Assessment (LCA), using ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b) as framework. In FARMnor, the environmental performance is calculated in a cradle to farm-gate life cycle assessment approach. The basic flows in hierarchically structured model are shown in Figure 1. Inventory flows and emissions from external inputs to the farm as import diesel, electricity, fertilizer, lime, silage foil, chemicals, machinery, buildings and feed ingredients from other countries are approximated, using the ecoinvent life cycle inventory (LCI) database (Frischknecht et al. 2005). Methane emissions were assessed with a Tier 2 approach, based on the specific algorithms for Norwegian conditions from Storlien et al. (2014), while manure storage emissions were calculated on IPCC (2019). For N-inputs from mineral fertilizer (emission factor 1, EF1), organic fertilizers (EF2), and crop residues (EF3) the same emission factor, named EF1 in Paustian et al. (2006), was used. Harvested yields were calculated based on the energy demand for milk and meat production as well as estimated losses based on Steinshamn et al. (2004).
Farm specific data on inputs and production for the years 2014 to 2016, collected from the advisory service of the dairy cooperative TINE, were used. The FARMnor model was improved to be able to automatically read data for each farm and to calculate the environmental performance.

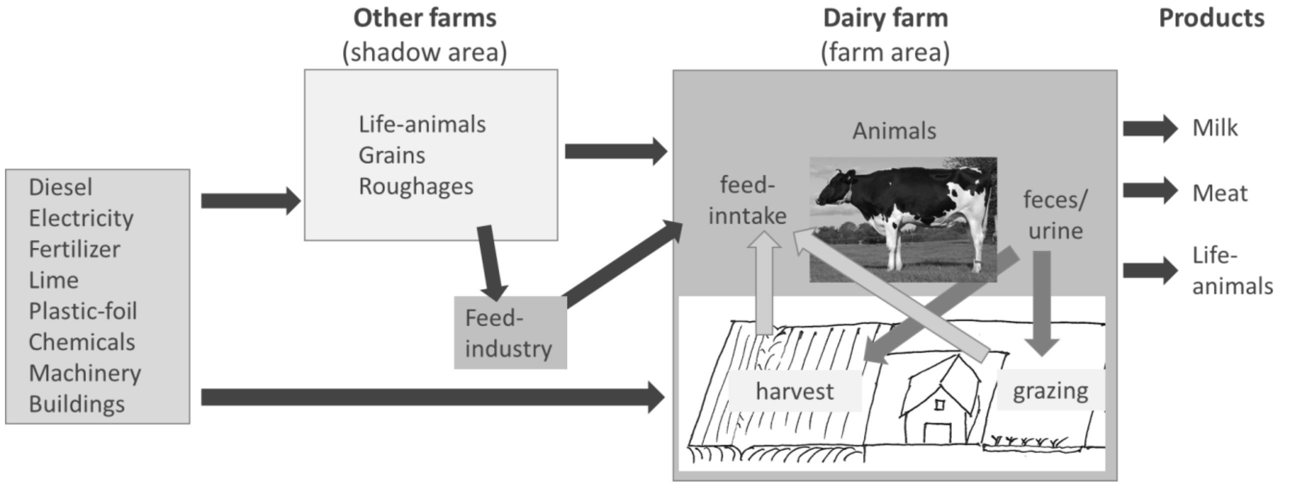

Figure 1. Basic flows, inputs, areas and products in the FARMnor model

The environmental indicators and nitrogen cost from farmed area were calculated based on atmospheric deposition, biological nitrogen fixation, use of fertilizer and manure (Koesling et al. 2017a). The methane emission from digestion was calculated for different animal groups based on the feed used, weight gain and the milk yield for dairy cows. Emissions linked to the production of purchased inputs were calculated using ecoinvent and the amount of the inputs based on the accounting data and transportation distance to the farms. There were little differences between the conventional and organic farms with respect to farm characteristics (Table 1). But because there were significant differences for most of the environmental indicators, we decided to present conventional and organic farms separately.

The functional unit (FU) was 2.78 MJ metabolizable energy, which is equivalent to 1.0 kg of ECM or 0.42 kg of meat or any combination of milk and meat amounting to 2.78 MJ (Koesling et al. 2017b). To ease the reading, we use the term FU in this work for the functional unit one kg energy-corrected milk (ECM). Both milk and meat are measured as delivered at farm-gate.

Results

Due to differences in farm characteristics and environmental and economic indicators, the data for the organic and conventional farming systems are presented separately, see Table 1.

For farm area and number of dairy cows per farm, there was on average little difference between the two farming systems. Despite small differences for the average values, the variation within farming system were higher than the difference of the average between the groups. For the dairy farm area, the milk quota, the number of dairy cows and all cattle, the coefficient of variation was between 50% and 60%, for both conventional and organic farms. However, the conventional had higher stocking density, higher milk production per cow, supplemented the cows with more concentrates, had higher forage yield than the organic farmers and needed less area per litre of milk delivered.

On average 1.2 kg CO_2 equivalents (kg CO_2 eq./kg ECM; GWP 100 years) were calculated to produce 1 kg milk delivered on organic farms, 1.4 on conventional. The organic farms also produced milk with lower energy intensity (3.1 MJ/kg ECM) and nitrogen intensity (5.0 kg N/kg N) than their conventional colleagues (4.1 MJ/kg ECM and 6.9 kg N/kg N respectively). The contribution margin was on average higher on organic farms than on the conventional (6.6 vs. 5.9 NOK/kg ECM). Without organic farming payments, the profit did not differ among the faming systems.

Shadow area includes area for purchased concentrates, roughages and live animals which is needed for the production level of milk and meat on the farm. The shadow area needed on other farms to

produce the purchased concentrates in relation to the area of the dairy farm was about 0.4 ha for each ha total area needed for dairy production in both farming systems. This indicates the level of dependency dairy farmers in Central Norway have on feed import.
Organic farms produced milk with a lower global warming potential and energy- and nitrogen-intensity and had a higher contribution margin. The coefficient of variation varied for the environmental and economic indicators between 11% and 26%.

Table 1. Farm characteristics, environmental and economic indicators

		Conventional farms (n = 185)		**Organic farms** (n = 15)	
	Unit	Mean	CV[d]	Mean	CV
Farm characteristics					
Dairy farm area	ha	46.2	58.0	46.5	55.6
Milk quota	1000 l	282	54.9	253	55.6
Dairy cows	LU[a]	36.5	51.3	35.4	53.9
Cattle	LU	57.4	57.8	49.7	55.6
Stocking rate	LU/ha	1.3	26.4	1.1	34.9
Milk production	kg ECM[b]/cow	8400	10.0	7939	10.2
Milk production	m^2/kg ECM[b] (total area)	2.96	22.2	3.58	13.5
Net energy intake of concentrates	MJ/cow	19150	14.2	15350	15.5
Net energy intake pasture, cows	MJ/MJ total	0.07	75.1	0.11	44.7
Replacement-rate cows	proportion	0.45	22.6	0.43	18.9
Treatment for mastitis	proportion	0.21	65.3	0.16	60.4
Net energy yield grassland	MJ/ha	34530	23.1	28850	17.9
Environmental and economic indicators					
Global warming potential[e]	kg CO_2-eq./kg ECM	1.36	16.8	**1.22	15.1
Energy intensity[e]	MJ/kg ECM	4.10	22.4	***3.14	10.9
Nitrogen intensity	kg N/kg N	6.91	18.5	***5.04	17.2
Concentrate area of total area	ha/ha	0.41	17.1	0.38	14.8
Total shadow area of total area	ha/ha	0.45	18.4	0.46	26.2
Contribution margin	NOK[c]/kg ECM	5.89	13.9	***6.60	14.7

[a] LU = Livestock unit; 1 LU equals the corresponding number of animals with an annual feed intake of 42000 MJ NEL (net energy for lactation)
[b] ECM = Energy Corrected Milk
[c] Exchange rate August 2020: 11 NOK ≈ 1 €
[d] Coefficient of variation, percent
[e] Both global warming potential and energy intensity are presented without infrastructure.
Mean numbers for indicators marked with asterisks show that the mean scores of conventional and organic farmers are significantly different at $**P < 0.01$ and $***P < 0.001$, based on analysis of variance using GLM procedure in SAS (SAS Institute 2011) with farming system as fixed effect.

Discussion

We found high variation of environmental performance and nitrogen utilisation. Conventional farms had a higher production of milk per farm area and total area, which is in line with the results of a study by Ponti et al. (2012) in Northern Europe. On the other side, organic farms produced milk on average with less environmental impact. The results are comparable to results found in literature (Baldini et al. 2017), but somehow higher. This may be due to lower yields and the long winter periods when dairy farmers need to base their feeding on preserved forages as grazing is not possible. There was high variation in the environmental indicators and in economic performance within both farming systems, as indicated by the coefficient of variation. This variation may be due to difference in intensity of use of farm management factors. We will further analyse the data and test the relationship between environmental and economic performance to management factors. This is to assess if there are factors associated with both improved profit and environmental performance.

Conclusions

The results show that there is a variation in the environmental performance of dairy farms in Norway. This information is lost, when only average values are presented or the data from ecoinvent are used. Despite that conventional and organic farms had on average about the same farm area and number of dairy cows, the environmental performance indicators differ between conventional and organic dairy farms, with exception of the proportion of concentrate and shadow area of total area. The FARMnor model allows to calculate the environmental performance for large number of farms based on recorded data. Based on a farm specific LCA and economic results, it is possible to describe the performance of individual farms and, based on the findings, to elaborate strategies for more environmentally friendly and profitable production. An advantage for farmers is that the model makes it possible to compare the current situation with alternative management on individual farms. The high variation of indicators found underline that the use of farm specific data and LCA-results are crucial to find farm specific improvements.
Calculating LCAs for a high number of farms can be used to describe the environmental performance of dairy production on a regional level or for farms. In the next step, the results can be used to identify means to produce milk with less GHG and to evaluate policy measures. The work has demonstrated that the updated version of FARMnor allows to calculate farm-specific LCAs for a large number of commercial dairy-farms based on their economic and advisory data, which is comparable to the approach used in Ireland (Murphy et al. 2013). Most of the indicators for environmental performance differed between organic and conventional farms, with organic farming having lower global warming potential, lower energy and nitrogen intensity and a higher contribution margin. Thus, using average values for dairy farming, as done in ecoinvent, is not taking into account differences between conventional and organic dairy farming.

Acknowledgements

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Abstract code: 222

Contributions of methane and nitrous oxide from pasture-based beef production systems to global warming under multiple scenarios and calculation methods

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Abstract

Although beef production systems are thought to contribute heavily to anthropogenic climate change, most studies to derive such a conclusion are calculated under the GWP_{100} impact assessment method, of which snapshot carbon footprint does not capture the long-term climate impact of short-lived greenhouse gases in an informative manner. In order to evaluate analytical consequences of accounting, and not accounting, for methane's relatively brief atmospheric residency compared to other greenhouse gases, a 100-year virtual experiment was conducted using high-resolution data from the North Wyke Farm Platform grazing trail in the UK. A 9 × 10 full factorial design encompassed various combinations of methane (Y_m: 4.5-8.5) and nitrous oxide ($EF_{3(PRP)}$: 0.4-4.0) emission factors, and global warming potentials were computed under three impact assessment methods. In addition to time-integrated metrics reported in the forms of GWP_{100} and GTP_{100}, time-specific climate impacts reported by GWP* were used to obtain an insight into how the relative importance of each gas dynamically changes over time. Under GWP_{100}, methane was found to be a driving factor in total emissions across all 90 scenarios, whilst under GTP_{100}, nitrous oxide was more dominant due to the relatively low impact-weight bestowed upon methane. Under GWP*, methane played a critical role in the overall carbon footprint for the first 20 years, but only a lesser role thereafter when it had largely decomposed. As nations around the world strive to reduce atmospheric greenhouse gas levels as far and as quickly as possible, R&D efforts should be targeted and prioritised. The results presented herein suggest that, for ruminant systems, focussing solely on methane may not be a prudent strategy, as nitrous oxide can play a far greater role in anthropogenic climate change depending on the scientific assumption behind the derivation of global warming potential.

Keywords: *beef; GWP*; IPCC; methane; nitrous oxide*

Introduction

Livestock systems have high degrees of uncertainties associated with biological processes that underpin production. In the presence of these uncertainties, point-estimates provided by life cycle assessment (LCA) models may not be sufficiently robust to comparatively assess differing farming strategies (McAuliffe et al., 2018). Furthermore, most LCA-based indicators currently used to evaluate climate impacts are single emission metrics to aggregate multiple greenhouse gases (GHGs), which can obscure temporal details of the climate response to emissions of different gases (Lynch, 2019). To address these issues, this paper explores the effect of emission factor uncertainty on carbon dioxide-equivalent (CO_2-eq) footprints reported under three impact assessment methods. The first is 100-year Global Warming Potential (GWP_{100}), the most common Intergovernmental Panel on Climate

Change (IPCC) calculation method which can be considered as the default approach, whilst the second is 100-year Global Temperature Change Potential (GTP_{100}). These two calculation methods differ significantly in their treatment of methane relative to nitrous oxide, and recent United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) recommendations suggest using these two metrics together to report the shorter- (GWP_{100}) and longer- (GTP_{100}) term impacts of a given GHG footprint (Jolliet *et al.*, 2018). Our third approach, GWP*, is a more recently developed dynamic metric, used here to illustrate the time-dependent impacts of different ratios of methane and nitrous oxide emitted. While GWP* provides similar insight to the dual metric approach using both GWP_{100} and GTP_{100}, it offers a mathematically simpler way of handling the GHG dynamics and at the same time eliminates the need to predefine the timeframe of interest (Lynch *et al.*, 2020).

Material and methods

Inventory data were collated from the permanent pasture beef enterprise on the North Wyke Farm Platform, a farm-scale grazing trial in Devon, UK, from 2016-2017. The system boundary included both breeding and finishing herds. The functional unit was set as 1 kg liveweight departing the farmgate. On-farm emissions were calculated using a modified IPCC Tier 2 approach (McAuliffe *et al.*, 2018). Emissions associated with background processes, such as field activities and the production of small quantities of supplementary feeds, were sourced from the LCA databases *ecoinvent* and *Agri-footprint*. A 9 × 10 factorial virtual experiment was designed to include various combinations of methane (Y_m: 4.5-8.5, in steps of 0.5) and nitrous oxide ($EF_{3(PRP)}$: 0.4-4.0, in steps of 0.4) emission factors, of which values have previously been shown to be the most important drivers of emissions uncertainty in beef production systems (Takahashi *et al.*, 2019). Carbon footprints were calculated for each scenario under GWP_{100} and GTP_{100} using the IPCC 5th Assessment Report methodology. The two impact assessment methods adopt CO_2-eq conversion coefficients of 28 (GWP_{100}) / 4 (GTP_{100}) for methane and 265 (GWP_{100}) / 234 (GTP_{100}) for nitrous oxide, respectively.

To further explore temporal dynamics of different gases, GWP* was additionally calculated for a single "pulse footprint", or the lifecycle impacts of emissions from a single production cycle on global warming potentials, following the method outlined in Cain *et al.* (2019). A pulse emission (rather than continuous emissions) was assumed to make the results directly comparable to GWP_{100} and GTP_{100}, which can only represent single production cycle. The GWP* analysis was carried out using a subset of the factorial design described above, composed of the middle-value (baseline) combination (Y_m = 6.5, EF_3 = 0.02) and the four corner (extreme) combinations of Y_m and EF_3, over a 100-year period following the emission. GWP* was reported in the unit of CO_2-warming-equivalent (CO_2-w.e.), where cumulative CO_2-w.e. over time corresponds directly to a contribution to global temperature change. The conventional GWP100 weighting was applied to longer-lived gases (CO_2 and nitrous oxide in the present case) while the contribution of methane was adjusted for the time elapsed since the emission according to a time-response function depicting its decomposition process.

Results

Emission factors and choice of impact method were both shown to affect reported climate impacts considerably (**Figure 1**). Under GWP_{100}, methane arising from enteric fermentation accounted for 39.9% of total emissions in the baseline scenario, whilst under GTP_{100}, it only accounted for 9.1%. Under GWP_{100}, reductions in emission factors equally resulted in lower reported footprints; under GTP_{100}, however, a smaller Y_m value did not necessarily produce a notable reduction in the overall footprint. $EF_{3(PRP)}$ had a comparable impact on the output metric under both methods.

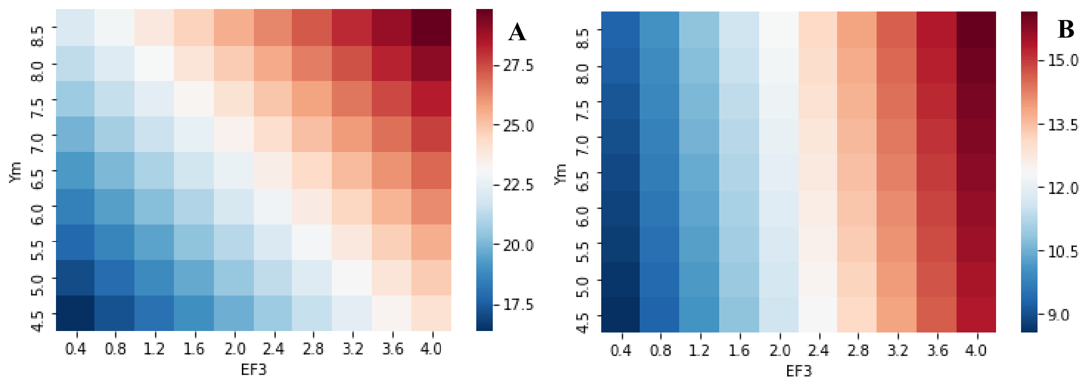

*Figure 1. Heatmaps of both global warming potential (**A**) and global temperature change potential (**B**). Values reported as kg CO_2-eq/kg liveweight beef cattle at the farmgate.*

The cumulative CO_2-w.e. contribution from CO_2 and nitrous oxide and was constant (by definition) once the initial emission was made, while methane emissions started with a large CO_2-w.e. value and then declined post-decomposition (**Figure 2A**). Combining the cumulative CO_2-w.e. over time across all three gases, initial carbon footprints (first 20 years) were large and more driven by the value of Y_m than EF_3. In contrast, EF_3 largely determined the reduction in cumulative CO_2-w.e. beyond this time frame, with Y_m only playing a minor role (**Figure 2B**).

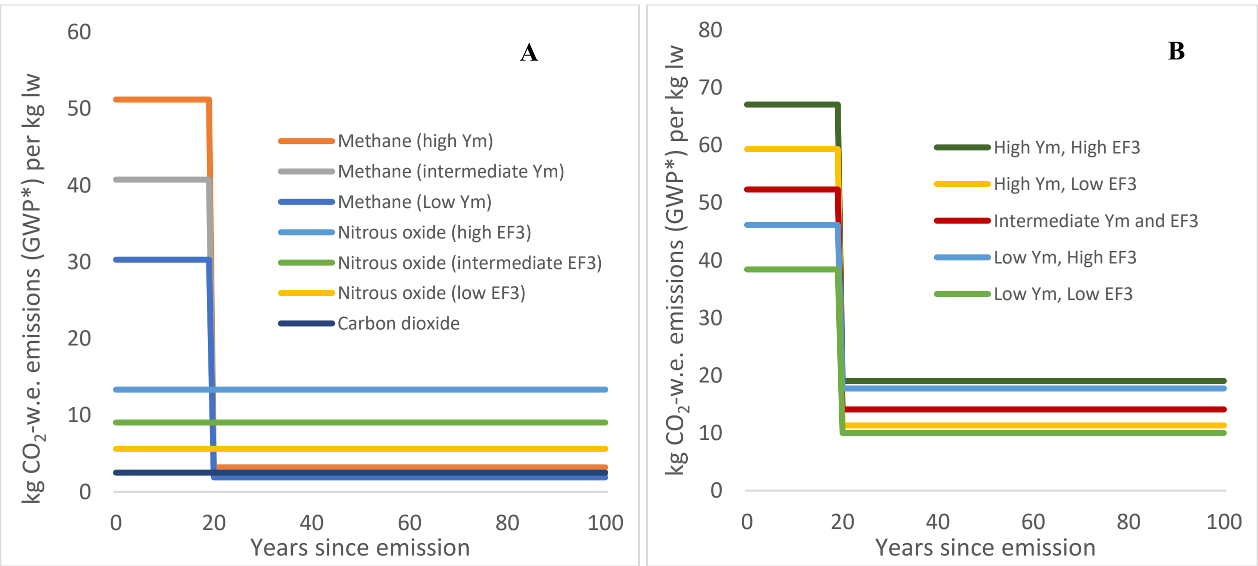

Figure 2. GWP CO_2-warming-equivalent emissions of individual gases (**A**) and total footprints (**B**)*

Discussion

The results above highlight the sensitivity of carbon footprints to the choice of metric to evaluate the environmental performance of farming systems. Under GWP_{100}, methane is by far the most dominant gas within ruminant systems; however, the valuation of methane varies greatly between different metrics, thus relying on a single system obscures vital information about other heat-trapping gases. Although this issue has been highlighted before (Reisinger and Ledgard, 2013; Lynch, 2019), the majority of climate impact studies on agri-food systems fail to acknowledge these caveats.

The different approach to carbon dioxide equivalence represented by GWP* can elucidate the dynamic differences between short- and long-lived gases and simultaneously demonstrate why different metrics can result in such different footprints. For example, **Figure 2** offers an explanation as to why the GWP_{100} and GTP_{100} footprints shown in **Figure 1** differ so greatly. As a time-integrated metric, the GWP_{100} footprints reflect a strong weighting on methane following its large impact over the first few decades following the pulse emission. For GTP_{100}, which is an end-point metric after 100 years, the effect of Y_m (and hence methane) gains relatively little representation as there is little warming remaining from the original emission at the timepoint of interest. From nitrous oxide, on the other hand, there is still a significant amount of ongoing warming under GTP_{100} at the 100^{th} year, and thus the relative importance of EF_3 is substantially amplified.

Further metrics could also be explored. For example, the IPCC 5^{th} Assessment Report provides values for GWP_{20}, and it has been suggested that this can be used for sensitivity analysis on "very short-term climate change effects" (Jolliet *et al*., 2020). Dynamic impacts could also be revealed by other quantitative methods, for example by exploring GTP at multiple time horizons or simply plotting the warming from each emission across time. Nonetheless, GWP* provides a straightforward illustration of the warming dynamics of each gas without requiring a predetermined temporal boundary or more involved mathematical modelling. GWP* can also contribute to a deeper understanding of the roles of different GHGs in overall global warming attributable to livestock production systems, which are biologically complex and thus difficult to holistically represent in deterministic models commonly implemented by LCA studies. An example of such applications includes the identification of the optimal chronological order under which R&D investments for reduction in different gases should be made (Pierrehumbert, 2014).

Conclusions

The reporting of methane's climate impacts in the unit of CO_2-eq was shown to be highly dependent on the impact assessment framework, and its relative importance in carbon footprints of beef production systems was shown to decrease substantially when using GTP_{100} rather than GWP_{100}. Meanwhile, nitrous oxide was shown to play a key role under all metrics (GWP_{100}, GTP_{100} and GWP*), suggesting that an excessive policy focus on methane to the detriment of nitrous oxide may result in a suboptimal intervention strategy to mitigate climate impacts associated with ruminant production. Readily implementable climate indicators based on single weightings between different GHGs cannot represent the dynamic impacts across multiple time scales and therefore cannot always provide long-term policy implications. Alternative, temporal calculation methods such as GWP* can be employed for these specific purposes.

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Abstract code: 103

Allocation between milk and meat in dairy LCA: critical discussion of the International Dairy Federation's standard methodology

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Abstract

Purpose Dairy products are of high importance for the food sector and LCA of cow milk is among the most common product LCAs. Different approaches have been used to deal with multifunctionality in dairy systems, like economic allocation, bio-physical allocation or system expansion, which makes the results hard to compare. This contribution critically evaluates the default allocation method between milk and meat proposed by the International Dairy Federation.

Methods The International Dairy Federation (IDF) proposed to use a physical allocation method to allocate environmental impacts between milk and meat in the dairy production. A linear approximation is used based on the ratio between the live weight of sold animals and the fat and protein corrected milk (FPCM). Only animals destined to the beef market are included, while heifers sold to another dairy are excluded. This linear relationship is a simplified approximation derived from a more complex model.

Results and discussion Two aspects can lead to biased or incomplete results depending on the system investigated: 1) the linear approximation and 2) the exclusion of heifers sold to another dairy. Since allocation is non-linear by definition, a linear relationship can approximate an allocation factor only in a very limited range. If the beef to milk ratio (BMR) is <3%, the linear approximation provides reasonable estimates. However, in more extensive dairy systems and by using multi-purpose cattle breeds, BMR values can be much higher. In addition all animals leaving the product system have to be considered.

We propose to calculate allocation factors based on the marginal net energy investments for 1 kg FCPM and 1 kg of average life weight gain, yielding values of 3.1 MJ/kg FPCM and 15-18 MJ/kg live weight.

Conclusions The allocation method between milk and meat in the dairy production proposed by IDF can be recommended, if BMR<3% and the whole dairy sector is investigated. For BMR>3%, alternative methods should be used to avoid underestimation of the environmental impacts of milk. If dairy production of a farm is analysed, also the heifers sold to other farms should be included in the outputs.

Keywords: *Allocation, dairy production, milk, meat*

Introduction

Dairy products are of high importance for the food sector and LCA of cow milk is among the most common product LCAs. Multifunctionality is an important issue in this context, since milk is inherently linked to co-products such as beef, leather, horn, or manure. Different approaches have been used to deal with multifunctionality in dairy systems, like economic allocation, bio-physical allocation or system expansion, which makes the results hard to compare. In order to standardize allocation in dairy LCA, the International Dairy Federation (IDF) has proposed a standard allocation method (IDF, 2015), which is now widely used in the LCA community. In this contribution, this method is critically evaluated, since in some cases the results can be strongly biased or incomplete.

IDF's recommended allocation

IDF (2015) has proposed to use a physical allocation method to allocate environmental impacts between milk and meat in the dairy production:

$$AF_{milk} = 1 - 6.04\,BMR \qquad (1)$$

where

AF_{milk} = allocation factor for milk [%]

$BMR = M_{meat}/M_{milk}$ is the ratio between the live weight of sold animals (M_{meat}, including bull calves and culled mature animals) and the fat and protein corrected milk (FPCM) (M_{milk}). M_{meat} includes only animals destined to the beef market and excludes heifers sold for another dairy.

This linear relationship was derived from the study of Thoma *et al*. (2013) on 531 US dairy farms as a proxy for a more complex relationship. It is also used in the product category rules of the EU for dairy products (EU, 2018), so it is a common methodology used in numerous LCA studies.

Discussion of the recommendation

According to ISO 14040/44 a physical allocation method is preferable to the economic allocation, which is also widely used. The main advantage of using a physical allocation method are its constancy in time and in different contexts because prices are volatile and differ between countries, regions and contexts. Therefore, we support the choice of this physical allocation approach.

However, we see two problems with using Eq. (1) for allocation between milk and meat: 1) The linear approximation, and 2) the exclusion of heifers sold to another dairy.

Linear approximation: By principle, a linear relationship can approximate an allocation factor only in a very limited range of values. An allocation factor is calculated from a ratio, and therefore the function is not linear but hyperbolic. Using Eq. (1) with a BMR of 0.165 gives an allocation to milk of 0, higher values result even in negative allocation factors, which obviously makes no sense.

Excluding heifers: Heifers sold to another dairy should be excluded, according to IDF (2015). This was a reasonable choice in the original study, covering the whole US dairy sector (Thoma *et al*., 2013). However, if the system boundary is a single farm, these heifers should be considered, as they are an output of the system investigated. We argue that these animals should be considered in the same way as animal destined to the beef market, possibly with different factors for NE_{heifer}. Ignoring these animals is not consistent with the ISO standards, as these animals are outputs with a value. In general, all animals leaving the system that are further used as dairy cows, for fattening or directly slaughtered, should be included as outputs. If heifers are purchased from another dairy to replace dairy cows, they are counted as inputs and their respective environmental impacts need to be considered.

The situation is different for animals that die or have to be killed but cannot be used neither for dairy production nor for beef production. In this case, these animals must be considered as losses with no positive economic value. Furthermore, replacement calves used on the same farm stay within the system and therefore are not considered as outputs.

Alternative allocation method

Here we propose an alternative allocation method, based on physical principles, but remedying the weaknesses of Eq. (1). It is based on the net energy needed to produce milk and to build up the body mass. In Thoma *et al*. (2013) the dry matter intake of farm-specific rations needed to provide the net energy for milk or growth was used as the basis for allocation; however, net energy requirement alone can effectively, and more simply reflect the biophysical relationships and are also the basis for the calculation of enteric methane emissions. Allocation based on net energy is calculated as:

$$AF_{milk} = \frac{NE_{milk} * M_{milk}}{NE_{milk} * M_{milk} + NE_{meat} * M_{meat}} \quad (2)$$

where

NE_{milk} = net energy needed to produce 1 kg of FPCM and
NE_{meat} = net energy needed to produce 1 kg body weight (live weight) and
M_{milk} and M_{meat} = the production of milk and meat (inclusive of animals sold as replacement to other dairies) at the enterprise (kg).

We use the equations 10.3 (for pregnancy), 10.6 (for growth) and 10.8 (for lactation) from IPCC (2019) and the following rules:

- Only the net energy to produce milk and body mass (net energy for growth) is considered. Net energy for maintenance and for activity is ignored, which implicitly means that it is allocated according to the same ratio as the milk and meat production.
- Net energy for pregnancy is needed for the growth of the calf. This energy is accounted for as building of the body mass before birth.
- Different coefficients are applied for the growth of dairy heifers and of female and male fattening animals.

Net energy for milk production depends on the fat content, with a standard fat content of 4% we get NE_{milk} = 3.1 MJ/kg FPCM. Net energy for growth depends a.o. on the age and gender of the animal, the body weight, and daily weight gain. To calculate it, scenarios for the dairy herd are defined with following assumptions: 3 lactations per cow, duration of pregnancy of 285 days, weight of calf at birth 40kg, mature dairy cow 650 kg, sales weight for fattening cattle at slaughtering 600 kg. The four calves born (assuming 50% females and 50% males) would have the following destination: one calf is used to replace the dairy cow, 5% is considered as loss, the rest can be either sold after birth, or fattened on the farm. For the animals sold we define three scenarios (Table 1). Taking the average of all three scenarios results in 16.0 MJ/kg BW. This value could be used as default, if the exact composition of the herd is not known. NE_{milk} and NE_{meat} are independent of the level of milk yield.

Table1: Use of calves and NE for growth in 3 scenarios. BW = body weight (live weight)

Scenario	Unit	A) Calves sold after birth	B) Calves fattened	C) Female calves sold as heifers, male calves fattened
Replacement	#	1	1	1
Loss (5%)	#	0.15	0.15	0.15
Sold after birth	#	1.85	0	0
Female heifers	#	0	0	0.425
Females fattened	#	0	0.425	0
Males fattened	#	0	1.425	1.425
Total	#	3	3	3
Total output	kg BW	724	1760	1675
NE_{meat}	MJ/kg BW	18.1	14.9	15.0
NE_{meat} (average)	MJ/kg BW		16.0	

Comparing to the original source of Thoma *et al*. (2013) reveals that most values were in the range BMR<3% and all values were <7%. Up to BMR of 3% the approximation gives reasonable estimates. We used this formula in a Swiss case study, where the BMR were between 4 and 12% (Zumwald et al., 2018). This study investigated dairy farms, but the whole bovine sector was included (cows, calves, heifers and beef cattle). It became clear that the Eq. (1) is not applicable and would lead to a significant underestimation of the environmental impacts of milk (Figure 1).

If we use the above scenarios and three levels of milk yield (3000, 7000, 10000 kg/cow/year, roughly representing the global average, EU average, and US average), we find that BMR values >3% are likely to occur (Table 2), depending on the production system and the exact boundaries defined (farm, sector, dairy cattle or all bovines). This is particularly the case, if the calves are grown up at the farm.

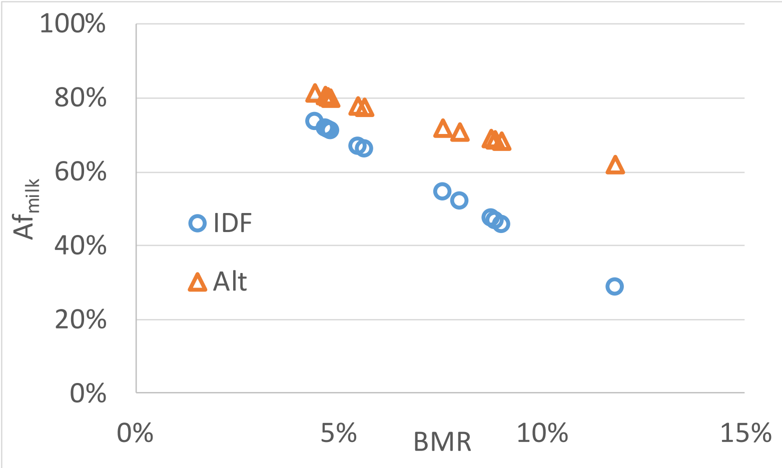

Figure 2: Comparison of the allocation factors for milk (AF_{milk}) with the formula from IDF (2015) and the alternative formula (Alt) for 12 Swiss dairy farms.

Table 2: BMR values for three scenarios (see Table 1) and three levels of milk yield.

	Milk yield [kg FPCM/cow/year]		
Scenario	3000	7000	10000
A) Calves are sold after birth	8.0%	3.4%	2.4%
B) Calves fattened	19.6%	8.4%	5.9%
C) Female calves sold as heifers, male calves fattened	18.6%	8.0%	5.6%

Using the described procedure, the allocation factors can be easily adjusted to the actual situation. The method considers only net energy, so it is well suited for energy-limited conditions. Including protein needs in addition to net energy could be a next development step to make the allocation more robust also in protein-limited conditions.

Conclusions

The allocation method between milk and meat in the dairy production proposed by IDF (2015) should be used with caution or in a adapted version: It is recommended to use Eq. (2) instead of Eq. (1), i.e. to calculate a ratio of the net energy needed to produce the milk and to build up the body mass instead of the linear approximation, as soon as BMR>3%. For the net energy needed, the following default values can be used: NE_{milk} = 3.1 MJ/kg FPCM and NE_{meat} = 16.0 MJ/kg BW. It is recommended to include also heifers leaving the system boundary in M_{meat}, rather than ignoring them.

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Abstract code: 123

Life Cycle Sustainability Assessment of beef production in Germany based on a farm level optimization model

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Abstract

Purpose

Beef production provides high quality protein for human consumption but is also associated with various environmental impacts. This study assesses the environmental, social and economic performances of a typical system for beef production in Germany, from cradle to farm gate.

Methods

Life Cycle Sustainability Assessment is applied by using the single farm optimization model FarmDyn, combined with extensive sensitivity analysis based on Latin Hypercube sampling and a statistical meta-model.

Results and discussion

Results expressed per kg of meat (as carcass weight) suggest that fodder production, the provision of inputs and enteric fermentation are major sources of GHG emissions. As for the financial performance, the provision of maize silage and bull calves represent the largest share of the variable costs. The system assessed consumes more protein than it delivers at the farm gate. The highest contribution to the on farm workload are the work spend on fields for fodder production and the daily routine with the animals (feeding and observation). The sensitivity analysis reveals that the most influential parameters in the environmental performance are the age at slaughter and the yield of the maize used as fodder crop.

Conclusions

A potential trade-off between feed to food conversion and global warming potential is identified. The same method will be applied to compare multiple beef production systems in the German context.

Keywords: *beef; LCA; sensitivity analysis; optimization model; farm model*

Introduction

Beef production is associated with various environmental impacts, such as those associated with greenhouse gas (GHG) emissions. The environmental performance of beef production systems is often analyzed through Life Cycle Assessment (LCA) (De Vries et al. 2015). However, a holistic assessment considering the environmental, economic and social dimensions of sustainability is still missing. In this study, the single farm optimization model FarmDyn (Kuhn et al. 2020) is applied to carry out a Life Cycle Sustainability Assessment (LCSA) of a typical beef production system in Germany, considering uncertainty in model parameters through a large-scale sensitivity analysis. The results can inform decision-makers about options towards more efficient and sustainable beef production systems in Germany.

Material and methods

The LCSA is carried out for beef production over a one-year period in two German farms, namely a dairy farm (F1) selling bull calves to be fattened on a second farm (F2) as young bulls. The Functional Unit (FU) is defined as one kg beef meat from young bulls (as carcass weight) delivered at the farm gate. The system encompasses the following processes: crop cultivation, manure management, feeding, and animal transport between farms. The system boundaries include cultivation of silage maize, grasslands and cereals for animal feed, as well as the production and transport of the fertilizers and pesticides used in each farm.

The two farms are defined based on data from the International Farm Comparison Network (Hemme 2000) and the Agri benchmark Network (Deblitz 2010). It is assumed that F1 has a herd of 110 dairy cows and 99 ha of land. It sells bull calves to be fattened in F2, which manages 70 ha of land and sells 283 finished bulls at the age of 18 months. F1 is located in Southern Germany, while F2 is located in the Northwestern part of the country. The LCSA includes the transport by lorry (34 t capacity) of the bull calves from the dairy farm F1 to the fattening farm F2 over an average distance of 600 km. Economic allocation is applied to distribute emissions and associated impacts among the co-products milk, calves and culled cow in F1**.** Cash-crops fulfill another function in the market and are therefore excluded from the system boundaries.

Life Cycle Inventory data is obtained from the economically optimized production program of F1 and F2 of FarmDyn, including bio-physical processes and economic flows at the farm level. Parameters for FarmDyn are defined based on data from the Kuratorium für Technik und Bauwesen in Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), capturing a typical farm management (Achilles et al. 2016). The farm optimization is restricted by farm endowments (land, labor, stable places). Environmental impacts are thus calculated for the optimized farm management plan, which refers to the following sub-stages: manure management, enteric fermentation, and fodder production. Emissions are estimated according to IPCC (2006), EMEP (2016) and Agroscope (Bystricky and Nemecek 2015). Up-stream emissions from the provision of major farm inputs are taken from average production processes in Ecoinvent version 3.6 (Wernet et al. 2016). These include seeds, fertilizers, plant protection products, imported feedstuff, bedding material and the production and use of agricultural machinery.

The ReCiPe method is applied for the Life Cycle Impact Assessment (LCIA) at the midpoint level over a 100-year period (Huijbregts et al. 2016). Specifically, the following impact categories are quantified, which are considered relevant for the assessment of beef production (De Vries et al. 2015): global warming potential (GWP), terrestrial acidification potential (TAP), freshwater eutrophication potential (FEP) and marine water eutrophication potential (MEP). As for social indicators, the on-farm workload by work type and the protein conversion ratio (PCR) from feed to food is considered as the competition between feed production and food production is of recent societal concern. The PCR is calculated based on Laisse et al. (2016), Ertl et al. (2016) and Wilkinson (2011) and the workload based on Achilles et al. (2016). FarmDyn provides the contribution margin (CM) per FU to be used as an economic indicator. The price of roughage production is obtained by using model specific marginal values to include opportunity costs of land.

The sensitivity analysis is carried out by creating statistical meta-models from model outcomes subject to changes in farm management parameters, by means of 1000 draws using Latin Hyper Cube sampling. Each draw yields a different model run with its optimized production program and associated emissions. The normalized result matrix is then used to create (linear) meta-models via ordinary least squares. The following parameters are considered for the sensitivity analysis: forage yields, concentrate prices, initial weight of the animals at the fattening farm, slaughter age of the animals, final weight of the animals and beef price at the farm gate.

Results and Discussion

Results from the LCIA with mean values of the model parameters are summarized in Table 1. The total GWP is estimated at 9.175 kg CO_{2eq} per FU. Both the enteric fermentation and the provision of farm inputs, especially imported feedstuff and fertilizer, make the greatest contribution to the results, accounting for 46% and 35% of the impact, respectively. Manure management and fodder production account for the largest share of TAP, due to on-site NH_3 emissions. Fodder production and input provision make the greatest contribution to MEP due to emissions from fertilizer production and application.

Table 1: Life Cycle Impact Assessment results per kg of beef meat in carcass-weight delivered by the dairy-beef production system assessed.

	Enteric fermentation	Manure management	Fodder production	Input provision	Animal transport	Total
GWP[1] as kg CO_{2eq}	4.219	0.804	0.926	3.226	5.88E-06	9.175
TAP[2] as kg SO_{2eq}		0.055	0.068	0.012	2.29E-08	0.135
FEP[3] as kg P_{eq}			0.001	3.65E-04	4.32E-10	0.001
MEP[4] as kg N_{eq}		0.003	0.011	0.013	1.04E-08	0.027

[1]Global Warming Potential, [2]Terrestrial Acidification Potential, [3]Freshwater Eutrophication Potential, [4]Marinewater Eutrophication Potential; Source: Own calculation

The GWP values obtained from this study are lower than those reported by Nguyen et al. (2010), which range from 16.0 to 19.9 kg CO_{2eq} per kg of beef meat produced by a dairy-bull fattening system. These differences mainly arise from the less productive bull breeds considered by Nguyen et al. (2010), besides the fact that they included CO_2 emissions from soil organic carbon losses. The results for TAP are in the range of those obtained by Nguyen et al. (2010).
The CM per kg of beef is estimated at 0.019€ per FU and variable costs add up to 3.675€ per FU. The provision of maize silage and the bull calves represent the largest share of the variable costs, i.e. 41% and 34%, respectively. The PCR of the whole system is estimated at 27.8%, which is in the lower range of the values obtained by Mottet et al. (2017). This highlights the low protein conversion efficiency of the system assessed due to the high share of silage maize and concentrates used as feedstuff. The total workload per FU is 2.4 minutes consisting of management (10%), stable maintenance (5%), fodder production (field work, harvest, and fertilization, 18%) and animal work (feeding and observation, 67%).

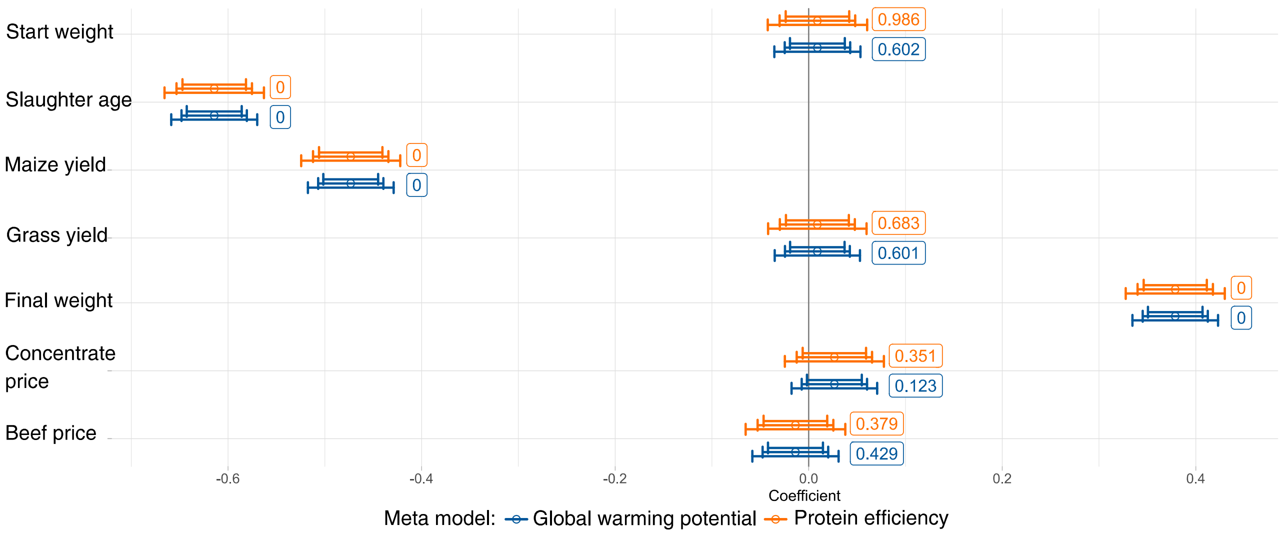

Figure1: Coefficient plot of the standardized linear ordinary least squares meta-models for global warming potential and protein conversion efficiency with the coefficient estimates in the boxes and error bars indicating the 90%, 95% and 99% confidence intervals.
Source: Own calculation

The linear meta-models estimated for the sensitivity analysis fit the differences in indicators outcomes quite well (R^2: GWP 72%, PCR 70%). Fig 1 shows the coefficient estimates (standardized beta-coefficients), p-values and confidence intervals of the two regression models with GWP and PCR as dependent variables, respectively. The coefficient estimates are shown in the boxes and the three error bars indicate the 90%, 95% and 99% confidence intervals. The age at slaughter, maize yield and final weight are highly significant and influential for the performance of the system. Increases in both ages at slaughter and maize yields reduces both GWP and PCR indicators. With a higher slaughter age the fattening intensity and therefore the demand for concentrates is reduced. The savings in concentrates outweighs the otherwise observed trend of lower GWP with higher intensity. An increase in the final weight increases both indicators indicating the same trend. The comparison of the models reveals potential tradeoffs between the conversion from feed to food and GWP, i.e. a reduction the GWP per FU can lead to a lower protein conversion efficiency, which should be considered by decision-makers for the adequate management of the system.

Conclusion

The LCSA performed shows that enteric fermentation, the provision of farm inputs and fodder production are the most emission intensive processes for the typical system for beef production in Germany. The provision of maize silage and bull calves represents the largest share of the variable costs. The system assessed consumes more protein than it delivers at the farm gate. The work spend on fields for fodder production and the daily routine with the animals are the most work demanding processes in beef production on the farm. The sensitivity analysis shows that the age at slaughter, maize yield and final weight of the animals are important drivers for differences in sustainability indicators. A potential trade-off is observed between the conversion from feed protein to food protein and GWP, showing the need to include other indicators in LCAs for more holistic analyses. The present study is a work-in-progress; the same approach will be applied in the near future to analyze further production systems in the German context by using a broader range of indicators.

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Is the effort worth it?: costs and benefits of measuring site-specific emission factors for carbon footprint analysis of pasture-based beef production systems

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Abstract

Purpose: One of the significant challenges pertaining to the collation of life cycle inventories for pasture-based beef production systems is a large degree of uncertainty associated with emission factors (EF), or parameters linking nutrient inputs into the farming system to greenhouse gas emissions arising from the system. Despite the strong evidence signalling spatial heterogeneity in these values due to variabilities in climate, soil and other geographical factors, the majority of LCA studies adopt EF derived outside the actual system boundary, most commonly in the form of parameters recommended by Intergovernmental Panel on Climate Change guidelines.

Methods: As these "generic" EF are designed to be applicable to a wide spectrum of production environments, their use does not guarantee locally accurate estimates of system-wide mid-point impacts. To investigate the quantitative importance of accounting for geographical uncertainties associated with EF with regards to the resultant policy implications, cradle-to-farmgate carbon footprints (CF) of pasture-based beef production systems in South West England were estimated using both global and site-specific EF. The latter values were derived from a pair of purposely designed field experiments to measure enteric methane emissions from cattle and nitrous oxide emissions from soils, respectively.

Results: The results showed that use of global point estimates for EF can cause ~10% errors on the final CF in the absence of animal heterogeneity. This margin, however, was smaller than the CF range across individual animals in the herd as well as the estimated impacts of moderate changes to on-farm management.

Conclusion: This finding suggests that the costly site-by-site measurements of EF are not always necessary, especially under situations where the competing resources could be better spent on other research and development activities. On the practical level, increasing the stocking rate and the parity number of breeding cows were both shown to hold a large potential to reduce CF, especially when complemented by strategic animal selection.

Keywords: *Beef cattle; greenhouse gas inventory; methane; nitrous oxide; primary data; uncertainty.*

Introduction

Carbon footprints (CF) are one of the standard metrics to evaluate system-wide contributions of a food commodity to global warming. However, as most CF studies of agricultural systems rely on existing "book value" emission factors (EF) to quantify greenhouse gas emissions that occur on the farm, localised effects such as climatic or soil conditions of the production environment are rarely accounted for in the analysis (McAuliffe et al., 2020). To investigate the quantitative importance of these "location uncertainties" with regards to the resultant policy implications, cradle-to-farmgate CF of pasture-based beef production systems were calculated using both global and site-specific EF. The latter set of EF was derived from a pair of purposely designed field experiments, to measure enteric methane (CH_4) emissions from cattle and nitrous oxide (N_2O) emissions from soils, respectively.

Material and methods

The study was carried out at the permanent pasture beef enterprise of the North Wyke Farm Platform in Devon, UK (Takahashi et al., 2018). Thirty (30) Charolais × Hereford-Friesian calves born in spring 2015 were reared alongside their mothers until weaning in autumn 2015 and then transferred to an adjacent finishing herd for slaughter in autumn 2016. Both breeding and finishing phases of the enterprise were included within the system boundary. The functional unit was set as 1 kg liveweight (LW) departing the farmgate.

For the baseline model, on-farm emissions were calculated using a modified Intergovernmental Panel on Climate Change (IPCC) Tier 2 approach (McAuliffe et al., 2018) under site-specific EF for IPCC Y_m (CH_4 from feed consumed), EF_1 (N_2O from synthetic fertilisers) and $EF_{3(PRP)}$ (N_2O from urine and dung). These three parameters have previously been shown to be the most important drivers of emissions uncertainty in pasture-based beef production systems (Takahashi et al., 2019). The local value for Y_m (0.078) was measured using the C-Lock GreenFeed Emission Monitoring system over a 137-day period. The values for EF_1 (0.013) and $EF_{3(PRP)}$ (0.002) were quantified using gas samples collected from static chambers over a 169-day period (McAuliffe et al., 2020).

Based on our earlier finding that ignoring inter-animal differences in growth efficiency leads to a biased estimate of farm-scale environmental impacts (McAuliffe et al., 2018), CF was initially calculated for each individual animal using the 100-year Global Warming Potential (GWP_{100}) impact assessment method and subsequently pooled together to create a whole-farm inventory. Following baseline estimation, a sensitivity analysis was conducted to investigate the impact of replacing site-specific EF with IPCC global point estimates for Y_m (0.065), EF_1 (0.01) and $EF_{3(PRP)}$ (0.02) as well as the lower and upper limits of their 95% confidence intervals. Furthermore, to relativise this impact in a wider context, scenario-based CF were estimated under four alternative farm management strategies, namely with lower/higher stocking rates (1.0/2.5 LU ha^{-1}) than the actual operation (1.3 LU ha^{-1}) as well as lower/higher parity numbers (± 2 calves) for breeding cows. In order to detect potential nonlinearity of parameter effects, all sensitivity and scenario analyses were carried out individually for the best (least polluting), median and worst (most polluting) animals.

Results

Mean cradle-to-farmgate CF (across 30 animals) was estimated to be 25.1 kg CO2-eq/kg LW. Inter-animal differences in environmental performance were largely explained by growth performance, with average daily gains post-weaning showing strong and negative correlations with global warming potential ($r = -0.81$, $p < 0.001$). Use of global point estimates for EF, and in particular that pertaining to enteric CH_4, was shown to cause up to 10% errors to resultant CF in the absence of animal heterogeneity (**Figure 1**, items 2-3). This margin, however, was smaller than the CF range across the entire herd (19%: **Figure 1**, item 1) as well as the estimated impacts of on-farm management changes (up to 108%: **Figure 1**, items 4-5). Increasing the stocking rate and the parity number were both shown to hold a large potential to reduce CF, especially when complemented by strategic animal selection. Finally, the CF range for individual EF, or the difference in CF values derived under EF at the lower and upper limits of IPCC 95% confidence intervals, was considerably narrower for Y_m (**Figure 1**, items 2b and 2c) than EF_1/EF_3 (**Figure 1**, items 3b and 3c) irrespective of animals. This suggests that, although enteric CH_4 contributes more to the overall CF of the production systems, the information value of site-specific EF is higher for soil-originated N_2O, as it will likely play a larger role in reduction of CF uncertainty.

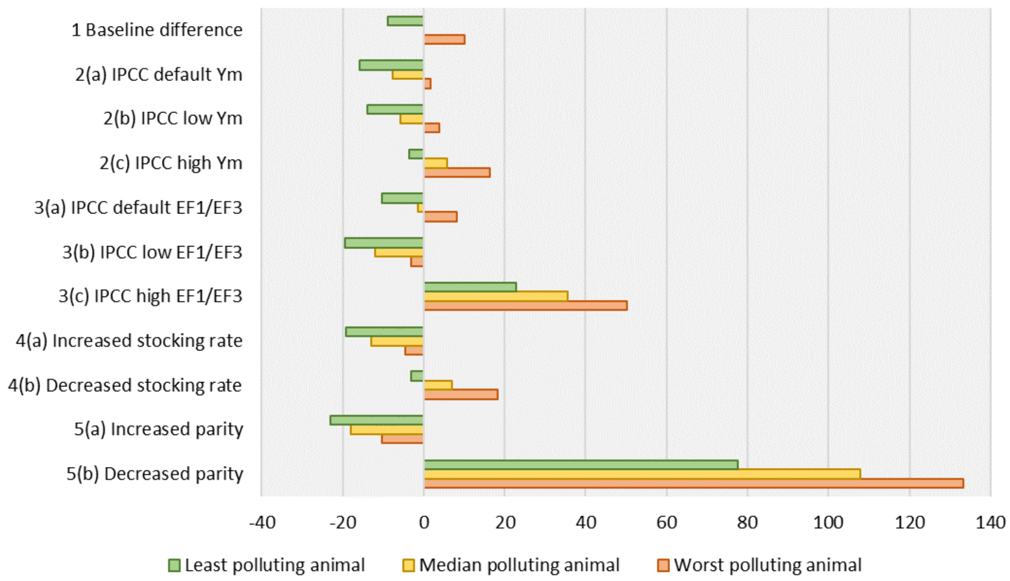

Figure 1. Relative impacts of adopting alternative emission factors and farm management strategies on animal-level carbon footprint. All values are percentage changes from the baseline result for the median animal (24.9 kg CO_2-eq/kg LW), which was computed under site-specific emission factors.

Discussion

The above results indicate that using generic EF at carbon footprinting of temperate grassland systems does not necessarily affect the study's accuracy adversely, thus site-by-site measurements of EF are not always necessary. This finding has important implications on national and global research and development strategies, as a considerable amount of investment is required to measure on-farm greenhouse gas emissions on a large number of locations under scientifically robust designs (López-Aizpún et al., 2020). Notwithstanding, further research is required to evaluate the universality of the finding, for example with regards to the study site's climate, soil and pasture/animal breeds, as well as their interactions with uncertainty concerning site-specific EF and resultant CF. On the practical level, no trade-off between economic profitability and environmental burdens was observed under the current analysis, with efficient resource use contributing to both causes at the same time.

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Abstract code: 273

Life cycle assessment of pasture-based beef production in Alentejo, Portugal

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Abstract

Purpose The meat production sector is a major contributor to greenhouse gas emissions. Pasture-based production is sometimes credited as environmentally friendlier but is less studied than more intensive production systems. These systems also provide ecosystem services in regions such as the Mediterranean through their influence on nutrient cycles. Here, we characterize and calculate the carbon footprint (CF) using data from 40 beef production farms in Portugal.
Methods We used a life cycle assessment approach considering all supply-chain emissions (direct and indirect) in a cradle-to-farm gate approach. The data collected from the farmers included agricultural operations, fertilizers, energy, number of animals per age group in the farm, average weight per age group, housing time per day, concentrate feed consumption and products sold (meat and others). Foreground emissions were calculated using the beef-specific BalSim model. Background emissions were calculated using ecoinvent (e.g. concentrated feed production).
Results and discussion On average, despite the extensive nature of the system, feed external to the farm is responsible for a significant fraction of the emissions. Further, a significant number of agricultural co-products is used in the farm for animal feeding. Results show significant heterogeneity between farms. Emissions from enteric fermentation, concentrate feed production and (organic and mineral) fertilizer application are the three main sources of impact. Emissions from manure management, however, are significantly reduced (compared to more intensive systems) because animals spend most of the time on the pasture (more than 80% of the year).
Conclusions Here, we present the first comprehensive study of beef production assessment at farm level in Portugal relying on farmers data. The most important limitation in this study was data unavailability (e.g. pasture intake) that prevented us from considering the role of type of feed on direct GHG emissions from enteric fermentation and nitrogen emissions from excretion.

Keywords: Meat production; Industrial Ecology; Climate change; Life cycle impact assessment

Introduction

Adapting to and mitigating global climate change are unique challenges for the near future (IPCC, 2014a). A significant proportion of greenhouse gas (GHG) emissions is originated by agriculture. Livestock production is one of the main contributors for this subtotal (Theurl et al., 2020). This contribution is estimated to be around 14.5% of the total annual anthropogenic GHG emissions globally (Opio et al., 2013), which means that the sector is determinant for curbing GHG levels worldwide. Livestock production concerns not only meat but also other animal products such as milk and eggs. It covers a vast variety of production methods with several scales of intensity. This high diversity requires an adequate characterization of the case study under analysis, since very different outcomes for the very same final product can frequently occur.

In the last few decades, a significant number of animal production innovations have been proposed to reduce environmental impacts and increase profitability. Some notable examples of production systems with the potential for improving the environmental performance of cattle production are organic and pasture-based systems (de Vries et al., 2015; Morais et al., 2018a). Pasture-based beef production uses grass for animal feed and requires less concentrate, thereby increasing feed self-sufficiency and reducing transportation (Hernández-Esteban et al., 2018; Morais et al., 2016; Morais et al., 2018c).
This work is focused in Portugal, specifically in the Alentejo region, were large areas are devoted to beef cattle production through extensive grazing. Out of approximately 20 million ha of utilized agricultural area in Alentejo, 67% are permanent pastures. The Mediterranean climate, soils and topographic characteristics of the region favor extensive beef cattle production (Morais et al., 2018c; Teixeira et al., 2018), which is one of the main agricultural productions in the region. There are approximately 1 million bovines in mainland Portugal, 57% of which are in Alentejo (INE, 2020). The typical production system consists in raising the calves on the farm or in specialized fattening farms, based on grazing plus roughage or concentrate feed, until they reach the required weight for slaughter. We present here the carbon footprint for a set of 40 farms, by quantity of final product.

Material and methods

Farm-level data was collected from 43 farms of Alentejo, Portugal, under the scope of the project Animal Future. The main activities in the farms were cattle production (30), sheep (5) or mixed production of sheep and cattle (8) and have an average area of 583 ha (23-3500 ha). 35% of the farms have a fraction of the area within NATURA 2000 and 32% are organic farms. Farmers had an average of 17 years of experience and 61% of them have other activities on farm unrelated with agriculture (tourism, forestry, etc.). Collected data includes information regarding, areas, crops, fertilizers application, resource utilization (fuels, water and electricity), feed consumption, number of animals per age group and quantity of live weight (LW) obtained. We divide the products produced in the farms between "*cattle for fattening"*, corresponding to calves sold for fattening outside the farm; "*cattle for meat*", meaning steers fully raised and fattened at the farm and sold for slaughter; and "*lamb for meat"*, corresponding to lambs fully raised and fattened at the farm and sold for slaughter. The 'BalSim' model (Teixeira et al., 2019) was used to obtain the profile of emissions at farm level. BalSim is a carbon (C) and nitrogen (N) mass balance approach based on the Organisation for Economic Co-operation and Development model, but tailor-made for semi-natural (SNP) and sown biodiverse pastures (SBP) in Portugal. The integrated model includes two interconnected mass balance models for C and N, each divided between three balanced sub-systems (pasture plants, animal and soil), which also enable the determination of the GHG balances. Each sub-system includes several pools with specific C and N inflows and outflows. The background emissions of all the materials used in each farm were obtained from ecoinvent 3.3 (Weidema et al., 2013). The used materials and energy included were: fertilizers, agricultural operations, concentrated feed, fossil fuels (gasoline and diesel), natural gas and electricity. A "cradle-to-gate" system boundary was used to include the multiple outputs and inputs of the farm.
The impact category selected in this study was global warming potential (GWP) for a time horizon of 100 years. The CF is expressed in kg of carbon dioxide equivalent (CO_2e). The characterization model used was the IPCC Fifth Assessment Report (IPCC, 2014b).

Results and discussion

Preliminary results show that the average carbon footprint per product type in the farms were 53.4, 25.7 and 34 kg CO_{2eq}/kg LW for cattle for fattening, cattle for meat, and lamb for meat respectively (Table 1). The CF for cattle for fattening has the highest variability, with a minimum of 27.4 kg CO_{2eq}/kg LW and a maximum of over 190 kg CO_{2eq}/kg LW. Cattle for meat has the smallest average emissions and the lowest standard deviation. Lamb for meat presents an intermediate average value of 34 kg CO_{2eq}/kg LW with a median of 28.1 kg CO_{2eq}/kg LW. Biogenic carbon was excluded from the analysis. Results depict only non-CO_2 emissions.

Table 1. Main results (kg CO_{2eq}/kg LW) for the different analyzed systems.

Parameter	Cattle for fattening	Cattle for meat	Lamb for meat
Average	53.4	25.7	34.0
Median	43.4	22.0	28.1
Minimum	27.4	9.2	21.3
Maximum	190.9	72.8	81.5
Standard deviation	30.4	13.6	16.4

Methane emissions from enteric fermentation correspond to 37.4% of the emissions, the highest fraction, while manure management accounts for 26.2% of the total emissions. Other N_2O emissions are 15.6% of the total emissions, and most of them are emissions from soils. Emissions from energy consumption are negligible (0.5% of the total).

The main assumption and limitation in this work was the use of national-level Tier 2 emission factors for these key sources of GHG emissions. We used the IPCC Tier 2 method as applied in the Portuguese GHG National Inventory Report (APA, 2018) to calculate both enteric CH_4 emissions, nitrogen excretion and emissions from excreta and manure management. Due to the importance of these emissions, Tier 3 models specific for these farms and breed of cows should be used. Another relevant limitation in this work is an absence of data for pasture intake. The composition of the feed is essential to understand and calculate more accurately the amount of nitrogen excreted and also emissions. Those data should be a priority focus for future research on this system.

Introduce new impact indicators should also be included in the future, namely impact indicators related with land use are especially relevant in agri-food products (Morais et al., 2016; Morais et al., 2018d; Teixeira et al., 2018b).

Conclusions

There is a high heterogeneity in the performance of the farms analyzed in the Alentejo region. The most significant contribution for GHG emissions is enteric fermentation, manure management and concentrated feed, despite the high feed self-sufficiency due to the pasture basis of the systems.

Acknowledgements

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Topic 4:
Food Waste Models
and Prevention Actions

Abstract code: ID 211

Evaluation of food waste prevention measures in the food service sector: can portioned salmon cut food waste, save costs and reduce environmental impacts?

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Abstract

Purpose – This paper provides a sustainability assessment of procuring salmon by restaurants, focussing on fish products with different convenience grades. The convenience grade of the fish bought (whole salmon, fillets or portions) determines where along the chain filleting and/or portioning takes place and thus where food waste from cut-offs is generated. As such, in order to reduce food waste, the interventions of purchasing filleted or portioned salmon rather than whole salmon are investigated.

Methods - For both food waste reduction measures, effectiveness is calculated by looking at food waste reductions achieved along the chain by better use of filleting and portioning cut-offs. Next, sustainability across the environmental, economic and social dimension is evaluated by calculating (a) avoided embodied environmental impacts and economic costs, (b) avoided food waste disposal environmental impacts and economic costs and (c) environmental, economic and social impacts and costs associated with implementing the measures.

Results and discussion - Purchasing fillets or portions instead of whole salmon leads to annual salmon food waste reductions of -89 % and -94 % respectively. The interventions further lead to net climate change impact savings along the salmon chain of -16 % (fillets) and -18 % (portions). Whereas the kitchen saves costs when switching to fillets (-13 %), a switch to portions generates additional net costs (+5 %). On a social level, no effects could be determined based on the information available. However, good filleting skills would no longer be needed in the kitchen and a time consuming preparation can be sourced out.

Conclusions – Switching to buying salmon products of a higher convenience grade lowers food waste volumes along the chain and reduces climate changes impacts as cut-offs are used or processed by manufacturers whereas restaurants throw them away. Moving to procuring only fillets results in net annual cost savings, whereas additional costs arise when moving towards portioned salmon.

Keywords: *food waste measure; sustainability assessment; convenience food; fish processing; food service; out-of-home*

1. Introduction

This paper applies a recently proposed sustainability assessment framework to evaluate food waste prevention measures (Caldeira et al. 2019a, Goossens et al. 2019) to a case study in the food service sector. The case study focusses on the interface between the food service sector and its food suppliers, investigating salmon products with different convenience grades. To reduce food waste, we propose purchasing filleted or portioned salmon (convenience grades 1 or 2 respectively) rather than procuring whole salmon (convenience grade 0). When filleting and/or portioning takes place in a large-scale kitchen most filleting and portioning cut-offs are thrown in the bin and end up as food waste. In case filleting and/or portioning takes place at the supplier manufacturing site, the cut-offs are centralised and used for internal or external processing. As such, rather than shifting food waste to another food supply chain stage, these fish by-products are prevented from becoming waste as they are used for other human consumption purposes or valorised as for example fish meal. The food waste savings are expected to lead to environmental benefits. The purchase of filleted or portioned fish however comes at a higher per kilogram price than whole fish, leading to many kitchen chefs hesitating to make this switch. But, if filleting and/or portioning is taken up by the kitchen, so are labour costs associated with this highly specialised skill. For a food service business, it is thus not always clear which option is most preferable.

This paper therefore assesses the extent to which purchasing salmon with a higher convenience grade can reduce salmon food waste along the chain and, at the same time, can improve sustainability across the environmental, economic and social dimension.

2. Material and methods

The case study was set up in collaboration with a major hotel group in Germany and its main fish supplier. The salmon portions assessed in this case study take up 52 % of the initial weight of a 4 kg salmon; filleting and portioning cut-offs respectively account for 38 % and 10 %. In case filleting takes place at the hotel kitchen, 100 % of the filleting cut-offs end up in the bin whereas only 1 % is binned if the fish is filleted by the supplier (complemented with 62 % being used for human consumption purposes and 37 % valorised as animal feed, Figure 1). After portioning of the fillets, the hotel kitchen uses 95 % of the cut-offs (staff meals, fish pans) whereas the remainder 5 % is thrown. The supplier on the other hand, will repurpose 100 % of the portioning cut-offs for human consumption (Figure 1). The two food waste measures under study refer to (a) procuring fillets instead of whole salmon, and (b) procuring portions instead of whole salmon.

Both measures are evaluated based on their effectiveness (food waste reduction potential) and their sustainability across the environmental, the economic and the social dimension (Caldeira et al. 2019a, Goossens et al. 2019). Results are expressed per year; with the functional unit being the number of portions served by the restaurant in 2018 (+/- 125,000 portions weighing 80 g each). The scenario in which a kitchen procures whole salmon is used as a reference scenario against which the two alternative scenarios (buying fillets or portions) are compared.

To evaluate the **effectiveness**, food waste reductions at the supplier and at the restaurant are assessed. Considered as food waste, are the filleting and/or portioning cut-offs that are disposed of, as well as storage losses. Based on the EU FUSIONS definition (Caldeira et al. 2019b, Östergren et al. 2014), filleting and portioning cut-offs removed from the supply chain and valorised as for example fish meal are not considered as food waste, but categorised as by-products. Any other food waste stream related to the fish farming stage, the cooking of salmon or plate leftovers are out of scope of this study, because they have no influence on these waste reduction scenarios.

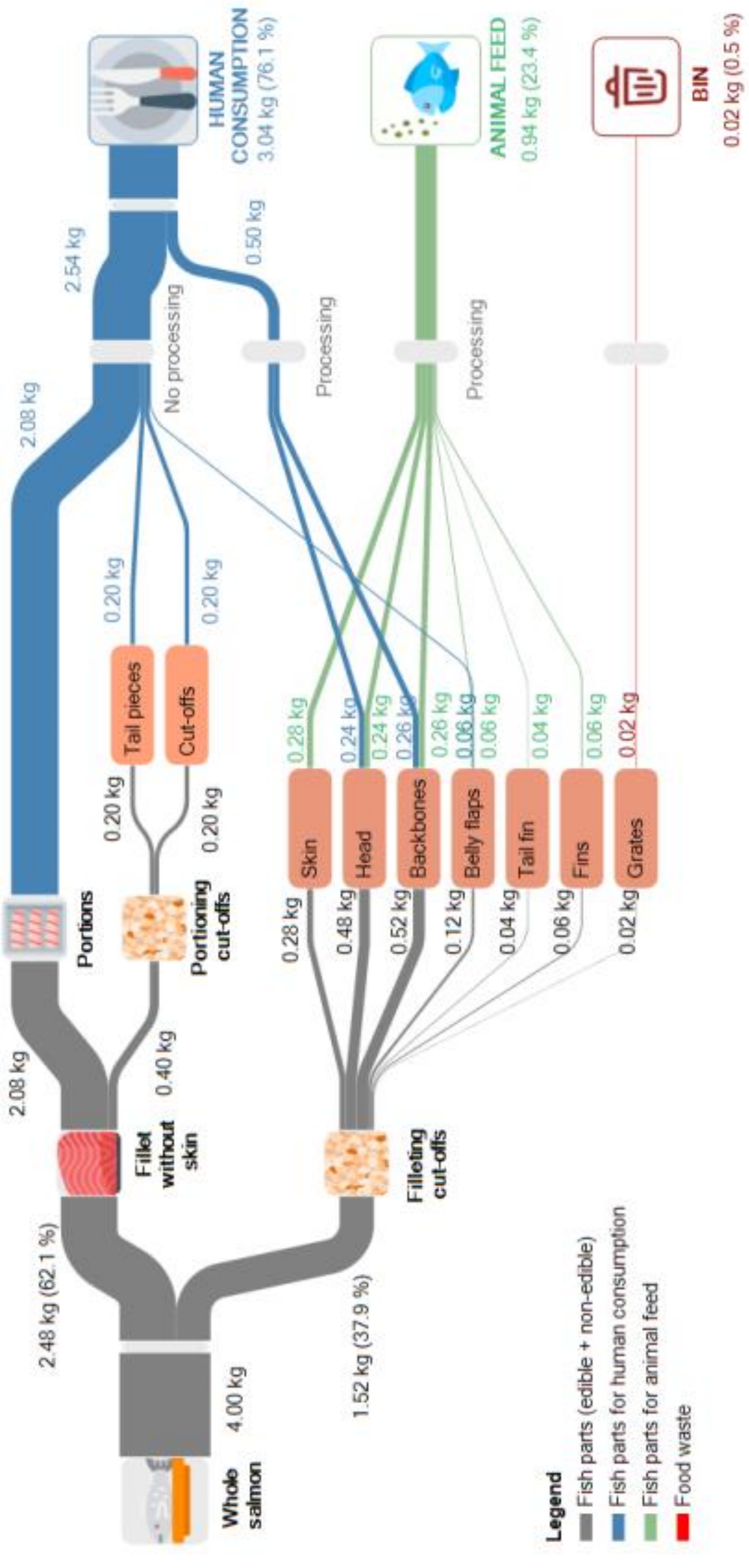

Figure 1. Sankey diagram for the purchase of portions by the kitchen: filleting and portioning by the supplier.

The **environmental and economic sustainability assessment** take into account embodied impacts or costs of food no longer wasted, the associated avoided disposal impacts or costs, as well as the impacts and costs specifically related to the implementation of the measure. The environmental assessment considers all impacts generated throughout the chain, from the fish farming stage up until arrival, storage and eventual filleting or portioning in the kitchen. All steps thereafter – such as preparation and serving of food, as well as plate leftovers – are out of scope.

The applied life cycle analysis (LCA) is based on the International Reference Life Cycle Data System (ILCD) framework. Focus is given to the calculation of greenhouse gases, expressed as CO_2 equivalents, resulting in a carbon footprint calculation of the system under study. Economic allocation is applied to divide environmental burdens between the fish portions and the filleting and portioning cut-offs. The economic cost calculations focus on costs borne by the hotel kitchen. All costs occurring in any of the previous steps of the food chain (such as staff costs, use of electricity and water, or equipment investments and maintenance at the supplier) are assumed to be reflected by the commodity price. For the **social pillar of the sustainability assessment**, this paper looks into how a switch towards fish with a higher convenience grade affects meal donation, jobs and working environment.

3. Results

Effectiveness - The total annual food waste along the chain is at its highest in the scenario where whole salmon is purchased, mounting to almost 9 tonnes per year (Table 1). Lower food waste volumes are achieved when buying fillets or portions with food waste volumes being reduced to less than 1 tonne per year. Moving from buying whole salmon to buying fillets or portions would lead to an 89 % or 94 % food waste decrease respectively. Based on the amount of edible food being binned in the reference scenario (purchase of whole salmon), about 4,800 to 5,000 fish servings (weighing 80 g each) can be saved per year when procuring fillets or portions.

Table 1. (a) Annual food waste volumes, environmental impacts and costs associated with each salmon procurement scenario (based on the hotel chain serving around 125,000 portions of 80 g each in 2018); (b) Effectiveness, net environmental impacts and net cost balance associated with the food waste measures under study.

		(a) Procurement scenario			**(b) Implementation of food waste measure**	
		Whole salmon	Fillets	Portions	Switch from whole salmon to fillets	Switch from whole salmon to portions
Food waste volumes / effectiveness	kg/year	8,753	924	506	-7,829	-8,247
	%				**-89%**	**-94%**
Environmental assessment	kg CO_2 eq./year	58,003	48,639	47,847	-9,364	-10,156
	%				**-16%**	**-18%**
Economic assessment	€/year	218,307	189,860	229,527	-28,448	+11,220
	%				**-13%**	**+5%**

Sustainability: environmental dimension (carbon footprint) – In case a kitchen procures whole salmon, almost 60 tonnes of CO_2 eq. per year are emitted along the salmon chain up until arrival and eventual filleting and portioning in the kitchen (Table 1). Switching to procuring filleted salmon, would lead to impact savings of almost 10 tonnes of CO_2 eq. per year, reflecting a 16 % decrease. If the kitchen would switch to buying portioned salmon, impact savings of 18 % would be achieved. The impact savings are mainly due to savings made in the distribution transport and packaging steps, due to the way the whole salmon, fillets and portions are packaged and distributed. Other contributing factors are the reduced storage losses and the economic allocation method being applied, resulting in fewer fish farming and transport impacts per portion.

Sustainability: economic dimension – Purchasing whole salmon costs the kitchen about € 218,000 per year (Table 1). The switch to procuring filleted salmon leads to annual net cost savings of 13 %. These are due to savings in the purchase of the fillets as compared to purchasing whole salmon, despite the higher per kilogram prices paid for fillets. The reason behind this is that, when purchasing a whole salmon, the kitchen also pays for the filleting cut-offs that are later on thrown. Other cost savings relate to labour cost savings, as filleting is outsourced to the supplier. In case of switching from purchasing whole salmon to portions, the labour cost savings are even higher. Nevertheless, there is a 5 % net cost increase following the high per kilogram price paid for portioned salmon as compared to whole salmon. Additionally, when purchasing portioned salmon, new costs arise as the restaurant now no longer has its portioning cut-offs available for making fish pans, and has to purchase these from the supplier. Moving towards buying portioned salmon instead of whole salmon was found to be profitable to the kitchen as soon as the portion prices are lowered by 5.12 %.

Sustainability: social dimension - Meal donation is not applicable in the present case study since all edible food that is prevented from becoming waste, is used within the processing industry. When it comes to how the food waste measures affect jobs and working environment, no concrete information could be obtained. However, the authors had informal conversations with the hotel and supplier, giving some insight in the issue. Good filleting skills would no longer be needed in the kitchen and a time consuming preparation can be sourced out. Implementation of the food waste measures under study leads to time savings of up to 6 minutes per day per kitchen. Whether or not this will lead to job losses for staff with specific filleting skills, will partly depend on the extent to which suppliers would continue to apply manual filleting (alongside machine filleting) which could compensate (at least partly) eventual job losses in the food service sector.

4. Discussion and conclusions

Potential to scale up to other food products - The food waste measures under study add to the potential of food services for reducing their overall food waste volumes by also focussing on their unavoidable food waste, whereas most food waste measures tend to focus on avoidable waste. The proposed measures affect only a very small percentage of the total amount of food waste arising in a commercial kitchen. Nevertheless, the concept applies to other fish species as well, and it may apply to other food products available in different convenience grades such as portioned meat and trimmed and pre-cut vegetables as well. As such, the food waste savings (and associated environmental impact savings) could be scaled up to a wider range of products since a higher convenience grade allows for better use and valorisation of by-products and trimmings of meat, fish, vegetables and fruits. Switching to products with a higher convenience grade may thus be a promising measure to fight food waste and increase sustainability of a food service business.

Nevertheless, due attention is needed when generalising the findings: in the present study there is no individual packaging, and packaging impacts thus do not increase (but instead decrease) when moving to a higher convenience grade. The same goes for electricity use during storage. When it comes to purchasing trimmed and pre-cut fruits and vegetables, however, the situation could be different. Additionally, the use of more convenience products could lower staff motivation, reduce opportunities for creativity in the kitchen and lead to a deskilling of staff.

Contribution to the greater societal goal of meeting the SDGs and moving towards a circular economy - Through its food waste reductions achieved, the food waste measures under study contribute to meeting SDG 12.3 while at the same time reduce the environmental impacts along the chain. Through increased valorisation, the proposed measures lead to a more efficient use of resources, hereby contributing to moving towards a circular economy. Whereas it may be hard to achieve valorisation at the level of a private consumer or a food service business, centralisation of food processing or preparation at the level of the manufacturer or food supplier facilitates using discarded (in)edible parts of a food product as a valuable feedstock for other industrial processes.

Conclusions - Rather than procuring whole salmon, this paper proposes purchasing fillets or portioned salmon to reduce food waste along the chain. Switching to buying filleted or portioned salmon does not only lead to substantial food waste reductions (up to 94 %), but also reduces climate change impacts along the chain (up to 18 % impact savings). Whereas a switch to procuring filleted salmon was found to lead to net cost savings for the kitchen, a switch to buying portions would only be profitable to the restaurant if portions prices would go down by about 5 %. On a social level, the outsourcing of the filleting and portioning would free up time in the kitchen and would lower the need for staff with good filleting skills.

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Abstract code: 6

Country-specific life cycle inventories for human excretion of food products

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Abstract

Purpose
We present a regionalized life cycle inventory model to account for human excretion of food products, constituting an update of a previous model developed by the author in 2008.
Methods
The updated model provides country-specific estimates on toilet activities (use of toilet paper, tap water, soap) and wastewater/excreta management, the latter addressing not only wastewater collection and treatment as done in developed countries, but also decentralized options such as septic tanks, latrines and even open defecation. The model provides inventories for 86 countries, linked to the ecoinvent database, which can be imported to the software SimaPro for further analysis.
Results and discussion
As an example, we show how ingestion of raw apples contributes to GHG emissions due to the previously mentioned activities.
Conclusions
Our results show that management of human excreta associated to raw apple ingestion has in many countries a higher carbon footprint than producing the apple itself.

Keywords: Human excretion, sanitation, inventory model, regionalization

Introduction

The end-of-life stage of food products inevitably leads to environmental impacts from activities which, more often than not, are omitted in life cycle assessment (LCA). We refer here to emissions from human digestion and its derived excretion products. Following digestion, the human body not only releases CO_2 and also (small amounts of) methane to the atmosphere, but it also releases liquid and solid excreta that needs management. In a developed-country context, excreta are managed through centralized sewers and wastewater treatment plants, while in developing countries human waste is often discharged without treatment, either as part of wastewater, or through latrines, or even by defecating in the open.

A model to include human excretion of food products in LCA studies was developed by Muñoz et al. (2008). Based on the nutritional composition of a specific food item or diet, defined as its content in water, carbohydrates, fat, protein, etc., the model provided a mass balance for nutrients in the human body, direct emissions to the environment from the latter and an inventory for management of human excreta through toilet use and wastewater treatment, using the wastewater treatment model from ecoinvent v2 (Doka 2007). A major shortcoming of this model was the fact that as far as excreta management is concerned, it reflected the typical conditions in a developed country in terms of toiletries consumption, and most notably, wastewater management through treatment in a modern wastewater treatment plant (WWTP).

We present an update to the model by Muñoz et al. (2008), in which the management of human excreta evolves from a static Western scenario to country-specific conditions, allowing us to reflect more accurately the range of environmental impacts from human excretion in different parts of the world with completely different sanitation realities.

Material and methods

The human excretion model has been updated from its 2008 version as follows:

- The mass balance developed for the human body in 2008 remains unchanged. This assumes that the same partitioning of nutrients to air and excreta from ingested food is valid regardless of the geography. Although it is well known that in developing countries solid excreta production per capita is higher than in developed countries (Rose et al. 2015), this can be attributed mainly to dietary differences, such as a higher fiber intake, rather than to differences in inherent nutrient absorption by different populations.
- The activity related to toilet use is updated, by providing country-specific estimates for consumption of toilet paper, tap water (for flushing, hand washing) and soap (for hand washing). Per capita toilet paper consumption by country is obtained from European Tissue (2020). For countries where this is not reported, it is estimated based on a correlation between toilet paper consumption vs. gross national income (GNI) per capita. Tap water consumption for toilet flushing and hand washing is taken as 18 L and 2 L per kg food intake in populations with full access to toilets and basic hygiene, as considered in the 2008 model, while these values are zero in the updated model for the percentage of population lacking toilet access or basic hygiene levels. Country-specific data on these levels are obtained from WHO-UNICEF (2019). A similar approach is considered to determine consumption of soap, where 5.4 g per kg food intake is considered for populations with basic hygiene (Muñoz et al. 2008) and zero for populations without it.
- The management of human excreta is linked to WW LCI v3 (Muñoz 2019), a model to calculate inventories for discharges of urban wastewater. The wastewater model WW LCI covers the entire supply chain for wastewater management (collection, centralized and decentralized treatment, emissions from untreated discharges, as well as sludge treatment and disposal by means of composting, reuse in agriculture, landfilling, incineration). The model is equipped with a database containing wastewater management statistics for 86 countries, representing 90% of the world's population. For the purpose of this update, WW LCI has been adapted to address sanitation options not previously included, namely latrines and open defecation, for which specific emission models have been built and populated with statistics on the level of penetration of these sanitation options by country.
- Human excreta in WW LCI is modelled as a mixture of 8 individual components: water, urea, faeces, fiber, phosphate, sulfate, toilet paper and soap. From these, Urea, faeces, fibre, toilet paper and soap are in WW LCI assumed to be readily degradable in WWTPs or when discharged without treatment to the environment. Urea is modelled as dissolved in wastewater, while the other degradable components are modelled as suspended matter, part of which is settled in primary sludge, with the remainder undergoing degradation through biological treatment. Concerning water, sulfate and phosphate no specific considerations are necessary, as WW LCI handles these substances without the need of further data input.
- Finally, the obtained inventories for human excretion are linked to ecoinvent and can be imported to the software SimaPro for further analysis.

Results and discussion

As an example, we show in Figure 1 the results for consumption of raw apples, with a composition of 84.5% water, 0.4% protein, 0.1% fat, 11.8% carbohydrates, 1.8% fibre and 0.011% phosphorus. Figure 1 shows the greenhouse-gas (GHG) emissions, expressed as kg CO_2-eq, per kg apple ingested and excreted in 86 countries. It can be seen that emissions range from 0.04 to 0.26 kg CO_2-eq/kg apple. The figure also shows a shaded area, representing the range of GHG emissions for production of an apple (at farm gate) according to literature, namely 0.04-0.11 kg CO_2-eq/kg (Figuereido et al. 2013; Milà i Canals 2003). For the particular case of apples, our results show that management of human excreta has in many countries a higher carbon footprint than cultivating the apple itself.

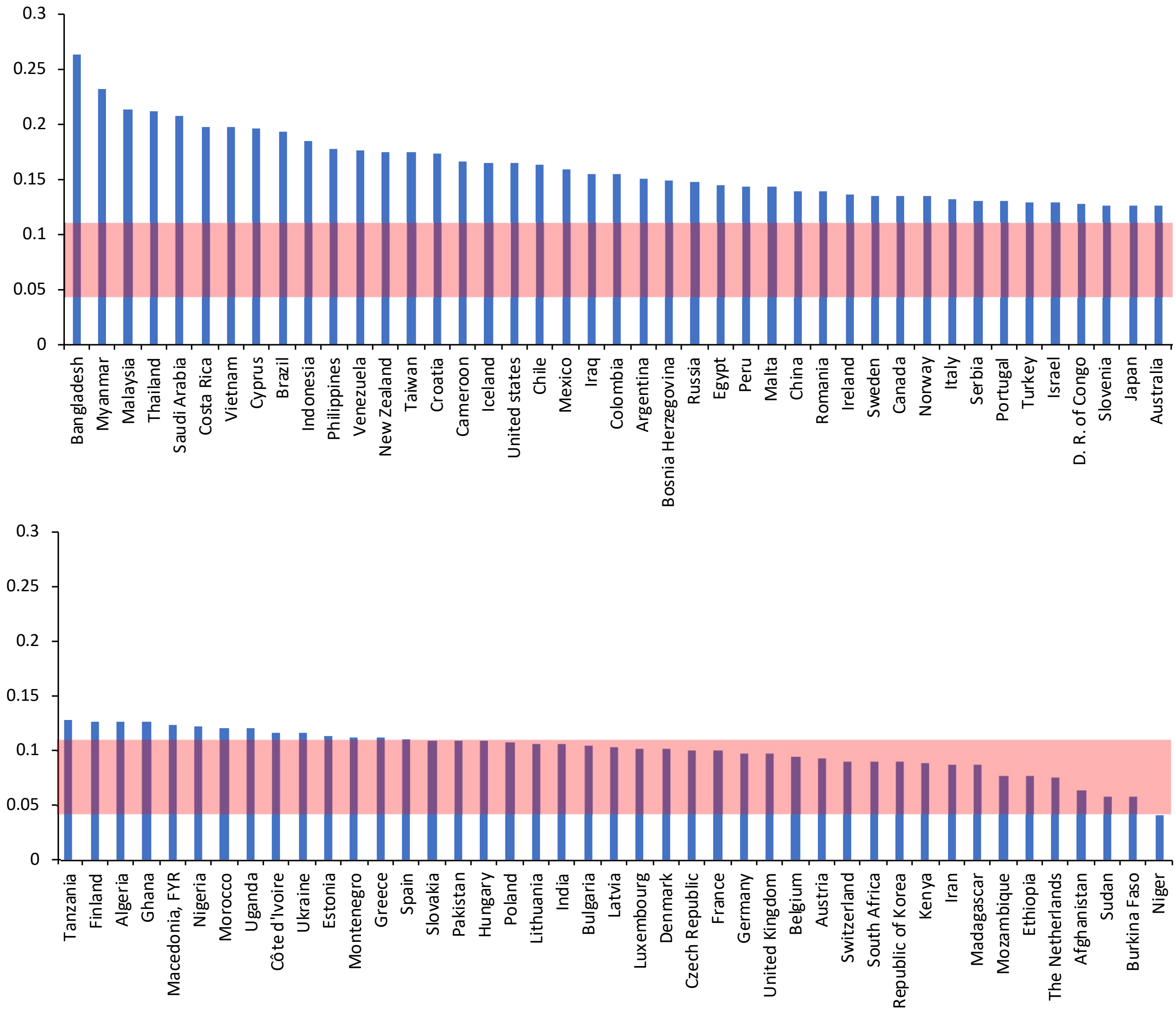

Figure 1. GHG emissions for the human excretion stage of raw apples consumed in 86 countries (kg CO_2-eq/kg apple).

A contribution analysis on GHG emission is shown in Table 1 for three countries. On the one hand, in a country like Bangladesh, which appears to have the highest GHG emissions from the 86 countries assessed, the impact is dominated by methane emissions from anaerobic degradation of human waste in latrines, the latter accounting for 95% of domestic sanitation in this country, according to the country profile in the WW LCI database. On the other hand, other developing countries show remarkably low emissions. An example of this is Niger, which has the lowest GHG emissions from the list of 86 countries. In this case, this is explained by the fact that open defecation is widely practiced in Niger (about 70% of the population), which in the model leads to both low methane

emissions as well as a lack of impacts from sanitation infrastructure (sewers, WWTPs, etc.). Finally, in a developed country such as Germany, the impact is associated to toiletries and tap water production, with wastewater management showing a low contribution. This relatively low contribution from wastewater is largely due to credits (substituted activities) associated to e.g. energy recovery from wastewater sludge (biogas production, incineration of sludge, etc.).
These results have shown only how human excretion contributes to GHG emissions, and for a single product (apples). Similar assessments can be carried out for other impact categories, such as eutrophication, acidification, etc., as well as for other food products or diets.

Table 1. Contribution analysis for GHG emissions for the human excretion stage of raw apples consumed in Bangladesh, Niger and Germany (kg CO_2-eq/kg apple).

Country	Contributions					
	Total	Toilet paper production	Tap water production	Soap production	Emissions from latrine or open defecation	Wastewater and sludge treatment
Bangladesh	0.264	0.007	0.002	0.006	0.248	0.0002
Niger	0.041	0.003	0.003	0.007	0.028	0.0002
Germany	0.097	0.061	0.012	0.017	0	0.007

Conclusions

As in Muñoz et al. (2008), we again stress the importance of including human excretion in LCA studies of food products. In fact, the model update presented in this work suggests that, besides a wide geographical variability, the environmental impacts of sanitation linked to food consumption have a higher magnitude than previously anticipated.

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Abstract code: 48

Social footprint of a packaging waste prevention campaign in the municipality of Zamudio, Spain

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Abstract

Purpose
We present the results of applying the Social Footprint method to evaluate the potential social benefit of a pilot packaging waste prevention campaign implemented in the municipality of Zamudio in Northern Spain.
Methods
The aim of this campaign was to reduce the number of single-use food wrappers and plastic bags used by the citizens while shopping in groceries, butcheries and fishmongers. To achieve this, the city council offered its citizens free reusable bags and containers. The study compared two scenarios, namely a 'business as usual' (BAU) situation for shopping, in which typically single-use materials are used, and a 'Campaign' scenario, which considers the consumption of reusable packaging according to the results of the Zamudio campaign. Primary data on packaging use were obtained from the surveys carried out during the campaign, while EXIOBASE v.3 was used as background database.
Results and discussion
The results of the social footprint show that the value of externalities, i.e. the social footprint in the Campaign scenario is 11% lower. If the rebound effect associated to the higher life cycle cost of the campaign is considered, the social footprint becomes 14% lower compared to the current situation.
Conclusions
This study is an example of how the concept of social footprint, together with a powerful tool like Exiobase, can pave the way for an operational approach to social LCA, avoiding excessive data requirements and the long lists of impact indicators currently proposed for bottom-up approaches.

Keywords: *Social LCA, rebound effect, Exiobase, Waste4Think*

Introduction
As part of the H2020 EU-funded project Waste4Think (https://waste4think.eu/), a pilot packaging waste prevention campaign was implemented in the municipality of Zamudio in Northern Spain. The main aim of this campaign was to reduce the number of single-use food wrappers and plastic bags used by the citizens while shopping in groceries, butcheries and fishmongers. To achieve this, the city council offered its citizens reusable bags and containers, that could be collected for free from the town hall through small gamification process (Figure 1). The campaign lasted from September 2018 to February 2019. During this period, researchers collected data on the level of penetration of these reusable packaging materials in local shopping. As part of the evaluation of this campaign, a social assessment by means of the social footprint method (Weidema 2016, Weidema and Schmidt 2018)

was carried out. The aim of this study was to determine whether or not the implemented strategies during the Zamudio campaign involved a lower social footprint, when compared to the current situation.

Figure 1. Reusable packaging materials distributed in the Zamudio campaign: reusable containers for meat and fish, bitsybags for fruit and vegetables.

Methods

The social footprint developed by Weidema (2016) constitutes a monetary summary measure of income redistribution and the sum of all productivity-reducing externalities related to a specific product or activity. It is calculated by a top-down approach using input-output data and can be understood as a 'streamlined' social LCA. It is constituted by two general components:

- The income redistribution impact (IR): calculated as the increase in utility caused by the transfer of money from one societal group to another. IR can be understood as a social benefit, given that it leads to an increase in utility.
- The productivity impact from missing governance (PI): calculated as the difference between the actual purchasing-power corrected value added and the potential value added when all productivity impacts are internalized. As opposed to IR, PI is a social detrimental impact.

The resulting social footprint of a product or activity can be defined as SF = PI - IR, where typically PI is of a higher magnitude than IR.

The social footprint was applied to two scenarios, similarly as in Muñoz et al. (2018) as follows:

- 'Campaign': in this scenario, we considered the consumption of reusable packaging according to the results of the Zamudio campaign. However, the figures we used do not reflect the real level of participation in the campaign, but rather an extrapolation to the entire municipality of the behavior of those citizens that initially participated in the campaign (it means, everybody who, at least, went to get the first reusable kit).
- 'Business as usual' (BAU): in this scenario, we consider the consumption of (typically single-use) packaging used in a 'no-campaign' situation.

The functional unit was the provision of packaging materials for shopping in groceries, butcheries and fishmongers in Zamudio during one year. The study tracked the entire supply chain for provision of packaging materials to local shoppers in Zamudio.

On the one hand, in the BAU scenario, the affected types of packaging were carrier bags, expanded polystyrene (EPS) trays, polyethylene (PE)-coated paper, wax paper and ultralight plastic bags. The estimated total amount of packaging materials corresponds to 2,273 kg/year. The full life cycle of these materials was considered, i.e. their production, use, and disposal. The use phase, however, does not involve any impacts from the point of view of the social footprint. On the other hand, in the Campaign scenario, shoppers use reusable containers during their shopping, however this does not completely avoid the use of single-use packaging, which is also considered. On top of the activities considered for the BAU scenario, this scenario includes the production of the plastic reusable containers and bags, their use for a certain period of time and their final disposal when they are no longer usable. In this scenario the use phase involves the activity of washing the reusable containers and bags with a certain frequency. The total consumption of packaging materials in this scenario is estimated at 834 kg/year.

Primary data on packaging use were obtained from online surveys carried out before, during and after the campaign allowing us to collect data on the level of penetration of the reusable packaging in local shopping. 334 citizens, 26.52% of the total dwellings, participated in a baseline inquiry to establish the shopping habits of the population. In the final stage of the campaign, 10% of the citizens carried out another survey, with the aim of comparing habits and to detect the use of reusable packaging in the long term, even if it was not supplied by the campaign. Additionally, all the participating commerce registered changes in packaging use habits among their customers during several weeks, in order to compare what is declared by the users and what they actually do. Questions about the wrappers preferred by citizens for different kind of foods (fruit, meat, fish) and also about carrier bags were asked and correlated with the general basket of food and frequency of shopping of Zamudio's citizens.

EXIOBASE v.3 (Wood et al. 2015) was used as background database, extended with social footprint indicators for each economic activity. Calculations were carried out with the software SimaPro 8.5.

As part of the social footprint study, we calculated the life cycle costs of the two scenarios. When the Campaign scenario leads to a different life cycle cost than the BAU scenario, this leads to a monetary imbalance that is addressed in the study as what is called a rebound effect (Font Vivanco and van der Boet 2014). When an activity leads to a reduction or increase in costs compared with a reference, this means the corresponding affected economic actor/s are left with either additional or less disposable income. This income is assumed to be spent in other activities, which in turn have a social footprint. The social footprint of this expenditure was calculated in the study on a per € basis, assuming the average expenditure behavior in Spain according to EXIOBASE.

Results and discussion

The results of the waste prevention campaign, when extrapolated to the entire population of Zamudio, lead to a lower social footprint than the BAU situation (Figure 2).

The net social footprint in the Campaign scenario, when the rebound effect is excluded, is 11% lower, and when the rebound effect associated to the slightly higher life cycle cost of the Campaign (12,420 €/year as compared to 11,860 €/year) is included, the net social footprint is 14% lower compared to the current situation. It must be highlighted that the rebound effect is subject to uncertainty, as it is assumed that reduced disposable income resulting as a consequence of this campaign will be spent according to average spending in Spain, which might not reflect reality accurately.

In the Campaign scenario, a substantial part of the social footprint is associated to the supply chain of washing (dishwashing plus handwashing) the reusable containers, which represents 61% of the total footprint. It can be seen that most of this is associated to dishwashing. The social footprint of dishwashing is mainly contributed by the supply chain of dishwasher components manufacturing.

Most of the social footprint benefit associated to the Campaign is found in the avoidance of plastic production supply chains, often taking place in developing countries such as China or in Africa. Besides plastics production, the Campaign scenario also shows relevant benefits associated to the lower packaging paper demand, as well as in several waste management activities.

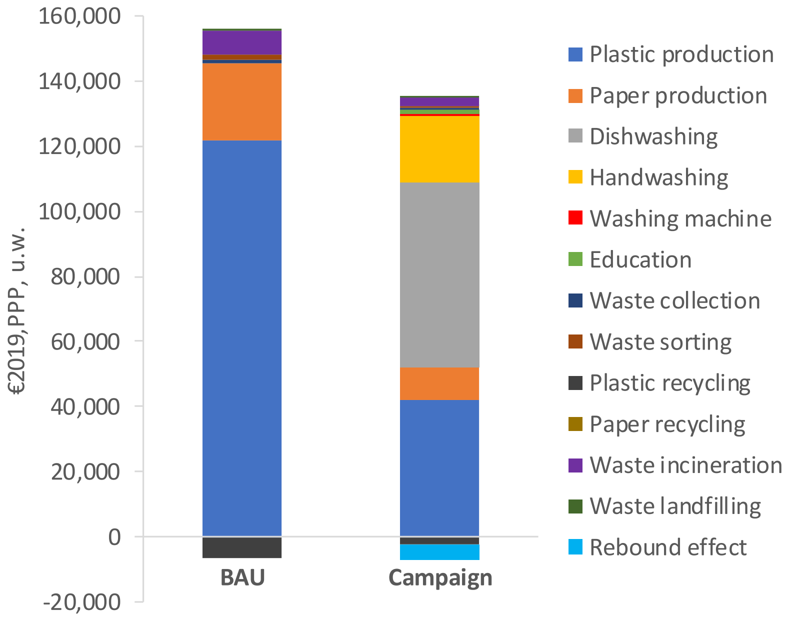

Figure 2. Contribution analysis for the social footprint.

The main benefit of the social footprint method lies in the use of widely available background information from databases such as EXIOBASE to assess impacts top-down. This means that some initial data are always available for practically any study, therefore reducing the overall cost of data collection. The quality of the available data may sometimes be insufficient, at the level of aggregation of economic sectors (a well-known issue for input-output databases) as well as in terms of world regions. In some cases, sub-country data might be required, or the country in which a case study takes place might not be available in the database, but clustered in a rest-of-the-World region. In other cases, the resolution of economic sectors might be insufficient. This is where alternative bottom-up approaches to social footprinting, such as the social impact valuation method (Vionnet and Pollard 2017) have their strength.

Conclusions

This study is an example of how the concept of social footprint, together with a powerful tool like Exiobase, can pave the way for an operational approach to social LCA, avoiding excessive data requirements and the long lists of impact indicators currently proposed for bottom-up approaches. As with environmental LCA, the social footprint can be applied to any production and consumption context, including food, as shown in Weidema and Schmidt (2018). Besides the social footprint, the study is also innovative as has been applied to an environmental education campaign aimed to prevention, in order to monitor and quantify its results and benefits.

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Abstract code: ID 260

Under- or over-packaging: a key question in the food waste debate?

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Abstract

In Europe annually 88 million tonnes of food are wasted, while 17 million tonnes of packaging are sent to final disposal, resulting in huge economic and environmental impacts. Both problems are interconnected since insufficient packaging leads to higher food waste rates, while abundant packaging results in unnecessary packaging impacts. The aim of this study is to provide guidelines for sustainable packaging solutions, optimizing packaging and reducing food waste.

In the present study, LCA and LCC are applied in order to identify sustainable packaging solutions, reducing food waste and packaging itself to the minimum, finding a balance between under- and over-packaging. In order to reach this goal, LCA and LCC are applied at three levels: state of the art level; technology level and end-user level. Based on the LCA and LCC outcomes on all three levels, guidelines are developed to support the choice of tailor-made sustainable packaging solutions for different food packaging combinations. The guidelines are summarized in an ecodesign decision tree for sustainable packaging.

Food packaging combinations are complex systems, influenced by not always predictable consumer behaviour. Therefore a "one fits all" solution does not exist. Contrarily, an ecodesign decision tree is proposed with an attempt to guide present food packaging combinations towards more sustainable "fit for purpose" solutions. In this context, the question of under- or over-packaging is a starting point that triggers the discussion on eco-efficient food packaging combinations. Other key issues are consumer behaviour, procurement planning, portioning, shelf life and packaging innovation. Under- or over-packaging is therefore not the only question in the food waste debate, but important enough to trigger the discussion.

Keywords: *LCA; LCC; under-packaging; over-packaging; food waste.*

Introduction

In Europe annually 88 million tonnes of food are wasted, corresponding to an estimated 20% of the total food produced each year, costing approximately € 143 billion (EU 2019), while according to Robertson (2012) just over 17 million tonnes of packaging are sent to final disposal (i.e. landfill or incineration without energy recovery), resulting in huge economic and environmental impacts. Both problems are interconnected since insufficient packaging leads to higher food waste rates, while abundant packaging results in unnecessary packaging impacts (Verghese et al. 2015). In other words, both under-packaging and over-packaging can occur in present food packaging combinations and represent suboptimal and inefficient situations.

The aim of this study is to provide guidelines for sustainable packaging, optimizing packaging and reducing food waste. The present study provides an example of how LCA and LCC can be used as a decision support tool to guide sustainable packaging. The research results, part of the MyPack H2020 project (MyPack 2018; Breedveld 2019), are preliminary and will be further elaborated.

Material and methods

In the present study, LCA and LCC are applied in order to identify sustainable packaging solutions, reducing food waste and packaging itself to the minimum, finding a balance between under- and over-packaging. In order to reach this goal, LCA and LCC are applied at three levels:

- State of the art level: with 100 performed screening LCAs and LCCs many cases of under-packaging and over-packaging are identified and food packaging clusters are defined.
- Technology level: in order to go beyond the state of the art and offer solutions for the under- and over-packaging situations identified within the 100 LCAs, novel technologies are proposed (e.g. biodegradable materials; high oxygen barrier packaging; heat resistant PLA; breathing film using an insertion; SiOx inert barrier). The sustainability of the technologies will be verified by means of LCA and LCC.
- End-user level: suitable technologies will be tested at three end-users: salads, baby food and organic products. During the end-user cases various scenarios can be explored (e.g. food waste, decoupling point, use scenarios, end-of-life scenarios), contributing to the formulation of guidelines for sustainable packaging solutions.

LCA and LCC are applied according to the ISO 14040/14044 standards on LCA (ISO 2006a; ISO 2006b), following an attributional modeling approach. Further methodological guidance on LCC is provided by the SETAC handbook on Environmental Life Cycle Costing (Hunkeler et al. 2004).

The functional unit is defined as one portion of consumed food by the final user, normalised to 1 kg. The consumed food has been evaluated together with its packaging. Secondary packaging has been only evaluated if it is part of the sales unit. The definition of the functional unit at the level of consumed food, instead of at the level of produced food at the store shelf, allows a more explicit visualization of the food waste impacts, as also argued by Wikström (2013).

The system boundaries include raw materials, transport, production processes, packaging, distribution and storage processes and product end-of-life. The following processes are excluded from system boundaries: transport of packed food from the distribution centre to retail, transport from retail to consumer, food preparation at the consumer and disposal of digested food. Transport processes to retail and from retail to consumer are excluded due to their limited impact. The food preparation at consumer has been excluded due to its dependency on consumer behaviour. The exclusion of disposal of digested food is common practice in LCA (EPD 2017).

In the 100 LCAs primary data have been collected for food ingredients and packaging materials of the selected food packaging combinations. For other processes secondary data have been used, originating from LCA databases like ecoinvent (2018), and Agri-footprint (2017) or literature data (LCA publications, EPDs). The use of secondary data is justified due to the screening character of the 100 LCAs and because the purpose of the study is not the assessment of a specific food-packaging combination, but an average evaluation of food packaging combinations on the market.

Multi-output allocation of datasets from LCA databases are based on economic allocation, if applicable. In case of end-of-life allocation the cut-off approach has been applied. Geographical and temporal boundaries refer to the current European market. Life Cycle Impact Assessment is performed with the ReCiPe method (Huijbregts et al. 2016) and the ILCD method (EC 2011) which at a later stage has been replaced by the EF method (EC 2019).

Based on the outcomes of the LCAs and LCCs on all three levels, guidelines are developed to support the choice of tailor-made sustainable packaging solutions for different food packaging combinations.

Results and discussion

The LCA results of the 100 screening LCAs and LCCs, the state of the art level, have been presented firstly individually by means of environmental data sheets (2B 2019). An environmental data sheet is an "environmental identity card" that reports environmental and economic performances of each food packaging combination by means of LCA and LCC. Secondly, LCA results have been presented collectively by means of grouping. Grouping has been done according to different criteria: the relative impact of food against packaging, the specific food sector, different types of packaging, and the magnitude of portions. Figure 1 shows an example of grouping of food against packaging impact, calculated with the single score of the ReCiPe method (Huijbregts et al. 2016), of one third of the investigated food packaging combinations.

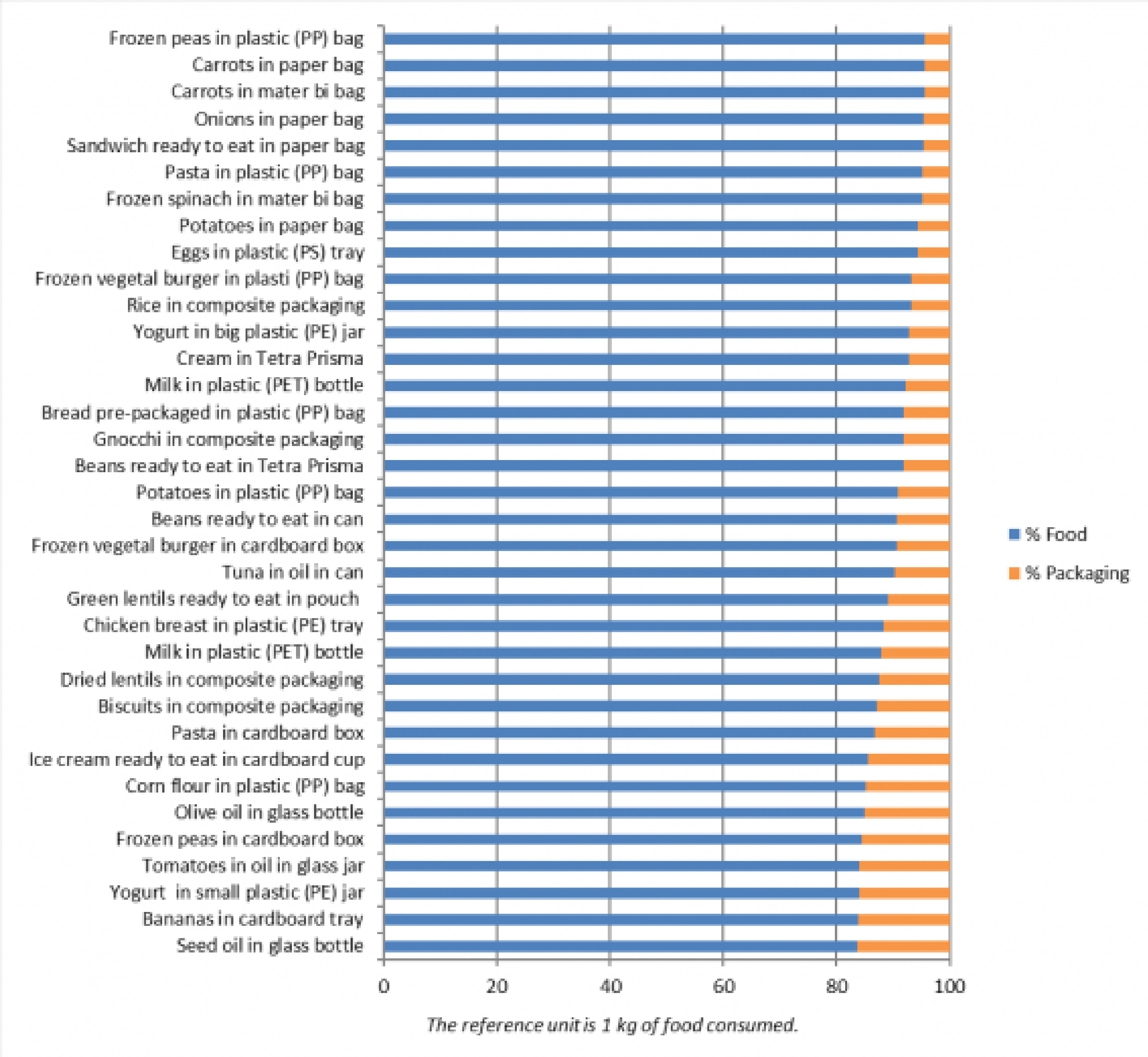

Figure 1: LCA results of analysed food packaging combinations, showing the food and packaging impact.

Furthermore, LCA and LCC are performed at the technology level and end-user level. At the technology level datasets have been created for 3 markets (i.e. biobased and biodegradable film for fresh and processed food; inert, heat resistant and barrier packaging for processed food; and blow device for fresh food) and associated technologies (e.g. biodegradable materials; high oxygen barrier packaging; heat resistant PLA; breathing film using an insertion; SiO_x inert barrier).

Finally, LCA and LCC are performed at the end-user level with selected case studies (salads, baby food, biscuits), where the above mentioned innovative packaging technologies are applied and compared to the baseline situation. Preliminary results show that innovative packaging technologies can improve the packaging situation in two directions:

- Under-packaging: packaging film for pre-cut salads can be improved by the use of a blow device (Altieri, 2018; Matera, 2020), allowing gas exchange between the inside and the outside of the packaging film lengthening the shelf-life from 1 week to 2 weeks, reducing food waste by 40% (2B 2020). In this example of under-packaging, additional packaging technology (i.e. blow device) results in a longer preservation of the salads and associated reduced food waste and reduced impact;
- Over-packaging: rigid plastic trays for baby food can be improved by the use of recycled materials. In this example of over-packaging, the rigid packaging already fulfils its function to protect the food but its impact can be reduced by using recycled materials, where food waste rates remain unaltered.

Based on the LCA studies various learning points can be identified (2B 2019). The environmental evaluation of packaging should be done in relation to the food product covering the entire life cycle, including the use phase and end-of-life. Modelling assumptions of use and end-of-life scenarios influence significantly the estimated environmental impacts of a food product. In particular, the percentage of food waste at retail and consumer level are relevant. The analysis of direct and indirect impact of packaging in the food-packaging supply chain enables to understand the relevance of hidden indirect impacts, like food waste.

For most cases, food has a higher contribution to the environmental burden of food packaging combinations than packaging. Packaging reduction is relevant, however possibilities to reduce food waste by innovative packaging solutions should not be overlooked, especially for those food items with a high environmental impact (e.g. dairy products). The use of innovative packaging solutions can improve the protective function of packaging and by doing this reduce waste and associated impacts. Tailor made portions enable food waste reduction where an increase of packaging can be justified when food waste reduces. Environmental impacts of fit for purpose packaging (e.g. a more protective packaging to extend the food shelf life) are related to consumer habits; often only postponed consumption can justify the use of more complex packaging.

In case food is well protected and food waste is already minimized, reuse and recycle scenarios can reduce the packaging impact. Packaging reuse scenarios become interesting when the reuse rate is high enough (e.g. 5-10 times for glass (2B 2019)). Eco-efficiency results reveal some correlation between environmental impacts and costs. Complex food (e.g. processed food) have higher costs and impacts than simpler food products.

Various guidelines are available to support the development of sustainable packaging solutions. Both in the public sector and the private sector guidelines have been created, like the Australian Packaging Guidelines of the Australian Packaging Covenant Organisation (APCO, 2020), the sustainable packaging mode of the Dutch Knowledge Institute for Packaging (KIVD, 2020), and private initiatives from companies such as Henkel (2020) and Lockheed Martin (2020).

Based on the LCA learning points, guidelines are developed to support the choice of tailor-made sustainable packaging solutions for different food packaging combinations (2B 2020). The added value of these guidelines in comparison to existing guidelines is the combination of quantitative eco-efficiency assessment with qualitative criteria. LCA and LCC are used both as ecodesign tools to recognize the packaging situation and identify hotspots, and as decision support tools to verify the eco-efficiency of the proposed improvement options.

Food packaging combinations are complex systems, a "one fits all" solution does not exist. Contrarily, an ecodesign decision tree is proposed with an attempt to guide present food packaging combinations towards more sustainable "fit for purpose" solutions (2B 2020). The ecodesign decision tree consists of the following steps (Figure 2).

Select your packaging strategy: under- or over-packaging as a starting point to improve food packaging combinations. Either improve the protective or preservation function of your packaging in order to reduce food waste for instance through innovative packaging technologies to overcome technical barriers and force a breakthrough to move away from suboptimal situations. Or reduce packaging impacts by means of reuse, recycled content, mono materials, alternative materials, weight reduction and recycling. Of course you can also work on both strategies, once your packaging function is optimised in terms of food waste reduction, you can continue working on packaging impact reduction. Check through eco-efficiency analysis environmental and economic aspects of your packaging solution in comparison to the baseline situation in order to avoid burden shifting and to confirm the "fit for purpose" of the packaging solution.

Work on the supply side in order to promote the market uptake of the new packaging solution (e.g. convenience, quality, value for money and communication). Work on the demand side assuring consumer acceptance, which is a potential barrier since consumers tend to associate packaging with waste problems and overlook positive aspects (i.e. food waste reduction). On the other hand, this is an opportunity: putting the question of under- or over-packaging on the agenda opens the door to consumers to link packaging with food waste reduction and influence consumer behaviour on for instance portioning choices and procurement strategy in relation to timing of consumption. In other words, if the consumer starts reasoning "I'll eat the salad today, so I'll choose the easiest packaging solution" or "I'll eat the salad after a week, so the packaging with blow device is the best fit for purpose packaging since I can avoid food waste", then we've gained a lot.

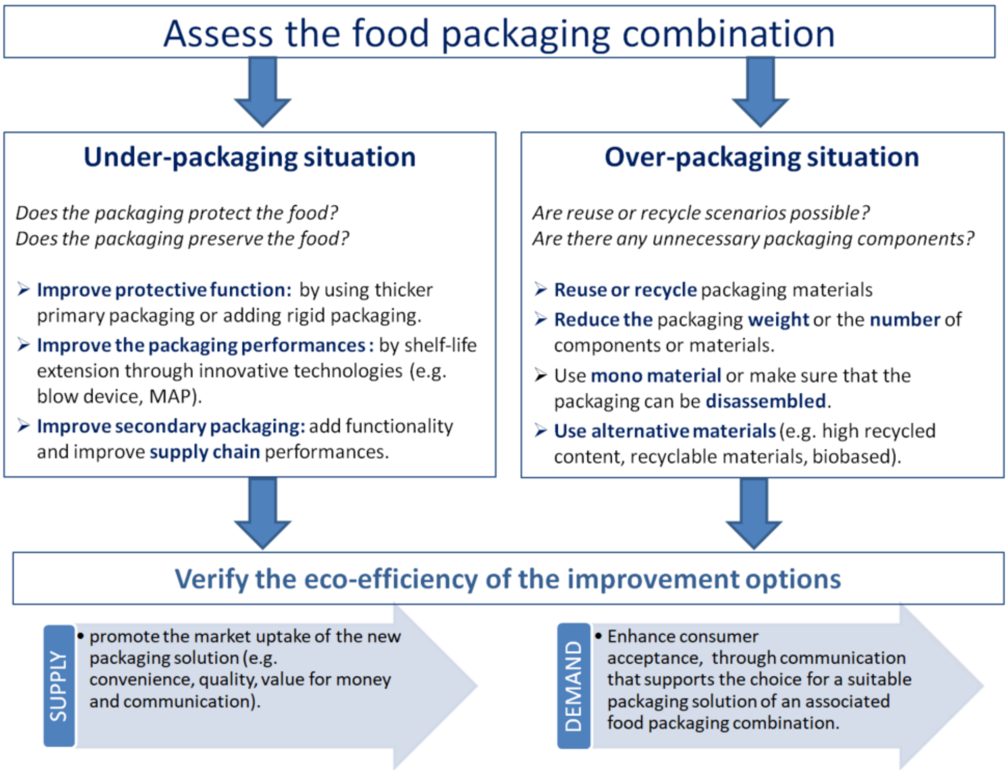

Figure 2: Ecodesign decision tree to support sustainable food packaging combinations (2B 2020).

Conclusions

Food packaging combinations are complex systems, influenced by not always predictable consumer behaviour. Therefore a "one fits all" solution does not exist. Contrarily, a decision tree is proposed with an attempt to guide present food packaging combinations towards more sustainable "fit for purpose" solutions. In this context, the question of under- or over-packaging is a starting point that triggers the discussion on eco-efficient food packaging combinations. Other key issues are consumer acceptance, procurement planning, portioning, shelf life and packaging innovation. Under- or over-packaging is therefore not the only question in the food waste debate, but important enough to trigger the discussion.

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Abstract code: 184

Using urban coffee ground waste for mushroom farming reduces environmental impacts

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Abstract

Urban agriculture allows for the innovative reuse of urban wastes that are typically destined for disposal. The environmental sustainability of circularity in agriculture has been evaluated with life cycle assessment (LCA) but remains poorly understood, especially for urban agriculture Furthermore, the modeling choices involved in LCAs of systems that reuse waste can be critical, and this has been little discussed in the literature. Our research questions were twofold: first, what effect does circular urban waste reuse have on urban agriculture's environmental impacts, and second, what LCA system modeling choices are appropriate to capture this? We performed a LCA of an alternative urban mushroom farm next to Paris, France, to evaluate the effect of using an urban waste (spent coffee grounds, SCGs) in comparison to a classical mushroom farm using straw. The alternative mushroom farm was a multifunctional system because it treated waste and produced mushrooms, and we accounted for this using system expansion. This was done by including the fate of the material that was not used at the farm: in the classical system, coffee grounds were incinerated, and in the alternative system, straw was used for mulch. Our results showed that the alternative farm had lower impacts than the classical farm in all impact categories by 15-89%. For most impact categories, this was due to lower impacts in both the farming sub-system and the expanded sub-system. However, for climate change, the alternative farming sub-system had larger impacts than the classical one due to increased transportation from delivery of SCGs. Ultimately, the impact of coffee ground incineration in the classical system offset this advantage. Our modeling choice of system expansion appeared suitable for this case because we were able to highlight these trade-offs between comparable systems. This would not have been evident if we had used substitution or allocation to reduce the alternative mushroom farm to a single-product system. Our work suggests that to evaluate use of alternative waste products in urban agriculture with LCA, a comparative study and system expansion are appropriate to highlight trade-offs and include external circular advantages.

Keywords (6): life cycle assessment; urban agriculture; mushroom farm; circular agriculture; system expansion; urban waste

Introduction

Circular and urban agriculture are gaining attention as means to potentially produce food with lower environmental impacts than typical linear, rural farms. Although urban agriculture is not necessarily circular by nature, urban farms and gardens are uniquely positioned to use urban waste, which may improve their environmental sustainability (Mohareb et al., 2017). Examples of this urban waste include excess building heat and CO_2 to support greenhouses, wastewater for irrigation, and organic waste composting to recover nutrients and organic matter to apply to crops (Mohareb et al., 2017). It has been estimated that urban wastes could largely supply the nutrient and water needs of urban agriculture in some cities, and conversely, urban agriculture could assimilate up to 17-52% of urban food waste (Weidner and Yang, 2020).

The method of life cycle assessment (LCA) has been used to evaluate environmental impacts of circular agriculture systems and compare them to conventional alternatives. Case studies have included as many as 7 sub-systems with circular exchanges (where waste from one sub-system used as an input to another sub-system), highlighting the complexity of modeling multi-product, multi-functional systems and reducing them to the typical single-product system considered in LCA (Fan et al., 2018). This complexity is dealt with allocation, or system expansion with or without substitution (Medeiros et al., 2019). In some cases, circular options perform better than the linear option only if external benefits from avoided burdens are included (eg, waste disposal), because inefficiencies can emerge in the loosely established circular systems (Medeiros et al., 2019). More experimental results are needed to evaluate the environmental sustainability of reuse of waste in agriculture, and in particular for urban agriculture. Additionally, a discussion on methodological choices for LCA is needed to determine appropriate modeling choices.

We investigated the environmental impacts of using urban waste in urban agriculture by performing a LCA of an urban mushroom farm. We compared this alternative oyster mushroom farm that uses an urban waste (spent coffee grounds, SCGs) as the main input, to a typical oyster mushroom farm using an agricultural co-product (straw) as the main input. We evaluated the environmental impacts of the two systems, and the suitability of our system modeling choices.

Materials and methods

We performed an attributional LCA with a cradle-to-market scope to evaluate the environmental impacts of oyster mushroom farming near Paris, France. The goal of this LCA was to evaluate the effect of using an innovative, circular substrate material (SCGs) for mushroom farming, instead of the typical material, (straw), by comparing results from the two systems. The life cycle inventory (LCI) was compiled through interviews with the farmers, farm records, and utility bills. We used the software SimaPro v9.0, the LCI database Ecoinvent v3.5, and the ReCiPe 2016 impact assessment method, for climate change, land use, water depletion, and freshwater eutrophication impacts.

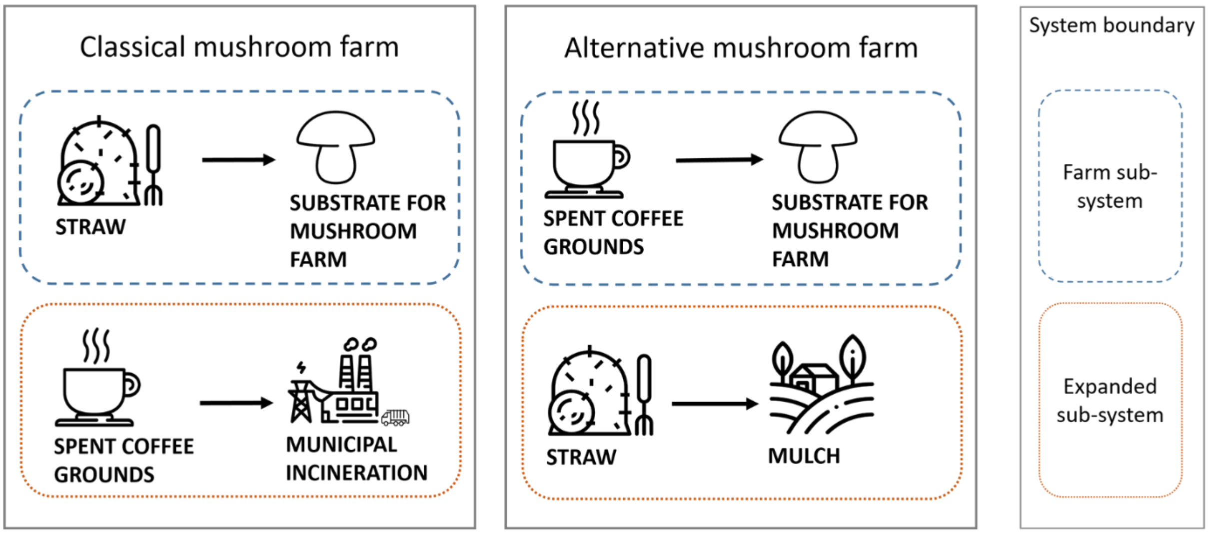

Figure 1: A graphical representation of the two systems being compared. First, in the classical system, the typical substrate material (straw) was used for mushroom production, and spent coffee grounds were incinerated. In the alternative system, spent coffee grounds were used for mushroom production, and straw was left in the field as mulch.

The farm is located in the Yvelines department next to Paris, France. Data were collected from operations during 2018, when 8,728 kg of mushrooms were grown and approximately 30 tons of SCGs were reused. According to the farmers, SCGs are not a common substrate material for mushroom cultivation because they are easily contaminated with pathogens. Additionally, supply chains for SCGs are not usually established and available to typical, rural mushroom farmers. Situated next to a city with large coffee consumption, this farm, along with a non-profit waste collection service, was able to tap into the city's waste stream and divert SCGs from incineration. Details about the system modeling and the LCI can be found in Dorr et. al (2020, under review). One important difference was that SCGs and wood chips were both major components of the substrate, comprising 42% and 29% by mass, respectively, but here we assume that only SCGs were used instead of wood chips.

Several options for modeling the use of SCGs and straw were available because they are recycled inputs, which are notoriously complicated for LCA modeling. In the classical system, straw was treated as a co-product of a grain system, since it is usually reused or sold and has value. Environmental impacts were allocated economically to the straw from the grain system, resulting in 10% of the grain impacts given, following the method used in Ecoinvent. We treated SCGs as a waste product, because there are not usually recycling flows for SCGs, and we assumed that in Paris they would have otherwise been incinerated (Syctom, 2018). This rendered the alternative mushroom farm a multifunctional system, because it performed the primary function of producing mushrooms, along with the secondary function of treating waste. We handled this multi-functionality using system expansion, meaning that the system of interest was expanded to include alternative performance of the system's additional functions. We expanded the systems to include not only the farming system, but also the system accounting for the alternate fate of the substrate material that was not used (Figure 1). In the classical system, the expanded sub-system accounts for SCGs by municipal waste treatment (incineration), and in the alternative system, the alternate fate of straw was mulching in the field, which had no impact. The functional unit of the systems was 1 kg of oyster mushrooms produced and 1 kg of SCGs treated.

Results and discussion

The alternative production system had smaller impacts than the classical production system by 15-89%. The difference in impacts between these systems come from two factors: first, in the farming sub-system there were different raw material and supply chain impacts from straw (low impacts allocated from grain production) and SCGs (no impacts because waste product). Specifically, straw was allocated 10% of the impacts of grain production. Second, from the expanded sub-system, which for the classical farm involves incineration of SCGs, and for the alternative farm involves using straw as mulch (no impacts). Both of these factors drove differences in impacts between the two systems, although they had varying influences depending on the final impact (Figure 2).

Climate change impacts for the classical system had a large contribution of impacts from SCG waste treatment (56%). However, comparing climate change impacts between only the farming sub-systems, the alternative system had larger impacts than the classical system. This was due to more frequent deliveries of SCGs than of straw, highlighting a trade-off in using alternative materials with informal, potentially inefficient supply chains. The comparison was more straightforward for the other impact categories, because the farming sub-system of the classical system consistently had larger impacts than the alternative system. Then, impacts from incineration in the expanded sub-system exacerbated these differences.

System expansion is often accompanied by substitution in LCAs, where the expanded alternative system is subtracted from the system of interest (Curran, 2013). Here, that would involve subtracting SCG incineration impacts from the alternative system. This would be useful to narrow the scope to a single product system, by changing the functional unit to simply 1 kg of mushrooms, and eliminating the need for a comparison to the classical system to observe the benefits of the circular system. This approach would be reasonable, and mathematically the relative results between the systems would be the same (Nakatani, 2014). However, our approach was more appropriate here for several reasons. First, if we perform this substitution, the climate change impacts of the alternative system are negative (-0.15 kg CO_2 eq. / kg mushroom). This is problematic because negative impacts are not intuitive and are difficult to use elsewhere (Curran, 2013). Second, the comparative nature of our study does not necessitate a single-product system; rather, two comparable systems with identical functions. This allows us to manipulate the system boundaries and capture external services, as long as the functions of the systems are comparable. Perhaps this approach- comparative LCAs using system expansion (without substitution) - is more appropriate for studying complex circular systems, rather than single-product LCAs using allocation or substitution. The former captures external activities and networks of actors in a complex system, rather than reducing it into a singular product system with embedded credits.

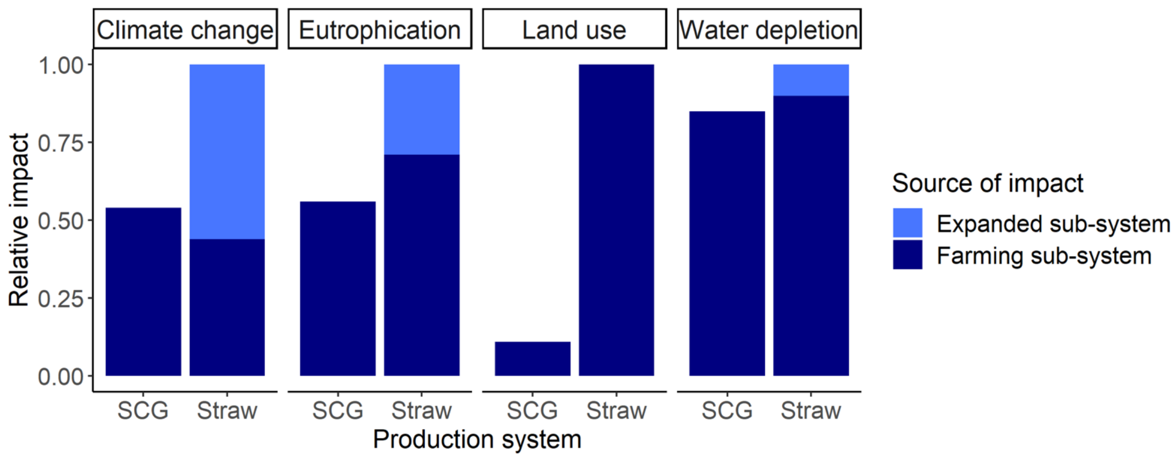

Figure 2: The alternative system using spent coffee grounds had lower impacts than the classical system using straw for all categories. This was due to differences in both the input materials and supply chains in the farming sub-systems, and differences in the expanded sub-systems. For the latter, the incineration of spent coffee grounds incurred large impacts for climate change in particular.

The decision to use system expansion was dependent on our choice to treat SCGs as waste, rather than as a co-product. Since food waste is not usually separately collected in Paris, the SCGs likely would have otherwise gone through the municipal waste stream if they had not been used by the mushroom farm (Syctom, 2018). The activities of the mushroom farm so directly affected the fate of the SCGs that we argue it is relevant to include this outcome. In contrast, straw was a co-product and raw material input with embedded impacts. The distinction between waste and co-product for residual biomass is blurry, and depends on several contextual factors. In fact, as a circular economy is increasingly pursued, materials that were once waste with no other use may transition to a co-product status, if it becomes the norm to use them (Olofsson and Börjesson, 2018). Then, these materials should be allocated some impacts, like the case of straw. In the future, or in other cities with large biomass collection systems, SCGs may be considered a co-product with impacts. Because reuse of urban waste is a promoted benefit of urban agriculture, particular attention must be paid to the waste status and alternative flows of these recycled materials when performing LCAs of urban agriculture.

Conclusion

In a comparative LCA of urban mushroom farms with typical and alternative input materials, the latter had lower environmental impacts. This improved performance was due to both the different impacts of the input materials themselves, and due to the external benefits from using waste that would have otherwise been incinerated. We used system expansion to take into account the additional function of the alternative system (waste treatment) by including the fate of the input material that was not used for mushroom farming. Although this method does not allow for a single product system, and may not be useful for benchmarking impacts of products, we found it was appropriate in this case. To evaluate circular exchanges of waste and co-products in LCA, system expansion may be more suitable than allocation because it can include a more complete set of actors and external benefits.

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Abstract code: 304

Obesity versus food waste treatment: sustainable strategies for dealing with avoidable food waste at consumer stage of value chains

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Abstract

Purpose

Food waste in developed countries is generated mainly at the end of value chains. Current treatment disposal methods include anaerobic digestion, incineration, wastewater treatment, composting, application as animal feed (for pets) and other options. Reducing of avoidable food waste through human consumption (redistribution, sharing) is perceived as better option. The aim of the study is in comparing the environmental impact of avoidable food waste utilization for human consumption by German population to the impact of conventional food waste management system.

Methods

Current study is theoretical and based on several published data sources, used for the calculation of four impact categories: global warming impact, land use, water footprint and energy demand. Estimation of health impact with extra food consumed included calculation of food calorific value (USDA National Nutrient Database for Standard Reference). Accumulation of weight and increase in obesity rates was calculated after (Swinburn et al. 2009). Calculations of demographic structure and current state of obesity rates in Germany relied on statistical sources. Identification of the environmental impact of current healthcare system and share of the healthcare related to overweight and obesity states was performed after (Steen-Olsen et al. 2012; Shephard 2019; Pichler et al. 2019).

Results and discussion

The results indicated that current waste management system was more beneficial for the environment than consuming excessive food by German population and requesting related medical services in categories of global warming potential (0.128 versus 0.6-2.4 Mt CO_2eq.), energy demand (-21 versus 16-66 PJ) and water footprint (-1607 versus 13.2-53 million m^3). However, land use impact allocated to the need of additional healthcare due to food consumed by humans was 13-80% lower than that of the current waste management system. Additional danger of consuming excessive food related to accumulated risks and further increased demand for health services. Following years would worsen the situation, making the choice for "food waste avoided diet" through redistribution unfeasible.

Conclusions

The results received do not allow for a simple answer on the selection of more sustainable strategies of dealing with excessive amount of food in every specific case. However, they allow to indicate preferable conditions for dealing with excessive food in model conditions, which account for health state of household members or group of people (population), nutrient density and amount of food, and time frame. Time factor and current obesity rates are the determining factors defining preferences for food wasting or consumption.

Keywords: *food waste; obesity; environmental impact; LCA; waste treatment.*

Introduction

In developed countries the food waste occurs in a great degree at the end of the value chains (at the consumer) (Kummu et al. 2012; Stenmarck et al. 2016). It is impossible to discuss the progress towards sustainable food systems without tackling the problem of food waste at the end of agri-food chains (Stenmarck et al. 2016; Beretta et al. 2017; Smetana et al. 2019, 2020; Pleissner and Smetana 2020).

There are 7-9.9 Mt of potentially avoidable food waste (51% of all waste) at the end of the supply chain in Germany (Noleppa and Cartsburg 2015; Schmidt et al. 2019c). Recently finished study (REFOWAS research project) concluded that around 40% of avoidable food waste in Germany arises in private households (Delley and Brunner 2018). Another study commissioned by BMEL in 2016 examined in a representative manner the compositions and waste treatment routes in Germany through surveys and measurements (Hübsch and Adlwarth 2017; Schmidt et al. 2019a).

Excessive amount of avoidable food waste, according to the waste management pyramid, should be preferably utilized as food (Papargyropoulou et al. 2014). At the same time, considering that 54.8% of Germans are overweight and obese, excessive food consumed could lead to serious consequences and spending of additional resources for the weight management or medical treatment of obesity-associated conditions and diseases.

What is cheaper for the environment and current state society to waste the excessive food (also considering all the upstream resources used) or consume and treat it as a metabolic waste? The question has deep conceptual roots and requires a holistic approach towards assessment of a few complex systems: food production, food waste treatment, and medical system. At the same time, the study is not aiming to justify the overproduction rates, neither the known priorities in dealing with food waste (Liu et al. 2019). It is rather a search for the guiding sustainability strategies for the consumers, canteens, restaurants and other end consumers for the dealing with excessive food.

Material and methods

The study relied on published data for the analysis and calculations of food waste amounts at household level in Germany: statistical data on general amount of food waste (Noleppa and Cartsburg 2015; Schmidt et al. 2019c); stratified detailed data on food waste amount and treatment routes at consumer level from the recent study of GfK SE (Hübsch and Adlwarth 2017; Schmidt et al. 2019a); detailed and deep analysis of food waste use and impact from the results of REFOWAS project (Schmidt et al. 2019c). The data from indicated sources allowed to define two variables of avoidable food waste amount at the household level: upper ~7 Mt (Noleppa and Cartsburg 2015) and lower ~3 Mt (Schmidt et al. 2019c). Relative distribution of food waste and related waste treatment scenarios were based on the study of GfK SE (Hübsch and Adlwarth 2017).

It was assumed that food waste at household level was treated (managed) in one of the ways indicated in the study (Hübsch and Adlwarth 2017). Quantification of environmental impacts was performed for four impact categories (global warming potential, land use, water footprint and energy demand). Calculations were based on average values from numerous LCA studies performed for food waste treatment with anaerobic digestion (Poeschl et al. 2012; De Vries et al. 2012; Kim et al. 2013; Lijó et al. 2014; Jin et al. 2015; Xu et al. 2015; Ebner et al. 2015; Woon et al. 2016; Di Maria et al. 2016; Ahamed et al. 2016; Mondello et al. 2017; Opatokun et al. 2017; Slorach et al. 2019), composting (Güereca et al. 2006; Blengini 2008; Cadena et al. 2009; Martínez-Blanco et al. 2010; Takata et al. 2012; Vázquez-Rowe et al. 2015; Di Maria et al. 2016; Raghuvanshi et al. 2017; Mondello et al. 2017), incineration (Kim et al. 2013; Ahamed et al. 2016; Mondello et al. 2017; Opatokun et al. 2017; Slorach et al. 2019), wastewater treatment (Dixon et al. 2003; Foley et al. 2010; Buonocore et al. 2018; Guven et al. 2018), feeding to pets (Herrera-Camacho et al. 2017; Su et al. 2018; Su and Martens 2018) and other methods which represent average impact values of all other waste treatment methods.

Calorific content of the wasted food was accounted from approximate composition in published studies (Hübsch and Adlwarth 2017; Schmidt et al. 2019b, c; Toti et al. 2019) and relevant calorific values from USDA National Nutrient Database for Standard Reference (US Department of Agriculture (USDA) 2018). Accounting of calorific content of potentially avoidable food allowed the estimation of overall excessive fat weight each representative of German population in general or for specific groups will be able to gain annually. In order to calculate the weight gain by German population, the study relied on the equation (1) developed by Swinburn et al. (Swinburn et al. 2009) for the population with constant height and age. German population was divided into groups with similar average age and height, and weight gain was calculated.

$$\left(\frac{W_2}{W_1}\right) = \left(\frac{EnFlux_2}{Enflux_1}\right)^{0.712} \qquad (1)$$

where, W_1 – initial weight of a person, kg; W_2 – resulting weight of a person in one year, kg; $EnFlux_1$ – initial energy flux, amount of energy consumed daily to maintain the body weight W_1, MJ; $EnFlux_2$ – changed energy flux, amount of energy consumed daily to maintain the body weight W_2, MJ.

The analysis of potential changes to the population included the accounting of demographic structure (United Nations 2019) and current state of obesity and overweight rates in Germany (DiBonaventura et al. 2018). Estimation of healthcare system environmental impact was based on large-scale LCA studies conducted for a few countries like USA (Eckelman and Sherman 2016), the United Kingdom (Sustainable Development Unit for NHS England and Public Health England 2018), Australia (Malik et al. 2018), and Canada (Eckelman et al. 2018). Current study relied on the estimates of carbon footprint available in literature (Steen-Olsen et al. 2012; Pichler et al. 2019), while for other impact categories it was assumed that share of healthcare impact was the same as the ratio of spending for healthcare system to the national GDP. The ratio in Germany is 11.45% (OECD 2019). Using estimated impact values per capita for water footprint, land use, fossil energy use (Hertwich and Peters 2009; Galli et al. 2012; Steen-Olsen et al. 2012; Weinzettel et al. 2013) it was possible to define German healthcare system impacts. Further, it was assumed that current share of healthcare impacts in developed countries associated with obesity state is in the range of 5% (Shephard 2019) and that adding extra weight would result in additional increase in 1-4%. The study concluded with the comparison of LCA results of conventional food waste treatment system and food reuse.

Results and Discussion

Representation of potentially avoidable food waste distribution with embodied calorific value indicated that highest portions of energy (more than 2 million GJ annually) was wasted with bakery products (in residual and organic bins and pets/animals) and cooked dishes (residual and organic bins). They were followed by fresh meat/fish, processed convenience foods and dairy products dumped in residual waste bins with values close to 2 million GJ annually. Similar energy amount was required for the wastewater treatment of wasted dairy products. Somewhat lower amount of energy (around 1 million GJ for each product category) ended up with fresh fruits, vegetables and meat/fish, as well as processed convenience products in organic waste bins. Similar calorific values were allocated to wasted cooked dishes through wastewater and other foods through residual waste bins.

Recalculation of wasted calorific energy per capita in Germany indicated the highest values allocated to wasted bakery products (around 174 MJ) followed by cooked dishes (around 108 MJ). Total energy per capita wasted with potentially avoidable waste in Germany is more than 128 000 kcal annually. Such amount of energy could transform in additional 6.29-13.6 kg of weight gain annually if added to currently consumed food. It should be noted that current level of calorific load for German population could result in baseline weight gain in the range of 9.26-12.87 kg / annually (average 10.2 kg annually). Joined calorific impact of current level of food consumption with consumption of potentially avoidable food waste could result in tremendous weight gain in range of 15.5-26.5 kg annually. On the other hand, waste treatment of avoidable food waste resulted in very diverse environmental impacts (Table 1).

The identification of the potential connection between excessive food consumed and environmental impact of such metabolic waste required the estimation of the current allocation of German healthcare resources to the treatment of overweight and obesity-related conditions. It was possible through relation on the literature resources (Steen-Olsen et al. 2012; Pichler et al. 2019; Cimprich et al. 2019) and assumptions on applicability of defined healthcare resources for the treatment of conditions related to overweight and obesity (Lehnert et al. 2015; Effertz et al. 2016; DiBonaventura et al. 2018). German healthcare system therefore was responsible for more than 60 million tons of CO_2eq. of GHG emitted; 1.6 billion GJ of energy used; 265 000 km^2 of land used; and 1.3 km^3 water depleted. Such huge amounts were in the range of values reported in literature for other countries (Eckelman and Sherman 2016; Sustainable Development Unit for NHS England and Public Health England 2018; Eckelman et al. 2018). Considering high levels of overweight and obesity in Germany (Schienkiewitz et al. 2017), 5% of healthcare resources can be allocated to the current treatment of overweight and obesity-associated conditions. Interesting that environmental impact of healthcare allocated to overweight and obesity-related activities was much lower than the metabolic waste (Serafini and Toti 2016; Toti et al. 2019) calculated for the German population for carbon water footprints and higher for land use.

Table 1. Environmental impact of treating avoidable food waste (annual values, GWP – global warming potential, ED – fossil energy demand, LU – land use, WF – water footprint)

Current waste treatment	GWP, kg CO_2eq	ED, MJ	LU, m^{2}a	WF, m^3
Residual waste (bin)	-184,080,600	-1,453,320,000	-2,993,760	-816,156,000
Organic waste (bin)	-766,22,000	-19,308,193,200	11,531,492,431	-704,697,504
Compost	162,921,650	539,400,384	181,920	-42,541,200
Wastewater	6,596,856	18,317,759	32,472	-13,751,472
Feed pets (animals)	192,956,000	9,288,000	339,991,200	18,216
Other	25,977,726	-319,747,725	231,640,935	-30,343,336
Total	127,749,632	-20,514,254,783	12,100,345,198	-1,607,471,296

Increasing Body Mass Index of German population (Schienkiewitz et al. 2017) with additional 15.5-26.5 kg of weight gain per capita annually (on average 10.2 kg due to current rate of overconsumption and 9.0 kg due to potential consumption of avoided food waste) indicated a rapid shift of German population, including undernourished part (1.8%) to extreme obesity and overweight rates from 18.1% to 54.0-65.4% and 35.9% to 22.05% respectively. In the case of even consumption by the complete German population of potentially avoidable food waste the overweight and obesity rates would reach 76-95% within 3-4 years. Such a rapid weight gain is associated not only with additional calories gained through consumption of potentially avoided food waste (plus 350 kcal daily), but also due to existing overconsumption of calories (around 500 kcal daily).

Such rapid increase in obesity rates was assumed to trigger the demand for healthcare resources in the scope of 1% (conservative case) to 4% (extreme case). Therefore, human consumption of potentially avoidable food waste due to the increased demand for healthcare services could increase impact on the environment: 0.6-2.4 Mt CO_2eq. for global warming potential; 16-66 million GJ for energy consumption; 2650-10600 km^2 for land use; 13.2-53.0 million m^3 for water footprint.

The comparison of environmental impacts of treating the avoidable food waste with current waste treatment technologies versus consuming it by the population of Germany indicated that the first option was more beneficial for the environment in categories of global warming potential, energy demand and water footprint (Table 2). Consuming potentially avoidable food waste by German population would result in increased GHG emissions (additional 0.48-2.3 million tonnes CO_2eq.), energy use (additional 36.9-86.1 million GJ) and water depletion (additional 1.62-1.66 billion m^3). At the same time conventional waste treatment require 1.14-4.57 times more land resources when treating potentially avoidable food waste at the end of the chain (Table 2).

There are several points which should be thoroughly discussed before making the final conclusions in the study. First, it should be noted that there was an extreme lack of data and trustable studies, which can be used for calculations. Therefore, the study relied on number of approximations, based on the most recent published data. The most crucial assumption in the study was associated with the allocation of 5% of healthcare system impacts to the treatment of overweight and obesity-related conditions (Shephard 2019). Application of other values of 3.27% (Lehnert et al. 2015) or ~ 17% (Effertz et al. 2016) did not change the relative conclusions. It is still necessary to highlight the need for more precise analyses of environmental impact of German healthcare system. Moreover, more studies are needed to define more accurately the allocation of healthcare resources to the treatment of overweight and obesity conditions in Germany and other countries.

Table 2. Environmental impact of treating potentially avoidable food waste with current treatment technologies in comparison with human consumption in Germany (reference year 2017, annual values, GWP – global warming potential, ED – fossil energy demand, LU – land use, WF – water footprint)

	GWP, tonnes CO_2eq	ED, GJ	LU, km^2a	WF, m^3
Current waste treatment	127,750	-20,514,255	12,100	-1,607,471,296
Consume and gain weight (LOW)	609,192	16,393,991	2,650	13,250,143
Consume and gain weight (HIGH)	2,436,770	65,575,963	10,600	53,000,572

Current study also has some limitations, which are mostly connected with several factors affecting human metabolism (and weight gain) through increased activities (sport) or uneven distribution of food energy within the population. Further studies should consider these factors. Even with such limitations, the study achieved the goal of defining the best of two options for current German population in dealing with avoidable food waste: better to waste food than to eat it.

Conclusions

The results of the study are not aimed to argue priority of waste management hierarchy to avoid overproduction (and thus wasting or overconsumption) (EC Directive 2008; Liu et al. 2019). However, they revealed that in specific cases (overweight population) it is better to treat food waste with existing or improved waste treatment methods than reuse (consumption of excessive amount) from environmental perspective. The results of the study are relevant for the populations with high levels of produced avoidable food waste at household level and high overweight and obesity rates. It does not allow for a simple universal answer on the selection of more sustainable strategies of dealing with excessive amount of food for all the cases (countries). However, it allows to indicate preferable conditions for dealing with excessive food in model conditions, which account for health state of household members or a population, nutrient density and amount of food, and timeframe.

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Topic 5:
LCA of Pigs and Pork Products

Abstract code: ID 310

Life cycle assessment of pig production in Italy considering a wet scrubber ammonia abatement system

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Abstract

Ammonia (NH_3) is the most common pollutant in the pig's environment. This study aims to provide an initial assessment of the environmental impact of a farm producing heavy pigs where a wet acid scrubber for NH_3 abatement was installed. The Life Cycle Assessment approach was applied. 1 kg of live weight was selected as Functional Unit. Two alternative scenarios were considered. In the baseline scenario (BS) the air was not treated, while in alternative one (AS) a wet acid scrubber was adopted. Using the characterization factors reported by the midpoint ILCD method 12 different impact categories were evaluated. The outcomes of this study highlighted how the best solution depends from the selected impact category. Indeed, the AS was the best one for "particulate matter formation", "acidification", "terrestrial eutrophication" and "marine eutrophication", the categories influenced by NH_3 emissions, and the worst for the other ones due to the higher energy and resource consumption related to the construction, maintenance, and operation of the scrubber.

Keywords: *Life Cycle Assessment, livestock activities, pig, ammonia, emission.*

Introduction

Air inside pig barns is characterized by either high concentration of ammonia (NH_3) and particulate matter (PM) that can pose a direct hazard to animals and workers health, or odors (VOCs). The same poor-quality air is released into the environment, causing odor nuisance and atmospheric pollution in the surrounding rural and urban areas (Schauberger et al. 2018). It is well known that the agricultural sector is mainly responsible for NH_3 emissions, arising principally from manure management and from fertilizers application (EEA, 2018). Released into the environment, NH_3 causes soil acidification, nutrient-N enrichment of ecosystems, and terrestrial eutrophication. Furthermore, NH_3 is a chemically active gas able in the atmosphere to react with sulfuric and nitric acids to form secondary inorganic PM ($PM_{2.5}$) (Schauberger et al. 2018). $PM_{2.5}$ is a threat to human health, several epidemiological studies show a causal link between PM exposure and cardiovascular and respiratory system damages (Carugno et al. 2016). According to Kiesewetter et al. (2015) in the Po valley it leads to a reduction in life expectancy of about 36 months. Po Valley is one of the European regions with the highest levels of PM due to the concurrent high density of anthropogenic sources and its orographic and meteorological characteristics unfavorable for pollutant dispersion (Carugno et al. 2016). In particular, Lombardy region is located in the middle of the Po basin and it presents the highest Italian pig population density, accounting for more than 4 million heads (ISMEA, 2019). Different strategies are available to reduce NH_3 emissions from pig housing: feeding strategies, slurry storage, treatment and application techniques, and air cleaning systems (Ti et al. 2019).
The LIFE-MEGA project (LIFE18 ENV/IT/000200) aims to reduce NH_3 and PM emissions from

piggeries, with a benefit for human health in rural and urban air quality. The project aims to develop and test in pig houses, located in the Lombardy region, two different abatement systems (dry and wet scrubber). The dry scrubber is a technology already used in other industrial contexts (e.g. baking), whereas the wet scrubber will be a prototype using citric acid. This study reports the preliminary results achieved in Italy in terms of environmental impact reduction using the wet acid scrubber.

Material and methods

The aim of the present study was to provide an initial assessment of the environmental impact of an Italian farm producing heavy pigs where a wet acid scrubber for air treatment was installed. The functional unit selected was 1 kg of pig live weight (LW) at the farm gate. Two alternative scenarios were considered: the baseline scenario (BS) representing the situation as it is, and the alternative scenario (AS) where the wet acid scrubber prototype (with 60% NH_3 removal efficiency) was adopted. Regarding the system boundary, a "cradle to farm gate" approach was applied, including all inputs (e.g. machinery, fuel, lubricant, organic and mineral fertilizers, pesticides, water, off farm feed) and outputs (emissions to air, soil and water) as reported in Fig. 1.

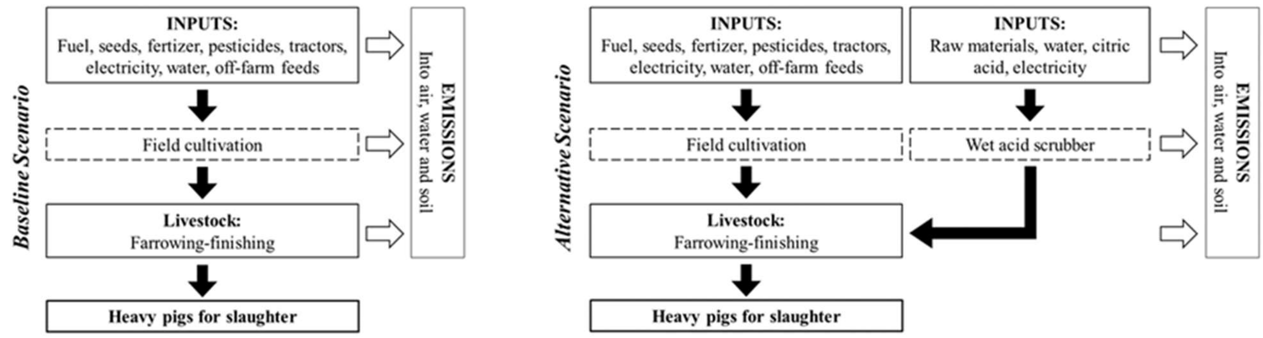

Figure 1. System boundaries for Baseline and Alternative scenarios

The case farm was an intensive farrowing to finishing farm, producing heavy pigs for traditional dry-cured hams, located in the province of Brescia (Italy). A farrow-to-finish system comprises all phases of pig production, from the farrowing phase to produce piglets till the growing-finishing one where pigs are raised till market weight (for dry-cured ham PDO disciplinary, minimum 160 kg LW at slaughter). The agricultural area of the farm was 100 ha, entirely used for maize grain production. Primary data were collected during surveys on farm carried out by experts by asking for information about: herd management, field production, feeding, and slurry management. Data related to the wet acid scrubber prototype were provided by the construction company. Table 1 report the main inventory data about herd traits and performances.

Table 1. Herd traits and performances

Zootechnical data	Unit	
Heavy pigs produced	no./year	10,050
Slaughter LW	kg	167
Sows	no.	730
Giving births/sow	no./year	2.32
Piglet weaned/sow	no./year	21
Average LW per reproduction sow	kg	200
Average LW per piglet	kg	23
Average LW per fatteners – 1^{st} phase	kg	40
Average LW per fatteners – 2^{nd} phase	Kg	103
Mortality	%	3

As concern secondary data, CH_4 and N_2O emissions were estimated according the IPCC guidelines (IPCC, 2019), whereas EEA guidelines (EEA, 2019) were used for NH_3 ones. Finally, background data concerning the production of the different inputs (e.g. seeds, pesticides, fertilizers, diesel, tractors and implements) were retrieved from the Ecoinvent Database v.3 (Weidema et al., 2013).

Twelve environmental impacts were evaluated: Climate Change (CC), Ozone Depletion (OD), Human toxicity, non-cancer effects (HTnoc), Human toxicity, cancer effects (HTc), Particulate matter (PM), Photochemical ozone formation (POF), Acidification (TA), Terrestrial eutrophication (TE). Freshwater eutrophication (FE), Marine eutrophication (ME), Freshwater ecotoxicity (FEx) and Mineral, fossil & renewable resource depletion (MFRD).

Results and discussion

Table 2 shows the environmental impacts of 1 kg of pig LW for the two scenarios analyzed. Besides the absolute values for the different impact categories it is reported also the variation between BS and AS calculated as: (Impact of AS – Impact of BS)/Impact of BS.

Table 2. Absolute environmental impacts for the baseline (BS) and alternative (AS) scenario

Impact category	BS	AS	Δ (%)
CC	3.55 kg CO_2 eq	3.65 kg CO_2 eq	+ 2.91
OD	3.12 kg CFC^{-11} eq · 10^{-7}	3.32 kg CFC^{-11} eq · 10^{-7}	+ 6.53
HTnoc	7.08 CTUh · 10^{-7}	7.29 CTUh · 10^{-7}	+ 3.00
HTc	1.9 CTUh · 10^{-8}	2.24 CTUh · 10^{-8}	+ 17.68
PM	3.28 kg $PM_{2.5}$ eq · 10^{-3}	3.20 kg $PM_{2.5}$ eq · 10^{-3}	-2.39
POF.	1.08 kg NMVOC eq · 10^{-2}	1.13 kg NMVOC eq · 10^{-2}	+ 4.66
TA	0.12 molc H+ eq	0.11 molc H+ eq	-8.53
TE	0.51 molc N eq	0.46 molc N eq	-9.34
FE	4.49 kg P eq · 10^{-4}	4.65 kg P eq · 10^{-4}	+ 3.46
ME	1.93 kg N eq · 10^{-2}	1.92 kg N eq · 10^{-2}	-0.21
FEx	23.74 CTUe	23.95 CTUe	+ 0.89
MFRD	2.42 kg Sb eq · 10^{-5}	4.88 kg Sb eq · 10^{-5}	+ 101.8

For 8 of the 12 evaluated impact categories, AS shows higher impact respect to BS, due to the impact associated with the wet acid scrubber construction and maintenance. The best solution depends on the selected impact category. Indeed, the AS was the best the impact categories influenced by NH_3 emissions (PM, TA, TE, and ME), for which a reduction of 2% (PM), 8% (TA), 9% (TE), and 0.2% (ME) was observed. The climate change impact was 3.55 kg CO_2 eq/kg LW and 3.65 kg CO_2 eq/kg LW for BS and AS, respectively, aligning with Bava et al. (2017) and González-García et al. (2015) results. The scrubber affects positively the impact categories influenced by the ammonia emissions while increase the impact of the other impact categories and, in particular, of MFRD.
Fig. 2 reports the hotspot processes of the farm for both scenarios.

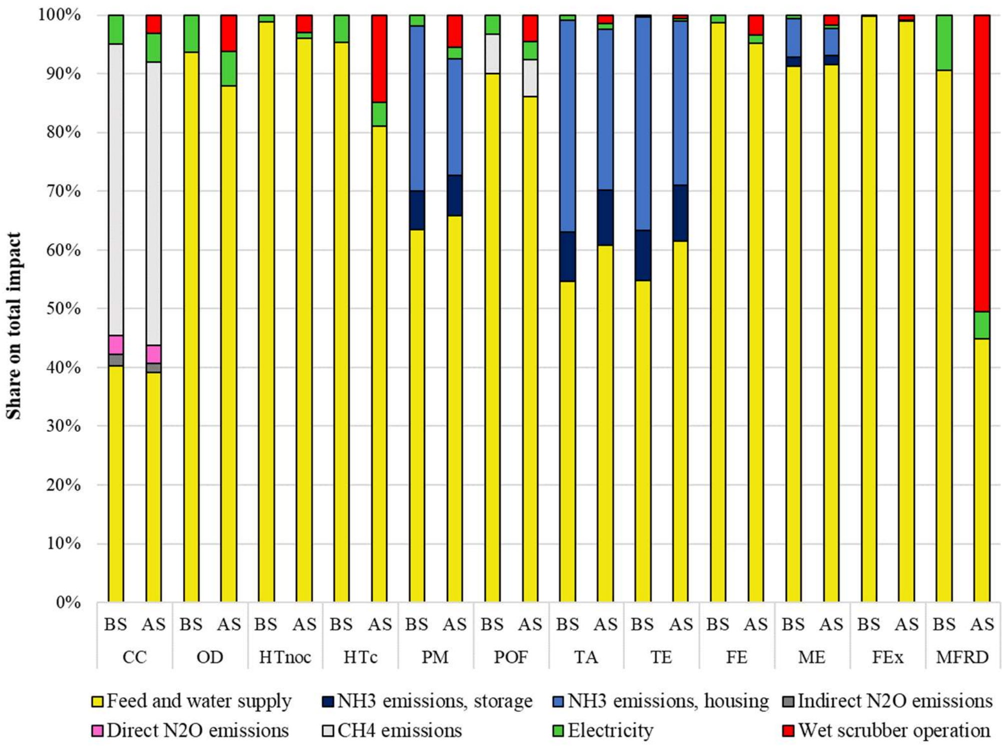

Figure 2. Environmental hotspots for BS and AS

Regardless of the scenario considered, feed production was the main hotspot in all impact categories and of heavy pig production, as also reported in other LCA studies (Bava et al. 2017; González-García et al. 2015). In the farm analyzed, only maize grain is partially produced on-farm, instead all other feed ingredients are purchased. As an example, the replacement of soybean imported from South America with protein sources locally produced certainly could affect the final impact (Bava et al. 2017). Moreover, also the use of precision feeding systems in growing and finishing phase could help in reducing the environmental impact of pig production (Andretta et al. 2018). CH_4 emissions affect significantly CC (50% and 48% in BS and AS, respectively). After feed, NH_3 emissions are the main responsible for PM, TA and TE impact share, ranging from 34% to 45% for BS and from 26% to 37% for AS. As expected, in AS NH_3-related impacts are less than in BS. Electricity is responsible for a share ranging from 0.2% to 4.9% for all the evaluated impact categories. Regarding the wet scrubber contribution to the environmental impact of 1 kg of pig LW at the farm gate, in AS it registers the highest relative contribution for MFRD (50%) and the lowest for TE (0.6%). A reduction of the scrubber impact could be achieved substituting the source of the electricity consumed (e.g., by installing a photovoltaic panel on the roof of stables). Even if not specifically foreseen in the Life MEGA project the use of renewable energy to feed the scrubber would probably improve its environmental performances.

Conclusions and perspectives

Although further evaluation is needed, these preliminary results are preliminary and provide a first quantitative indication of the environmental benefits that can be achieved by the introduction of the wet acid scrubber technology. The high livestock density present in Lombardy makes it a region susceptible to nitrates leaching, as a consequence most of the fields are recognized as Nitrate Vulnerable Zones (NVZ) in the context of the Council Directive 91/676/EEC. So, it is crucial to find effective ways to reduce the excessive nitrogen loads. As demonstrated in this work, the wet acid scrubber is an effective strategy to reduce NH_3-related impacts, although it increased the other impacts evaluated. Possible optimizations of the air treatment system should focus attention on reducing the consumption of water and acid, increasing their recycling. Moreover, the enhancement of ammonium citrate salt (produced by the reaction between NH_3 and citric acid) as nitrogen fertilizer could further reduce the environmental impacts due to the replacement of mineral fertilizer. In addition, the field application of the discharge water is another valuable strategy to reduce the use of mineral fertilizer, as demonstrated by de Vries and Melse (2017). Finally, in the next steps, the LIFE-MEGA project foresees the implementation of the scrubber with a microclimatic tool, that will activate its functioning only when fixed pollutants thresholds are exceeded, thus achieving the best indoor air quality and minimizing energy and citric acid solution consumption.

Acknowledgements
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LCA case study for copper and zinc oxides used in animal nutrition

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Abstract

Feed production has a huge contribution to the environmental footprint of edible animal products. The life cycle assessment (LCA) of feed crops has been well addressed, however the LCA of feed additives is still lacking. The objective of this study was to develop a comprehensive dataset for a zinc (Zn) and copper (Cu) sources named HiZox® and CoRouge®, respectively (Animine, France), in compliance with Product Environmental Footprint Category Rules (PEFCR) requirements. The study was based on the method as described in the PEFCR Feed for food-producing animals, and the experimental unit was 1 kg of zinc or copper used in animal nutrition. The system boundaries were from cradle-to-plant, 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. The carbon footprints of HiZox® and CoRouge® were 5.70 and 3.30 kg of CO_2-eq. per kg of mineral supplied in the diet, respectively. The impact on freshwater ecotoxicity (EcotoxF) was 15.8 and 53.6 CTUe for Zn and Cu, respectively. For resource use (ResUse), concerning mineral and metals, the impact was, respectively, $1.92E^{-03}$ and $2.45E^{-03}$ kg Sb-eq for Zn and Cu. These impacts are higher than the ones found in the literature for crops, but are in line the LCA values for other feed additives, like industrial amino acids. The LCA of HiZox® and CoRouge® was compared with a reference inorganic sulfate source. For Carbon Footprint, the relative impact was 44% and 37% of the reference sulfate source, for HiZox® and CoRouge®, respectively. In conclusion, now Animine is meeting its commitment to provide a high-quality PEF related dataset to be used by the feed industry in their own PEF assessments. 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.

Keywords: *animal nutrition, trace minerals.*

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, 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 zinc (Zn) and a copper (Cu) sources named HiZox® and CoRouge®, respectively (Animine, France), in compliance with PEFCR requirements.

Material and methods

The PEF study was based on the method as described in the PEFCR Feed for food-producing animals, and the experimental unit was 1 kg of zinc or copper 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).

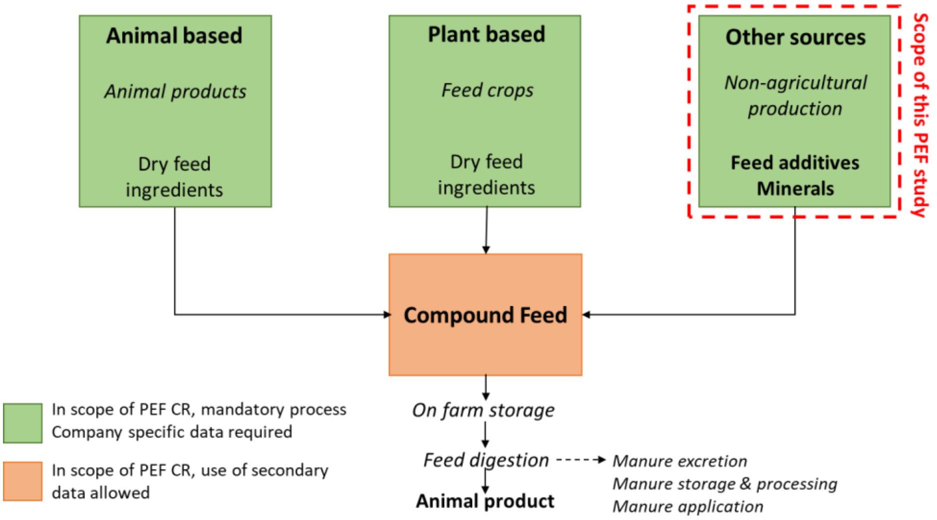

Figure 1: System boundaries considered in this PEF study (based on PEFCR, 2018).

Results

The results of LCA for both sources are presented in the Table 1. The carbon footprint of HiZox® and CoRouge® was 5.70 and 3.30 kg of CO_2-eq. per kg of mineral supplied in the diet, respectively. The impact on freshwater ecotoxicity (EcotoxF) was 15.8 and 53.6 CTUe for Zn and Cu, respectively. For resource use (ResUse) - mineral and metals, the impact was, respectively, 1.92E^{-03} and 2.45E^{-03} kg Sb-eq for Zn and Cu.

Table 1. Life Cycle Assessment of a potentiated zinc oxide (HiZox®) and dicopper oxide (CoRouge®). The functional unit is 1 kg of mineral

	Carbon footprint	Acidification terrestrial & freshwater	Eutrophication freshwater	Eutrophication marine	Ecotoxicity freshwater	Resource use, mineral and metals
	kg CO_2 eq	mol H+ eq	kg P eq	kg N eq	CTUe	kg Sb eq
HiZox®	5.70	0.137	2.43E-04	9.28E-03	15.8	1.92E-03
CoRouge®	3.30	0.022	4.86E-05	4.09E-03	53.6	2.45E-03

The LCA of HiZox® and CoRouge® was compared to a reference inorganic sulfate source (Figure 2). For ResUse, HiZox® had a higher impact than the reference sulfate, while CoRouge® had 77% of the impact of a sulfate source.

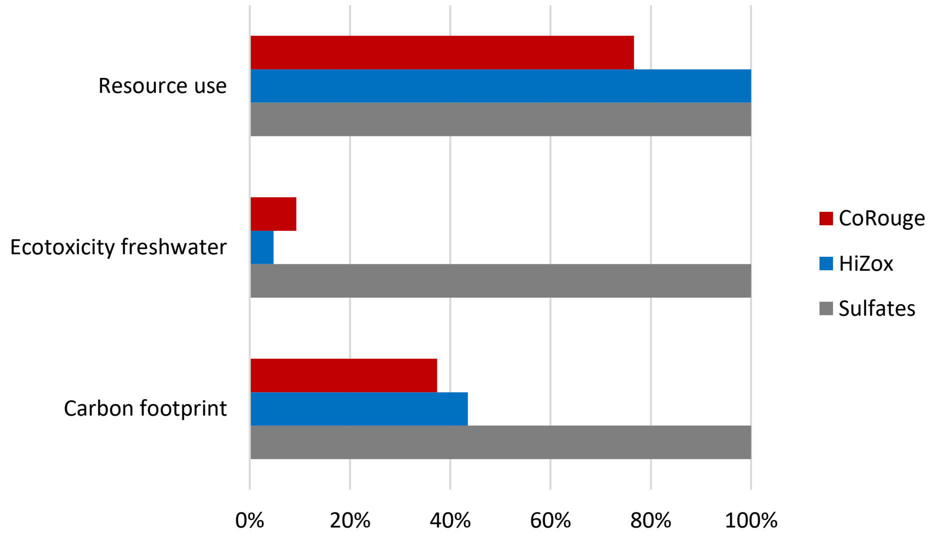

Figure 1. Comparison between Animine's sources and a reference sulfate (results in % of the highest impact)

For the other categories, sulfates have the highest impact. HiZox® had 95% and CoRouge® 91% lower EcotoxF impact than a sulfate. For Carbon Footprint, the relative impact was 44% and 37% of the reference sulfate source, for HiZox® and CoRouge®, respectively.

Discussion

As expected, the values of LCA found for HiZox® and CoRouge® 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.

Metals are the greatest contributors to EcotoxF (Plouffe et al., 2015), and to ResUse – as they are non-renewable resource (Titon, 2003), which makes important the assessment of those categories by the trace minerals industry.

The reason why HiZox® has a higher impact on ResUse than the sulfate reference may be related to the fact that HiZox® is obtained from a special high grade (SHG) zinc oxide source, instead of recycled Zn sources, to ensure low level of contaminants (Cd, As, Pb) in the final product.

For the other impact categories, the lower impact of Animine's products can be related to their higher mineral concentration (>75% of metal), together with a low contaminants' level.

Conclusions

Now Animine is meeting its commitment to provide a high-quality PEF related dataset to be used by the feed industry in their own PEF assessments. 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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Environmental assessment of precision feeding strategies in growing-finishing pigs

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Abstract

Purpose. Feed production and excretion of nutrients by the animals are major sources of the environmental impacts of pig production. New communication and information technologies (NTIC) allow the development of precision feeding (PF) in pig-fattening units, which appears as a promising way to decrease environmental impacts of pig production. Therefore, we performed a life cycle assessment (LCA) of pig production with either conventional or PF applied to growing-finishing pigs.
Methods. Two sources of data were involved: experiments and simulations performed using a model of pig fattening. A first experiment compared two-phase (2P) *ad libitum* (AdLib) feeding to *ad libitum* PF. A second experiment compared 2P restricted (Res) feeding to restricted PF. With the model, four feeding programs – 2P, 2PLCP (2P with low crude protein content), MP (daily multiphase group feeding) and PF – were simulated according to two feeding levels: AdLib and Res. A cradle-to-farm gate LCA was performed for each strategy, with the kg of live pig at farm gate being the functional unit. Five categories of impacts were evaluated: ILCD climate change (CC), ILCD acidification (AC), CML 2001 eutrophication (EU), CML 2001 land occupation (LO) and CED V1.8 non-renewable and fossil energy demand (CED).
Results and discussion. PF slightly increased feed conversion ratio (FCR) and total feed intake compared with their reference 2P strategies, excepted in the *in vivo* experiment comparing PF-AdLib to 2P-AdLib. In this latter case, FCR was improved with PF. PF resulted in reduced N intake and N excreted relatively to 2P feeding in both *in vivo* and virtual experiments, whatever the rationing plan applied. PF always decreased AC and EU by reducing nitrogen excretion. With experimental data, CC was reduced in PFAdLib but not in PFRes compared to their respective 2P strategies. Simulated results showed a decrease in AC, EU and LO impacts, but not in CC, what is probably due to the small difference in total feed consumption between *ad libitum* and restrictedly-fed pigs (5 kg/pig).
Conclusions. PF can reduce environmental impacts of pig production, particularly AC, EU and LO. Nevertheless, the definition of constraints on amino-acid and crude-protein contents and feed formulation should be made in accordance with local practices (i.e., feeding level) in order to obtain environmental gains expected with PF.

Keywords: *livestock farming; precision agriculture; simulation; in vivo experiment.*

Introduction

Environmental impacts of pig farms are associated to the production of feeds and to on-farm emissions that result from nutrients excreted by pigs (N, P, organic matter…). The fattening unit has a major contribution to these impacts (Dourmad et al., 2014). The use of new information and communication technologies in pig fattening units, with the development of smartphone applications, sensors and robots, offers new possibilities to improve animal management in the next future. In this context, precision feeding (PF) appears as a promising way to reduce the environmental impacts of pig farms, in particular when applied during the fattening period (Andretta et al., 2018). Precision feeding is defined as the set of technologies that aim at collecting individual production data of animals, calculating the individual nutritional requirements, and distributing daily to each pig the feed supply that meets its requirements.

Some studies already measured or estimated the reduction of nutrient excretion allowed by PF (Brossard et al., 2019). However, very few assessed through Life Cycle Assessment (LCA) the environmental gain of PF. Therefore, the aim of this study was to estimate the environmental gain of PF by conducting LCA of pig production with and without application of PF to pig fattening.

Material and methods

PF with *ad libitum* feed supply (PF-AdLib, tuning the composition of the blend to the individual daily requirement) and PF with restricted feed supply (PF-Res, tuning the composition of the blend to the individual daily requirement according to the amount supplied) were evaluated. In PF-AdLib, pigs have the opportunity to express their growth potential while restriction is usually applied in France to improve feed efficiency and leanness at slaughter. Since PF devices are still under development and will improve in the next future (Brossard et al., 2019), benefits from PF-AdLib and PF-Res were assessed with two different sources of data:

- *In vivo* experiments applying PF. In this case, the environmental gain is representative of the improvement that could be obtained through the application in commercial farms of present PF technologies. First experiment was conducted at the INRAE Pig Phenotyping Experimental Facility (France) (https://doi.org/10.15454/1.5573932732039927E12) and compared PF-AdLib with *ad libitum* two-phase feeding with low crude protein supply (2PLowCP-AdLib) with 64 pigs (Brossard et al., 2019). The second experiment was conducted at the IFIP Experimental farm of Romillé (France) and compared PF-Res to restricted two-phase feeding (2PLowCP-2PRes) with 96 pigs (Quiniou et al., 2018). In each experiment, pigs were fattened in a single pen equipped with an automatic weighting device. Feed supply was performed with precision feeders that recorded feed intake of each pig and provided the adjusted blend of two feeds (A and B, with 1.0 and 0.45 g of standardised ileal digestible lysine (Lys) per MJ of net energy (NE) and 9.73 MJ NE/kg feed) to each pig of the PF group. In both cases, the daily assessment of individual requirements was made with a decision support system based on InraPorc (2006). In both experiments, pigs of the control group received a blend providing 0.9 g Lys/MJ NE up to 65 kg of average LW (growing) and then 0.7 g Lys/MJ NE (finishing).
- Virtual experiment with a pig-fattening unit model (Cadéro et al., 2018). This approach provided the asymptotic potential environmental gain to which PF can get closer in the future, assuming that growth potential of each pig is perfectly known. Four feeding strategies were designed with AdLib and Res supplies, and feeds formulated with 9.5 MJ NE/kg: 2P (growing: 16% of crude protein content (CP), 0.95 g Lys/MJ NE; finishing: 15% CP, 0.73 g Lys/MJ NE); 2PLowCP (growing: 15% CP, 0.95 g Lys/MJ NE, finishing: 13% CP, 0.73 g Lys/MJ NE); Multiphase feeding by group (MPGr), in which pigs are daily fed a blend of feed A (17% CP, 1.04 g Lys/MJ NE) and feed B (10% CP and 0.43 g Lys/MJ NE); individual multiphase feeding (PF) in which a specific blend of feed A and feed B is provided daily to each pig. Feeds were least-cost formulated in four economic contexts (mean annual feed ingredient prices in 2010-2011, 2012-2013, 2013-2014 and 2016-2017) and feeding strategies simulated in each of them.

LCA included the impacts associated to the production of feed ingredients, transportation of raw materials, feed fabrication and transportation between production and utilization locations, emissions in farm buildings associated to pigs and manure in pits below animals, and emissions from manure storage. The system boundaries also included the production of piglets and post-weaning stages, with average performance in France, as well as the device operation for PF strategies. We considered fully

slatted floor in building and storage of manure under animals, followed by an external storage of manure in uncovered pit. Functional unit was the kg of live pig at farm gate. Five categories of impacts were assessed using characterization methods available in Simapro, version V8.5.2 (PRé consultants, Amersfoort, the Netherlands): ILCD for climate change (CC, kg CO2-eq) and acidification (AC, molc H+-eq), CML 2001 for eutrophication (g PO43-) and land occupation (LO, m^2.year), CED V1.8 for demand in non-renewable energy (NRE, MJ).
Outputs obtained with the virtual experiment were subjected to variance analysis (ANOVA) using a generalized linear model to assess effects of the feeding strategy applied. Fixed effects were tested using each of the 32 scenarios, crossing feeding strategy and economic context, as the statistical units. We used the stats package (V3.3.0) and the glm function of R software for this analysis.

Results and discussion
Animal performance in virtual and in vivo experiments was modified by the feeding strategy applied (Table 1). When comparing precision feeding to the reference two-phase strategy, mean slaughter weight was reduced (-1 to 2 kg), feed conversion ratio (FCR) and total feed intake were increased, excepted in the in vivo experiment comparing PF-AdLib to 2P-AdLib. In this latter case, feed conversion ratio was improved with precision feeding. Precision feeding resulted in reduced N intake and N excreted relatively to two-phase feeding in in vivo experiments, whatever the rationing plan applied. In the virtual experiment, 2PlowCP vs. 2P, MPGr vs. 2PlowCP, and PF vs. MPGr reduced incrementally N intake and N excreted, whatever the rationing plan applied. For a given feeding sequence, restricted supply vs. ad libitum supply of the feed reduced both N intake and N excreted.

Table 1. Effect of the feeding strategies on animal performance, N intake and N excreted with feeding strategies tested experimentally or through simulation (least-square means for the virtual experiment).

Feeding Strategies[1]	Slaughter weight (kg)	Feed conversion ratio (kg/kg)	Total Feed intake (kg/pig)	N intake (kg/pig)	N excreted (kg/pig)
In vivo experiment with ad libitum supply of feeds					
2PLowCP-AdLib	117	2.85	234	5.21	3.13
PF-AdLib	117	2.69	222	4.99	2.88
In vivo experiment with restricted supply of feeds					
2PLowCP-Res	115	2.87	214	4.65	2.73
PF-Res	113	2.96	218	4.35	2.45
Virtual experiment					
2P-AdLib	118^{f}	2.78^{c}	248^{d}	6.00^{h}	3.84^{h}
2PLowCP-AdLib	118^{f}	2.78^{c}	247^{d}	5.48^{f}	3.32^{f}
MPGr-AdLib	117^{c}	2.83^{f}	249^{e}	5.36^{d}	3.25^{e}
PF-AdLib	117^{c}	2.83^{e}	249^{e}	4.81^{b}	2.69^{b}
2P-Res	117^{d}	2.75^{b}	243^{b}	5.88^{g}	3.72^{g}
2PLowCP-Res	117^{e}	2.74^{a}	242^{a}	5.36^{e}	3.20^{d}
MPGr-Res	117^{b}	2.80^{d}	244^{c}	5.25^{c}	3.14^{c}
PF-Res	116^{a}	2.80^{d}	243^{c}	4.74^{a}	2.63^{a}
P-value[2]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
RMSE[3]	0.05	0.002	0.21	0.002	0.003

[1]2P-AdLib: two-phase with *ad libitum* feed supply, 2P-Res: two-phase with restricted feed supply, PF-AdLib: precision feeding with *ad libitum* feed supply, PF-Res: precision feeding with restricted feed supply, 2PlowCP-AdLib: two-phase with low crude protein content and *ad libitum* feed supply, 2PlowCP-Res: two-phase with low crude protein content and restricted feed supply, MPGr-AdLib: multiphase by group with *ad libitum* feed supply, MPGr-Res: multiphase by group with restricted feed supply.
[2] P-value refers to the effect of the feeding strategies tested in the virtual experiment.
[3]RMSE: root mean square error.
[a, b, c, d, e, f, g, h] Means followed by same letter do not differ significantly (P >0.05) according to Fischer's test.

The effect of precision feeding on CC was not consistent across experiments. In the *in vivo* experiment with AdLib supply of feeds, PF reduced CC by 4%, but not in the *in vivo* experiment with restricted supply of feeds. Since CC is largely determined by the impact of the feed, this result is associated to the improved FCR with PF-AdLib and the impaired FCR with PF-Res, relatively to their respective reference 2PLowCP strategy. The virtual experiment did not highlight any significant effect of the feeding strategy applied on CC. Our result is explained by a decrease in N2O emissions compensated by impaired FCR with MPGr and PF strategies. This is not fully consistent with Andretta et al. (2018) who found 6% of reduction for CC with their in vivo experiment. However, their experiment compared a three-phase feeding with higher crude protein content for the first feed than in our experiments. Moreover, in their case, the first feed was formulated to cover the nutritional requirements of the most demanding pig whereas we formulated the feeds at 110% of the average digestible lysine requirement.

Table 2. Effect of the feeding strategies on environmental impacts per kg of live pig at farm gate with feeding strategies tested experimentally or through simulation (least-square means for the virtual experiment).

Feeding Strategies[1]	NRE (MJ)	CC (kg CO_2 eq)	AC (molc H^+ eq)	EU (kg PO_4^{3-} eq)	LO (m^2.year)
In vivo experiment with ad libitum supply of feeds					
2PLowCP-AdLib	21.38	2.48	0.0822	0.0179	3.85
PF-AdLib	21.02	2.40	0.0777	0.0171	3.72
In vivo experiment with restricted supply of feeds					
2PLowCP-Res	21.19	2.47	0.0779	0.0173	3.79
PF-Res	21.32	2.47	0.0746	0.0170	3.85
Virtual experiment					
2P-AdLib	18.3^{ab}	2.26	0.0784^{d}	0.0203^{c}	4.08
2PLowCP-AdLib	19.1^{bc}	2.29	0.0718^{c}	0.0192^{b}	3.92
MPGr-AdLib	19.4^{c}	2.32	0.0716^{bc}	0.0191^{b}	3.94
PF-AdLib	19.2^{c}	2.27	0.0630^{a}	0.0178^{a}	3.87
2P-Res	18.2^{a}	2.25	0.0771^{d}	0.0201^{c}	4.06
2PLowCP-Res	19.0^{abc}	2.27	0.0703^{b}	0.0190^{b}	3.89
MPGr-Res	19.3^{c}	2.30	0.0704^{b}	0.0189^{b}	3.91
PF-Res	19.2^{c}	2.26	0.0624^{a}	0.0177^{a}	3.85
P-value[2]	0.0006	0.145	<0.0001	<0.0001	0.136
RMSE[3]	0.396	0.036	0.0006	0.0004	0.128

[1]2P-AdLib: two-phase with *ad libitum* feed supply, 2P-Res: two-phase with restricted feed supply, PF-AdLib: precision feeding with *ad libitum* feed supply, PF-Res: precision feeding with restricted feed supply, 2PlowCP-AdLib: two-phase with low crude protein content and *ad libitum* feed supply, 2PlowCP-Res: two-phase with low crude protein content and restricted feed supply, MPGr-AdLib: multiphase by group with *ad libitum* feed supply, MPGr-Res: multiphase by group with restricted feed supply.
[2] P-value refers to the effect of the feeding strategies tested in the virtual experiment.
[3]RMSE: root mean square error.
[a, b, c, d, e, f, g, h] Means followed by same letter do not differ significantly (P >0.05) according to Fischer's test.

Precision feeding reduced AC and EU in both in vivo experiments, by 2 to 5%, relatively to the control 2PLowCP strategy. In the virtual experiment, the progressive reduction in N excreted when moving from 2P to PF strategy resulted in reduced AC and EU. Precision feeding reduced AC by 19% when compared to 2P, and by 12% when compared to 2PLowCP. Precision feeding reduced EU by 12% when compared to 2P, and by 7% when compared to 2PLowCP. The extent to which precision feeding reduces AC and EU was higher in the virtual than in both in vivo experiments. This is consistent since in vivo experiments provide an assessment of the environmental gain allowed by present PF technologies whereas the virtual experiment gives access to an asymptotical future potential improvement. In the virtual experiment, precision feeding increased NRE relatively to the reference 2P strategy. Since NRE depends largely on the NRE of the feeds, this is largely explained by the impaired FCR observed with PF, and by the energy consumption of PF devices. In the in vivo experiments, PF had no consistent effect on NRE. The feeding strategies investigated did not affect LO.

Monteiro et al. (2016) also tested through simulation the effect of various feeding strategies, including PF, on the environmental impacts of pig production. In the French context, they highlighted that PF systematically reduced FCR and the environmental impacts, compared to two-phase feeding. Their results were obtained with the same pig profiles as in the present study. In their case, improved FCR may be explained by the formulation of different feeds for female pigs and barrows. Indeed, the maximum level of Lys of feed A in their study was 1.075 g/MJ NE whereas it was 1.04 g/MJ NE in the present study (same for female pigs and barrows). The different conclusions drawn from these studies suggest that the environmental gain allowed by PF is very sensitive to the ability of the PF strategy to cover the nutritional requirements of the most demanding pigs.

Conclusions

Environmental assessment of precision feeding applied to growing-finishing pigs was obtained with experimental and simulation data. Environmental gain of PF is clear for acidification and eutrophication impacts, as a result of reduction of N excretion. Mitigation of acidification and eutrophication impacts with present PF devices appears still far from the asymptotical potential evaluated. Results are more contrasted for the other environmental impacts. Environmental gain allowed by PF is very sensitive to the way it is applied (Lys content of pre-diets, environmental impacts of feeds, feed supply) and its ability to cover nutritional requirements of most depending pigs. Therefore, there is still room of improvement of PF devices and strategies to fully benefit from the conceptual idea of adjusting individually and daily the nutrients' supplies to the nutrients' requirements.

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Abstract code: 197

Cost-effectiveness of environmental impact abatement measures in a European pig production system

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Purpose: Many emerging technologies and alternative farm management practices have the potential to improve the sustainability of pig production systems. The implementation of such practices is not always economically viable. Our goal was to assess the cost-effectiveness of such environmental mitigation strategies in pig systems, using an Environmental Abatement Cost analysis.
Methods: We considered four pig housing (improved insulation, increased ventilation efficiency, frequent slurry removal, increased slurry dilution) and three manure management related abatement strategies (anaerobic digestion, slurry acidification, slurry separation), implemented as stand-alone and as a set of "pig housing–pig housing" and "pig housing–manure management" combinations. We calculated their annual equivalent value through a discounted cash flow analysis and then their annualized abatement potential through a cradle-to-farm gate life cycle assessment. The baseline system against which the analysis was conducted was a typical Danish pig production system, over a 25-year time horizon. The environmental impact categories considered were Non-Renewable Resource Use, Non-Renewable Energy Use, Global Warming Potential, Acidification Potential and Eutrophication Potential.
Results and discussion: Pig housing–anaerobic digestion combinations were the most cost-effective options for global warming potential, non-renewable resource and non-renewable energy use. The largest profits they generated for these categories were €0.237 per ton CO_2 eq., €0.146 per g Sb eq. and €1.75e^{-04} per GJ abated respectively. Anaerobic digestion was the most cost-effective stand-alone investment, also generating profits for global warming potential (€0.206 per ton CO_2 eq.), non-renewable resources use (€0.0493 per g Sb eq.) and non-renewable energy use (€1.00e^{-04} per GJ) mitigation. Stand-alone slurry acidification achieved the largest abatement potential for acidification and eutrophication potential but increased costs by €303 per ton SO_2^- eq. and €1190 per ton PO_4^{3-} eq. respectively.
Conclusions: Several "win-win" strategies can enhance farm profitability while also achieving sizeable environmental abatement potential. Measures for mitigation of global warming potential, non-renewable resource and non-renewable energy use required higher investments than for acidification potential and eutrophication potential, but also generated profits. The framework developed in this study can potentially aid decision making in the choice of environmentally and economically sustainable pig system modifications.

Keywords: *Cost-effectiveness; Environmental abatement cost curves; Life cycle assessment; Pig housing; Manure management; Pig production*

1. Introduction

Emerging manure management strategies, such as slurry acidification (Acid) or anaerobic digestion of slurry (AD), and modifications or alternative management of the pig housing have been associated with mitigation of environmental impact (EI) from pig production systems (Rigolot et al., 2010; Ten Hoeve et al., 2014; Santonja et al., 2017). Realizing such investments in an economically viable manner is pivotal in farmer/manager decision-making. Accordingly, comprehensive assessment of the cost-effectiveness of alternative investments often requires sophisticated analysis of any benefits and costs associated with their implementation.

Bio-economic analysis may be used to combine environmental and economic models to simulate the complex linkages between these two aspects of farming systems (Miah et al., 2017). Life cycle assessment (LCA) models are used widely to evaluate the EI associated with the operation of a supply chain (Guinée, 2002), and valuation methods such as discounted cash flow analysis for the economic appraisal of long-term investment projects (Nolan et al., 2012).

The goal of this study was to develop an integrated modelling framework to evaluate the environmental and economic consequences of environmental impact abatement measures in a pig farming system. We applied the framework to evaluate the cost-effectiveness of a set of environmental abatement measures related to the pig housing and manure management components of a conventional, Danish pig production system, for five different potential environmental impacts.

2. Material and methods

The baseline system was a typical, 500-sow, integrated pig farm that produced slaughter pigs at 110 kg in Denmark (Santonja et al., 2017; Pexas et al., 2020). The environmental and economic performance of potential abatement scenarios were compared against this baseline.

2.1. Abatement measures

The four pig housing related abatement measures developed were a daily slurry removal scenario (FSR), increased slurry dilution at slurry pits (ISD), improved insulation using polyurethane boards (IMIN) and increased ventilation efficiency (IVE) with increased maintenance of the ventilation system (Santonja et al., 2017). The three manure management scenarios we considered were slurry acidification (Acid), on-farm anaerobic digestion of slurry (AD) and slurry separation (SP) scenarios as they represent the most common manure management alternatives in Denmark (Ten Hoeve et al., 2014; Pexas et al., 2020). The implementation of abatement measures was considered as stand-alone and through all possible "pig housing–pig housing" and "pig housing–manure management" combinations (25 possible combinations).

2.2. Economic model

Output and input prices were normalized using mean values over 2012–2017 to smooth inter-year variability. Budgeted cash margins per kg of live weight pig meat were assumed constant in real terms over the investment planning horizon (25 years). This modelling approach is consistent with the Life Cycle Cost Analysis method, but due to data constraints we did not consider end-of-life values for disposal of the capital equipment. Whole-farm net present value (NPV), annual equivalent value (AEV) and internal rate of return (IRR) were estimated through a discounted cash flow over the 25-year time horizon for each scenario (Eqs. (1)–(2)). We used AEV to guide our selection of the top ten combinations of abatement measures, based on their economic performance.

Eq. (1) $NPV = \sum_{t=1}^{T} \frac{REV_t - OPEX_t - RenC_t}{(1+DR)^t} - ICI$ Eq. (2) $AEV = \frac{DR(NPV)}{1-(1+DR)^T}$

Where:

T = total number of years in the time horizon (25 years), t = each year, REV = revenues, OPEX = operating expenses, RenC = periodic renewal costs for technological equipment where their economic life was less than 25 years, ICI = initial capital investment, DR = discount rate.

2.3. Environmental Life Cycle Assessment (LCA)

An attributional, cradle-to-farm-gate LCA framework was developed in SimaPro 8.5.0.0 according to Pexas et al. (2020), to evaluate the annualized environmental impact of the Danish pig farm under baseline conditions and with the implementation of the selected abatement measures. The environmental impacts assessed were Non-renewable resource use (NRRU), Non-renewable energy use (NREU), Global Warming Potential (GWP), Acidification Potential (AP) and Eutrophication Potential (EP). The abatement potential of each scenario was calculated as its difference in each environmental impact when compared to the baseline (separately for each EI category) using a Monte Carlo pairwise comparisons method (Mackenzie et al., 2015).

2.4. Cost-effectiveness analysis

The cost-effectiveness of each abatement measure was assessed using the cost of abatement metric, calculated through Eq. (3):

Eq. (3) $$€\ per\ unit\ of\ pollutant\ abated = \frac{\Delta AEV}{\Delta EI} \times -1$$

Where, ΔAEV = difference in annual present value between the abatement scenario and the baseline calculated through the discounted cash flow analysis, and

ΔEI = abatement potential of a measure for a specific EI category assessed, calculated as the difference in EI compared to the baseline through the environmental LCA.

3. Results

3.1. Economic analysis

Table 1 summarizes whole-farm net present values, annual equivalent values and internal rate of return for the baseline and selected abatement scenarios. Only four of the selected abatement scenarios were more profitable than the baseline ($AEV_{Baseline}$ = €38,909): $AEV_{AD\ \&\ IVE}$ = €49,099, AEV_{AD} = €44,048, $AEV_{AD\ \&\ IMIN}$ = €42,903 and $AEV_{IMIN\ \&\ IVE\ \&\ AD}$ = €41,675. The implementation of any other abatement measure reduced farm profitability, with standalone slurry acidification generating the lowest whole-farm AEV at €11,515.

3.2. Environmental impact assessment

Table 2 summarizes the annualized environmental impact results for all impact categories and the top ten selected abatement measures based on their AEV. Stand-alone anaerobic digestion and "pig housing-anaerobic digestion" combinations achieved the largest abatement potential for NRRU, NREU and GWP, ranging from -9.67% to -14.7%, -33.5% to -40.8% and -9.62% to -11.8% respectively. Of the stand-alone pig housing related abatement measures, only increased ventilation efficiency significantly reduced these impact categories, by -1.77%, -4.60% and -1.79% respectively. Improved insulation reduced GWP by -1.33%. Slurry acidification exhibited the largest abatement potential of -24.6% for AP and -11.4% for EP, followed by increased slurry dilution (-5.29% for AP and -0.850% for EP). Improved insulation significantly reduced AP by -1.40% and EP by -0.174%, while increased ventilation efficiency mitigated AP by -0.860% and EP -0.244%. The mitigation potential of abatement measures was improved through their combined implementation.

3.3. Cost-effectiveness

"Pig housing-AD" combinations and stand-alone AD were the most cost-effective options for mitigation of NRRU, NREU and GWP. They generated profits that ranged from €0.146 to €0.0326 per g Sb eq., €1.75e^{-04} to €3.55e^{-05} per GJ and €0.237 to €0.0350 per ton CO_2 eq. mitigated respectively. All other measures increased costs from €0.147 to €67.6 per g Sb eq., €2.29e^{-04} to €1.44 per GJ abated, and €0.0279 to €148,077 per ton CO_2 eq. mitigated. For the mitigation of AP and EP, no scenario generated profits. Slurry acidification increased costs by €303 per ton SO_2^- eq. for AP and €1,190 per ton PO_4^{3-} eq. abated for EP. Although slurry dilution exhibited large abatement potential for both impact categories, it largely increased costs by €4,174 per ton SO_2^- eq. and €186,032 per ton PO_4^{3-} eq. abated.

4. Discussion

Many of the mitigation strategies exhibited sizeable environmental impact abatement potential but also generated large abatement costs, which were mainly attributed to high capital and operating expenses associated with the implementation of an abatement measure (i.e. slurry acidification), particularly for the scale of a typical Danish pig farm. Through this framework, farm managers could identify economic impact hotspots that may help improve the cost-effectiveness of potential abatement measures. Important trade-offs were identified also in cases when abatement measures significantly reduced system environmental impact for some categories but greatly increased it for others (i.e. the case of anaerobic digestion). Our findings suggest that synergistic effects in the combined implementation of abatement measures can largely improve system environmental and economic performance over a greater range of impact categories, than stand-alone investments

4.1.Conclusions

Although, we did not identify "silver bullet" solutions when targeting the improved environmental and economic performance of a pig farming system, several "win-win" strategies can enhance farm profitability while also achieving sizeable environmental abatement potential. The whole-farm, cost-effectiveness assessment framework presented here has potential to guide decision making for investments in pig housing and manure management that mitigate environmental impacts.

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Abatement measure	**Whole-farm net present value (€)**	**Whole-farm annual equivalent value (€)**	**Whole-farm internal rate of return (%)**
Baseline	731,505	38,909	6.41
Anaerobic Digestion – **AD**	825,804	44,048	5.88
Increased Ventilation Efficiency – **IVE**	727,427	38,693	6.40
Improved Insulation – **IMIN**	693,103	36,867	6.16
Frequent Slurry Removal – **FSR**	341,746	18,178	4.56
Increased Slurry Dilution – **ISD**	286,799	15,298	4.29
Slurry Acidification – **Acid**	216,488	11,515	3.93
AD & IVE	920,492	49,099	6.21
AD & IMIN	804,328	42,903	5.76
IMIN & IVE & AD	781,303	41,675	5.68
IVE & IMIN	687,361	36,664	6.13
AD & FSR	436,045	23,259	4.49
IVE & FSR & AD	433,929	23,146	4.48
IVE & ISD	409,441	21,840	4.89
IMIN & FSR & AD	399,248	21,296	4.33
IMIN & IVE & FSR & AD	393,506	20,990	4.31
IVE & FSR	336,015	17,923	4.53

Table 1: Whole-farm net present value over the time horizon, whole-farm internal rate of return and whole-farm annual equivalent value for the selected abatement measures. Stand-alone implementation presented above the double, horizontal line and combinations of abatement measures presented below.

Abatement measure	**Non-Renewable Resource Use (g. Sb eq.)**	**Global Warming Potential (t. CO_2 eq.)**	**Acidification Potential (t. SO_2^- eq.)**	**Eutrophication Potential (t. PO_4^{3-} eq.)**	**Non-Renewable Energy Use (GJ)**
Baseline	2171 (± 352)	4927 (± 66.7)	38.6 (±.921)	42.0 (± .583)	21,184 (± 697)
Anaerobic Digestion – **AD**	-14.7 (± 2.37)	-3.17 (± .208)	+13.0 (±.378)	+8.01 (± 1.53)	-33.5 (± 1.15)
Increased Ventilation Efficiency – **IVE**	-1.77 (± .000701)	-1.79 (± .0146)	- .860 (± .00339)	- .244 (± .000336)	-4.60 (± .0331)
Improved Insulation – **IMIN**	+.153 (± .0471)	-1.33 (± .0538)	-1.40 (± .0865)	- .174 (± .0110)	-4.37 (± .198)
Frequent Slurry Removal – **FSR**	+1.29 (± .0840)	- .00762 (± .00434)	-1.05 (± .148)	- .202 (± .0201)	+ .468 (± .00761)
Increased Slurry Dilution – **ISD**	+3.84 (± .870)	+ .348* (±0.0271)	-5.29 (± .310)	- .850 (± .0503)	+1.45 (± .0994)
Slurry Acidification – **Acid**	+8.37 (± 2.29)	+8.89 (±0.220)	-24.6 (± .263)	-11.4 (± .895)	+2.71 (± .648)
IVE & ISD	+6.25 (± .824)	- .540* (± .0375)	-5.25 (± .305)	- .678 (± .0447)	- .515 (± .120)
IVE & FSR	- .814 (± .0537)	-1.14 (± .0143)	-1.15 (± .137)	- .196 (± .0200)	-2.14 (± .0327)
IVE & IMIN	-2.16 (± .0502)	-2.32 (± .0626)	-1.63 (± .100)	- .207 (± .0134)	-6.58 (± .223)
AD & IVE	-12.1 (± 2.51)	-4.19 (± .205)	+12.2 (± .347)	+7.84 (± .216)	-35.8 (± .494)
AD & IMIN	-11.4 (± 2.45)	-4.36 (± .191)	+11.4 (± .359)	+8.00 (± .223)	-38.3 (± .386)
AD & FSR	-9.67 (± 2.33)	-3.04 (± .212)	+11.9 (± .349)	+8.19 (± .226)	-33.6 (± .550)
IMIN & FSR & AD	-13.8 (± 2.42)	-4.38 (± .181)	+10.5 (± .344)	+8.33 (± .692)	-38.4 (± .385)
IMIN & IVE & AD	-13.2 (± 2.53)	-5.59 (± .180)	+11.1 (± .344)	+7.72 (± .211)	-40.8 (± .388)
IMIN & IVE & FSR & AD	-14.7 (± 2.42)	-5.24 (± .188)	+10.8 (± .344)	+8.28 (± .333)	-40.6 (± .385)
IVE & FSR & AD	-12.6 (± 2.43)	-4.06 (± .193)	+11.4 (± .329)	+7.89 (± .218)	-35.8 (± .475)

Table 2: Annual environmental impact of the typical integrated Danish pig farm under baseline conditions along with the annual abatement potential of each stand-alone measure and selected combinations of abatement measures (as % of impact under baseline). Asterisk (*) indicates non-significant differences with the baseline. Green = reduced environmental impact, Red = increased environmental impact.

Abstract code: 321

Eco-friendly feed formulation reduces the environmental impacts of pig production without consequences on animal performance

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Abstract

Purpose. Animal feeding has a major contribution to the environmental impacts (EI) of pig production. Including EI of feed ingredients into the feed formulation problem has been proposed as a way to reduce EI of pig production. The objective of this study was to test the ability of innovative formulation methodologies in growing pigs to reduce EI of pig production, while taking into account their possible effects on growth performance.

Methods. We compared three different formulation methodologies: least-cost formulation (control diet) in accordance with usual practices in commercial farms; multiobjective (MO) formulation (ecodiet) considering feed cost and EI calculated by Life Cycle Assessment (LCA); MO formulation using feed ingredients locally produced by farmers (local diet) to reduce the impact of feed transport. Ninety-six pigs were distributed between the three experimental groups with pigs individually weighted and fed using an automatic feeding system. Five categories of impacts were evaluated: ILCD climate change (CC), ILCD acidification (AC), CML 2001 eutrophication (EU), CML 2001 land occupation (LO) and CED V1.8 non-renewable and fossil energy demand (CED), at both feed plant gate and at farm gate, with the one kilogram of feed and the one kilogram of live pig as functional units.

Results and discussion. At feed level, MO formulation reduced CC, CED, and AC impacts but increased LO and sometimes EU impacts. These formulations reduced proportion of cereals and oil meals into feeds (feed ingredients with high impacts) while proportions of alternative protein sources, like peas, faba beans or high-protein agricultural co-products increased (feed ingredients with low impacts). Since animal performance was not affected by the dietary treatment, results obtained at farm gate with MO formulation with either standard or local feed ingredients were similar to those obtained at feed level.

Conclusions. Diet formulation is a way to reduce the EI of pig production. Indeed, selecting feed ingredients with lower EI like locally produced proteins or high-protein agricultural co-products seems to be an efficient way to reduce impacts of pig production without consequences on animal performance.

Keywords: *Multiobjective feed formulation; Experiment; Feed ingredients; Pig fattening.*

Introduction

Livestock production significantly contributes to global environmental change through: greenhouse gas emissions, water pollution, acidification, and primary energy consumption in particular in territories with high concentrations of livestock. Environmental impacts from pig production are linked to feed production, direct farm energy use (electricity, gas and oil consumed) and emissions from housing and manure management (Leinonen and Kyriazakis, 2016). In particular, animal feeding accounts for 55 to 75% of climate change, 70 to 90% of energy use and 85 to 100% of land occupation (Dourmad et al., 2014).

Therefore, there is a possibility to reduce environmental impacts by selecting feed ingredients with relatively low impacts like alternative protein sources (peas, faba beans, high-protein agricultural co-products, Wilfart et al., 2016). The traditional feed formulation is only based on feed cost and does not consider its environmental impacts. Including impacts of feed ingredients into the feed formulation problem has been proposed as a way to reduce the impacts of pig production. To this end, Garcia-Launay et al. (2018) developed a multi-objective (MO) formulation method based on environmental impacts of feed ingredients calculated by Life Cycle Assessment (LCA).

Previous studies including environmental objectives into the feed formulation problem (MacKenzie et al., 2016; Garcia-Launay et al., 2018) obtained diets with lower proportions of cereals and oilmeals and higher proportions of alternative protein sources (peas, faba beans or high-protein agricultural co-products). However, MacKenzie et al. (2016) and Wilfart et al. (2018) investigated the potential of reduction of environmental at farm gate with modelling studies that hypothesizing that animal performance was maintained with the feeds obtained. With an experimental approach, Shaw et al. (2002) showed a negative effect of wheat middling incorporation in pig diet on growth performances. Replacing soybean meal by rapeseed meal in pig diet may also decrease animal performance (Hulshof et al., 2016). Consequently, this approach might impair pig performance and the improvement obtained at feed level. The objective of this study was then to test the ability of innovative formulation methodologies in fattening pigs to reduce the environmental impacts of pig production, while taking into account their possible effects on growth performance. The global approach adopted was to use innovative formulation methodologies to obtain feeds, to test them experimentally on growing-finishing pigs and to use the results of the experiment to assess the associated environmental impacts.

Material and methods

Feed formulation. We compared three different formulation approaches: least-cost formulation (control diet) in accordance with practices in commercial farms; MO formulation (ecodiet) and MO formulation using feed ingredients locally produced by farmers (local diet) to reduce the impact of feed transport. In all types of feed formulations, feeds were formulated with linear programming. In least-cost formulation, only feed cost was minimized. In MO formulation (Garcia-Launay et al., 2018, 2019), the objective function included global environmental impacts calculated through LCA, i.e. climate change, non-renewable and fossil energy demand, acidification, eutrophication and land occupation, under varying ϵ-constraint of maximum feed cost :

$$f(x) = \sum_{i \in I} \mathrm{coef}_i \frac{\mathbf{Impact_i}^t\mathbf{x} - \mathbf{Min_i}}{\mathrm{Ref}_{\mathrm{impact}_i} - \mathrm{Min}_i} \qquad \mathbf{c}^t\mathbf{x} \leq \boldsymbol{\epsilon} \qquad \boldsymbol{\epsilon} = \{\mathrm{Ref}_{\mathrm{price}}, \ldots, \mathrm{Max}_{\mathrm{price}}\}$$

$\mathbf{Impact_i}^t$: matrix of impact i of feed ingredients; $\mathbf{c}^t$: matrix of feed ingredients' prices; $\mathrm{Max}_{\mathrm{price}}$: price of feed when formulating without ϵ-constraint; Min_i: level of impact i when formulating at lowest impact i; $\boldsymbol{x}$: matrix of incorporation rates of feed ingredients; $\mathrm{Ref}_{\mathrm{impact}_i}$ and $\mathrm{Ref}_{\mathrm{price}}$: impact i and price of least-cost formulated feed; coef_i: weighting factor of impact i with weighting factor of CC being double of weighting factor of the other impacts..

The best formula is identified when the marginal decrease in the environmental index ($\mathrm{Impact}_i^{tx}/\mathrm{Ref}_{\mathrm{impact}_i}$) becomes lower than the marginal increase in the cost index $\mathrm{c^tx}/\mathrm{Ref}_{\mathrm{price}}$..

Local diet was formulated with ingredients locally produced by farmers (cereals and proteins like peas and faba beans) and rapeseed meal.

Animal study. The experiment was conducted at the INRAE Experimental Facility (UE3P) located in

Saint Gilles, France, in accordance with the French legislation on animal experimentation and with approval by the Regional Ethical Committee (authorization : 2019041815163846). Ninety six Pietrain x (Large White x Landrace) pigs were fattened in a single pen equipped with an automatic weighting device and with automatic feeders, allowing daily individual recording of live weight and feed consumption. Pigs were allocated to the three experimental groups (control diet, ecodiet and local diet) in a randomized complete block design according to sex and litter origin. Each experimental group had an equal number of entire males and females (n=16 per group x sex). The experiment started at 40kg and ended at 115kg body weight. From 40 to 65kg, pigs received experimental diets corresponding to growing pig requirements and from 65 to 115kg, pigs received experimental diets corresponding to finishing pig requirements. Before moving to the experimental room, pigs were tagged in the right ear with a serial number and an RFID chip for identification in the sorter (which also served as weighting machine) and in the automatic feeders. Pomar et al. (2011) described in more details the automatic feeding system used in this experiment. All pigs were fasted 24h before slaughter. Carcass weight, lean meat percentage and carcass yield were measured at slaughterhouse.

Life Cycle Assessment. LCA was conducted individually for each pig according to individual animal performance and impacts of diets were allocated according to the relative contribution of growing and finishing diets. Two system boundaries and functional units were considered:
- one kg of feed at feed factory gate, including resources and emissions associated to the production of feed ingredients, their transportation to the feed factory and feed fabrication.
- one kg of live weight gain of fattening pig, which additionally included resources and emissions in farm buildings associated to pigs and manure in pits below animals, emissions from manure storage and from manure spreading.

We considered fully slatted floor housing and temporary storage of manure under animals, followed by an external storage in uncovered pit. Environmental impacts of manure management were estimated using a system expansion approach (Garcia-Launay et al., 2014). Impacts of feed ingredients were from the ECOALIM data set (Wilfart et al., 2016) Five categories of impacts were assessed using characterization methods available in Simapro, version V8.5.2 (PRé consultants, Amersfoort, the Netherlands): ILCD for climate change (CC, kg CO_2-eq) and acidification (AC, molc H+-eq), CML 2001 for eutrophication (g PO43-) and land occupation (LO, m^2.year), CED V1.8 for demand in non-renewable energy (NRE, MJ).

Statistical analysis. Animal performance and LCA data at farm gate were analysed (using R version 3.5.1) through variance analysis testing the effects of sex, experimental group and sire, considering the pig as the statistical unit.

Results

Control diet contained 70% of cereals, 10% of alternative protein sources, 10% of oilmeals, and 5% of wheat middlings. Ecodiet contained 45-50% of cereals, 7% of oilmeals (only in growing diet), 25% of alternative protein sources and 20% of wheat middlings. Local diet contained 60-70% of cereals, 5% of oilmeals (only in growing diet) and 30% of alternative protein sources.

At diet level, ecodiet *vs*. control diet reduced CC impact at feed factory gate by 30%, CED impact by 15%, AC impact by 20%, EU impact by 12% and LO impact by 3% (Table 1). Local diet *vs*. control diet reduced CC impact by 20%, CED impact by 20% and AC impact by 20%. However, relatively to control diet, local diet increased EU impact by 3% and LO impact by 20% (Table 1).

At animal level, we did not observe any effect of the dietary treatment on growth parameters, total water consumption and slaughter parameters (P>0.05) (Table 2). Final BW, average daily gain, feed conversion ratio, lean meat percentage and carcass weight were significantly different between entire males and females (P<0.01) (Table 2).

At farm gate, ecodiet *vs.* control diet reduced CC impact by 18%, CED impact by 15%, AC impact by 7%, EU impact by 7% and LO impact by 4% (P<0.01) (Table 1). Local diet *vs.* control diet reduced CC impact by 12% and CED impact by 15% (P<0.01) (Table 1). No modification of AC impact was observed with the local diet *vs.* control diet. However, relatively to control diet, local diet increased EU impact by 5% and LO impact by 22% (P<0.01) (Table 1).

Discussion

Proportion of cereals and oilmeals in ecodiet and local diet vs. control diet decreased while proportions of alternative protein sources (peas, faba beans or high-protein agricultural co-products) increased. This is consistent with previous studies including environmental objectives into the feed formulation problem (MacKenzie et al. 2016; Garcia-Launay et al. 2018). Moreover, MO formulation substituted soybean meal by rapeseed meal, peas or faba beans. Indeed, cultivation of soybean in South America has high impacts, related to deforestation and large transport distances (Van der Werf et al., 2005), and locally produced protein sources like peas and faba beans have lower impacts (Wilfart et al., 2016). Environmental impacts of co-products like wheat middlings are allocated according to their economic value which induces lower impacts than the crop (Wilfart et al., 2016). This resulted in lower CC, CED and AC impacts with MO formulation (Table 1). These results are consistent with the results from Eriksson et al. (2005) and van Zanten et al. (2015) who found a reduction of environmental impacts by replacing soybean meal by peas or rapeseed meal. We confirm that substituting cereals and soybean with rapeseed meal, peas, faba beans or wheat middlings is efficient to reduce the environmental impacts of pig feeds in Europe. The use of locally produced protein resulted also in a decrease in CC impact at feed level, but it had a minor effect on EU impacts and increased LO impact (Table 1). Indeed, local protein sources need more land than co-products or imported soybean (Wilfart et al., 2016).
Performance of pigs were not affected by the feeding strategy, indicating that both the ecodiet and the local diet formulation may be efficient strategies to reduce environmental impacts at farm gate without compromising performance or carcass quality. This is not always the case in the literature, with some studies indicating impaired performance with increasing use of rapeseed meal, peas, faba bean or co-products or reduced crude protein content. This may be related to the higher variability of composition of these feedstuffs, whereas in the present study they have been analyzed for adjusting their real nutritional value.

Since animal performance was not affected by the supplied diet, results obtained at farm gate with MO formulation with either standard or local feed ingredients were similar to those obtained at feed level (Table 1). Ecodiet significantly reduced all the impacts. Local diet significantly reduced CC, CED and AC impacts but increased LO impact and had no effect on EU. Production systems with a higher proportion of locally ingredients might thus require more land. The use of co-products appears an efficient way to reduce environmental impacts of pig production. However, the amount of co-products available is limited and if applied at large scale this approach can change the demand for various feed ingredients and affect feed price.

Conclusions

Diet formulation is a way to reduce the environmental impact of pig production. Using feed ingredients with lower environmental impacts, such as locally produced protein or high-protein agricultural co-products seems to be an efficient way to reduce impacts of pig production without adverse consequences on animal performance.

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Table 1: Environmental impacts of diets (per kg of feed) and at farm gate (per kg of weight gain)

Impacts of diets (per kg of feed)					
	Control diet	**Ecodiet**	**Local diet**		
CC (kg CO_2 eq)	0.48	0.34	0.38		
CED (MJ)	4.07	3.49	3.29		
AC (molc H^+eq)	0.0094	0.0076	0.0078		
EU (kg PO_4^{3-}eq)	0.0037	0.0032	0.0038		
LO (m².y)	1.41	1.37	1.67		
Impacts at farm gate (per kg of weight gain)					
	Control diet	**Ecodiet**	**Local diet**	**RSD**	**Statistics**
CC (kg CO_2 eq)	2.50^a	2.06^c	2.20^b	0.13	G**, S***, D***
CED (MJ)	14.58^a	12.47^b	12.43^b	0.12	G**, S***, D***
AC (molc H^+eq)	0.15^a	0.14^b	0.15^a	0.10	G**, S***, D**
EU (kg PO_4^{3-}eq)	0.295^a	0.273^b	0.308^a	0.11	G**, S***, D***
LO (m².y)	4.63^b	4.45^b	5.69^a	0.15	G**, S***, D***

CC = climate change (kg CO_2eq); CED = non-renewable and fossil energy demand (MJ); AC = acidification (molc H^+eq); EU = eutrophication (kg PO_4^{3-}eq); LO = land occupation (m²/y); G = gender; S = sire; D = diet; RSD: Residual standard deviation, **P<0.01, ***P<0.001; [a,b,c] Means with different superscript are significantly different between the experimental diets (P<0.05).

Table 2: Effect of diets on the growth performance of pigs

	Control diet	**Ecodiet**	**Local diet**	**RSD**	**Statistics**
Animals, n	31	29	30		
Initial BW, kg	40.8	40.5	40.9	0.10	
Growing BW, kg	61.4	61.1	60.6	0.09	G**
Final BW, kg	113	113	113	0.08	G**
Duration, d	78	78	78		
ADG, g/d	926	927	931	0.10	G***
ADFI, kg/d	2.50	2.50	2.60	0.11	S***
FCR, kg/kg	2.64	2.64	2.74	0.10	G***, S***
Total water consumption, L/	386	399	434	0.30	S**
Carcass yield, %	78.2	78.3	78.4	0.01	G**, S*
Lean meat, %	61.0	61.3	60.7	0.03	G**
Carcass weight, kg	88.4	88.3	89.0	0.08	G**

ADG = average daily gain (g/d); ADFI = average daily feed intake (kg/d); FCR = feed conversion ratio (ADFI/ADG); RSD: Residual standard deviation; G = gender; S = sire; **P<0.01, ***P<0.001.

Abstract code: ID 293

Designing breeding programs to reduce environmental impacts of pig production

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Abstract

Purpose The purpose of the study was to investigate the possibility of breeding pigs to reduce environmental impacts. The investigated impact categories, and goals for the breeding programs, were to reduce: Global Warming Potential (GWP), Terrestrial Acidification Potential (TAP), Freshwater Eutrophication Potential (FEP), Agricultural Land Use (ALU), Fossil Resource Scarcity (FRS) and Cost of Production (CoP). A general framework was developed first, and then applied to pig systems in Denmark (DK) and Great Britain (GB).

Methods A pig Life Cycle Assessment (LCA) and bio-economic model was used to estimate the effects of breeding for six breeding goals, one for each environmental impact category plus the CoP, per 1 kg live animal at farm-gate. Breeding goal weights (BGW) assigned to each phenotypic trait were estimated based on the LCA model as the change in impact category caused by a one unit change in the mean of each trait. BGWs were then used in the breeding software SelAction to estimate genetic change in each trait per generation, which were reintroduced into the LCA to quantify the impact of ten generations of selection. An uncertainty analysis was carried out to quantify the effects on the impact categories from variation in feed intake and composition resulting from optimising for least cost.

Results and discussion The CoP-reducing breeding program produced the highest reductions in impacts for the majority of the impact categories, although the differences between the six breeding programs were rather small. The DK system showed larger relative reductions in impacts than the GB system. The uncertainty analysis led to larger reductions for GWP and FRS, and smaller reductions for TAP, FEP and ALU, in the GB system. The alternative feeding scenarios gave similar results for the DK system.

Conclusions In this study, integrating environmental impact objectives directly in the breeding goals of pigs, did not produce significant greater reductions in environmental impacts than were already achieved by breeding to minimise CoP. Our results also suggest that any breeding program, both aimed at reducing CoP or any of the investigated environmental impact, might result in larger reductions in environmental impacts than previously thought.

Keywords: Life Cycle Assessment; pig; breeding; traits

Introduction

Animal breeding has traditionally been utilized to reduce cost or increase profitability of animal production and this has led to substantial improvements in multiple performance traits (Kanis et al. 2005). In recent years, however, the focus solely on economic objectives in commercial breeding programs has been challenged (Pelletier 2010) and recent studies have shown that it is possible to reduce environmental impacts from domestic livestock by breeding (Macleod et al. 2019). This study investigates the possibility of breeding pigs to improve environmental sustainability of pork production.

We developed a framework that enabled estimation of the impact categories of the pig production system after 10 generations of selection, with the feed composition adapted to the performance of the future pig. We hypothesised that, through integrating a pig breeding program with an LCA model of pig production, it would be possible to achieve reductions in specific environmental impact categories by targeting these impacts directly in the breeding goal. The study investigated the outcomes of breeding programs designed to reduce the following impact categories: Global Warming Potential (GWP), Terrestrial Acidification Potential (TAP), Freshwater Eutrophication Potential (FEP), Agricultural Land Use (ALU), Fossil Resource Scarcity (FRS) and Cost of Production (CoP) after 10 generations of selection under production systems in Denmark (DK) and Great Britain (GB). Since a constant feed energy concentration was assumed in the breeding program, an uncertainty analysis was carried out to quantify the effects of variation in feed intake and composition that resulted from choosing feed based on least cost.

Material and methods

A previously developed LCA model for pork production was extended to account for the effect of genetic improvement (Misiura et al. 2019). In short, the model predicted energy and protein requirements from performance, feed intake and composition from requirements and feed ingredient prices, and environmental impacts from feed, and estimated manure mass and composition. The LCA model was expanded to include economic elements to estimate CoP. Only directly scalable elements were included to comply with standard LCA principles (Heijungs and Suh 2002), i.e. costs of buildings, loans and accounting were excluded. CoP was therefore estimated from the cost of feed ingredients (included in previous models), pelletisation (55 £ per ton), labour (18.16 £/h in DK, 13.05 £/h in GB), and manure management (0.73 £/m^3 in DK, 1.30 £/m^3 in GB). per

Phenotypic traits included in the model were based on the traits modelled in Ottosen et al. (2020) that had a mechanistic effect on the outcomes of the LCA model (model traits) or that were recorded in the breeding program (index traits). Included traits were: average daily feed intake, average daily gain from weaning to the end of the late weaning phase, average daily growth from the start of the grower phase to the end of the finisher phase, gilt age at sexual maturity, back fat thickness, lean meat percentage, total litter mass gains from birth to weaning, number of piglets born alive, litters per sow per year, last parity when the sow was active in the herd, mortality rate from weaning until end of finisher phase, mortality from birth until weaning, and residual feed intake. Average daily feed intake and back fat thickness were index traits, and the remaining traits were model traits.

Genetic and phenotypic correlations, genetic variances and heritabilities were obtained from the same literature sources and in a similar manner as in Ottosen et al. (2020). As per breeding practice, two breeding lines that were crossed to produce growing pigs were simulated: a terminal sire line and a maternal line. Each consisted of a herd of 40 boars and 400 sows of the present average commercial population in the investigated countries.

Development of breeding programs requires estimation of breeding goal weights (BGW), which are defined as the impact of a one unit change in the mean of each model trait on the chosen breeding goal, while keeping the mean of all other traits constant. Each of the six impact categories was investigated as a breeding goal. BGW were produced under the assumption of constant energy

concentration in the feed, since it improved stability of the model. This meant that when traits reduced the energy requirements in a phase, feed intake decreased in proportionate amounts. Since the LCA model had a number of approximations, estimating BGWs from a small change in a trait did not give consistent results. Instead, a second order polynomial was fitted to the outcomes of the LCA model for a range of means of each trait, which was then differentiated and evaluated at the current mean of the trait to estimate the BGW.
The resulting BGW, along with population structure, correlations, variances, and heritabilities were then used as inputs into the scientific breeding simulation software SelAction (Rutten et al. 2002), to estimate responses to selection per generation for each of the model trait, separately for the sire line and the maternal line. Response in the crossbred pig was estimated as the average response in the sire and maternal line for growth performance and carcass traits, but as response in the maternal line for female reproduction traits. These responses were assumed to be small and approximately constant over generations; they were multiplied by 10 to estimate the trait means after 10 generations of selection, and then used in the LCA model to estimate the change in impacts. Feed intake and composition are influential inputs to LCA models in pig systems (Misiura et al. 2019). We therefore performed an uncertainty analysis to reflect the potential variation in feed intake and feed composition while meeting all nutritional requirements in the least cost feed formulation. This was done formulating diets for least cost without fixing their energy concentration so that the optimum balance between feed intake and feed cost was found to minimise overall feed costs within a realistic range for feed intake (Least Cost Feed Intake; LCFI). All LCFI feeds were balanced to meet or exceed animal nutritional requirements.

Results
Fig 1 shows reductions in all impacts after 10 generations of selection for each breeding goal and for both countries. The CoP breeding program, which reflects current commercial breeding, led to the expected reduction in the CoP-impact, but also in the environmental impacts where major reductions were observed. In fact, the CoP breeding program had the highest reductions in GWP, TAP, FEP and CoP impact categories for both countries. The difference between the different breeding goal programs were, however, much smaller than the overall reduction for every impact category, although the TAP breeding program performed slightly worse than the other breeding programs for all impact categories in the DK system. The DK TAP impacts category had the largest reductions, followed by the ALU, FEP, CoP, GWP, and FRS impact categories. The reduction in impact categories in the GB system was largest but similar for the FEP and CoP impact categories, followed by ALU, FRS, TAP, and GWP. For all breeding programs and for all impact categories, the DK system had a larger proportional (18.1 %) as well as absolute reduction, than the GB system (13.7 %) relative to the baseline system, although the DK system had larger impacts that the GB system for all impact categories and breeding programs, both before and after 10 generations of selection (not shown).
Fig 2 shows the change in impacts under the LCFI scenario for the crossbred pigs in both countries subtracted from the changes seen in Fig 1. The additional reduction in impact categories in the LCFI were for all cases small, especially for the DK system. All additional reduction to impact categories for all breeding programs were similar to each other. In the DK LCFI system, ALU and CoP were reduced slightly more whereas GWP, FEP and FRS were reduced slightly less compared to what was seem in Fig 1. In the GB LCFI scenario, GWP was reduced much more, whereas FRS and CoP had minor additional reductions, compared to Fig 1. However, the TAP and ALU impact categories had slightly less reductions than those seen in Fig 1. Uncertainty due to variability in the feeding system was therefore larger in GB than in DK.

Discussion
The breeding programs aimed at reducing different impact categories were very similar in their reduction of impact categories after the 10 years of selection. Reducing feed intake, higher inclusion

of cheaper less polluting ingredients and reducing the manure produced reduced both the CoP and the environmental impacts. Within the scenarios we modelled, it was not possible to reduce specific environmental impact categories by integrating these directly into the breeding goals, compared to the traditional CoP breeding program. Even though the CoP breeding program had the highest reduction in most impact categories, the differences between the breeding programs were too small to confirm with certainty that breeding to minimise cost was the most effective strategy to reduce environmental impacts for all systems.

Considering the overall size of the reductions in impacts from the breeding programs, the effect of breeding to reduce impacts was comparable with outcomes from previous studies on changes to management. With a typical generation time of around one year in pigs, the predicted reductions in environmental impacts were substantially better than what has previously been proposed (Macleod et al. 2019), likely due to the more advanced modelling approach. Since the model predicted differences between breeding goals to result only in minor differences in impact responses, the above reductions in impacts should be possible to achieve with the present commercially used CoP breeding program, with no or only minor additional costs to the breeding program. It should be noted that any improvement in pig genetics can be implemented simultaneous with improvements in management, which could lead to even greater reductions in impacts. The estimated reductions in impacts from pig production in the future were likely underestimated since no improvement in feed production and manure management was accounted for, which could be expected to be implemented over the period. The additional impact reductions predicted in the LCFI scenario were small for the DK system but larger for the GB system. This might be due to the larger flexibility in the feed formulation in the GB system than in the DK system, where the access to cheap co-products can lead to major shifts in other ingredients, and thereby in environmental impacts. This indicates that farmers can achieve greater reductions in environmental impacts (and CoP) by precision feeding in some systems.

Conclusions

This study found substantial reductions in all impacts for all breeding goals for both the DK and GB systems after a 10 generations breeding program. However, we did not find any noticeable difference between the different goals, and the CoP breeding program reduced environmental impacts as much as or more than the environmental breeding program. Further, optimising the feed intake of the future pig for least cost led to substantial reductions in some environmental impacts in the GB system.

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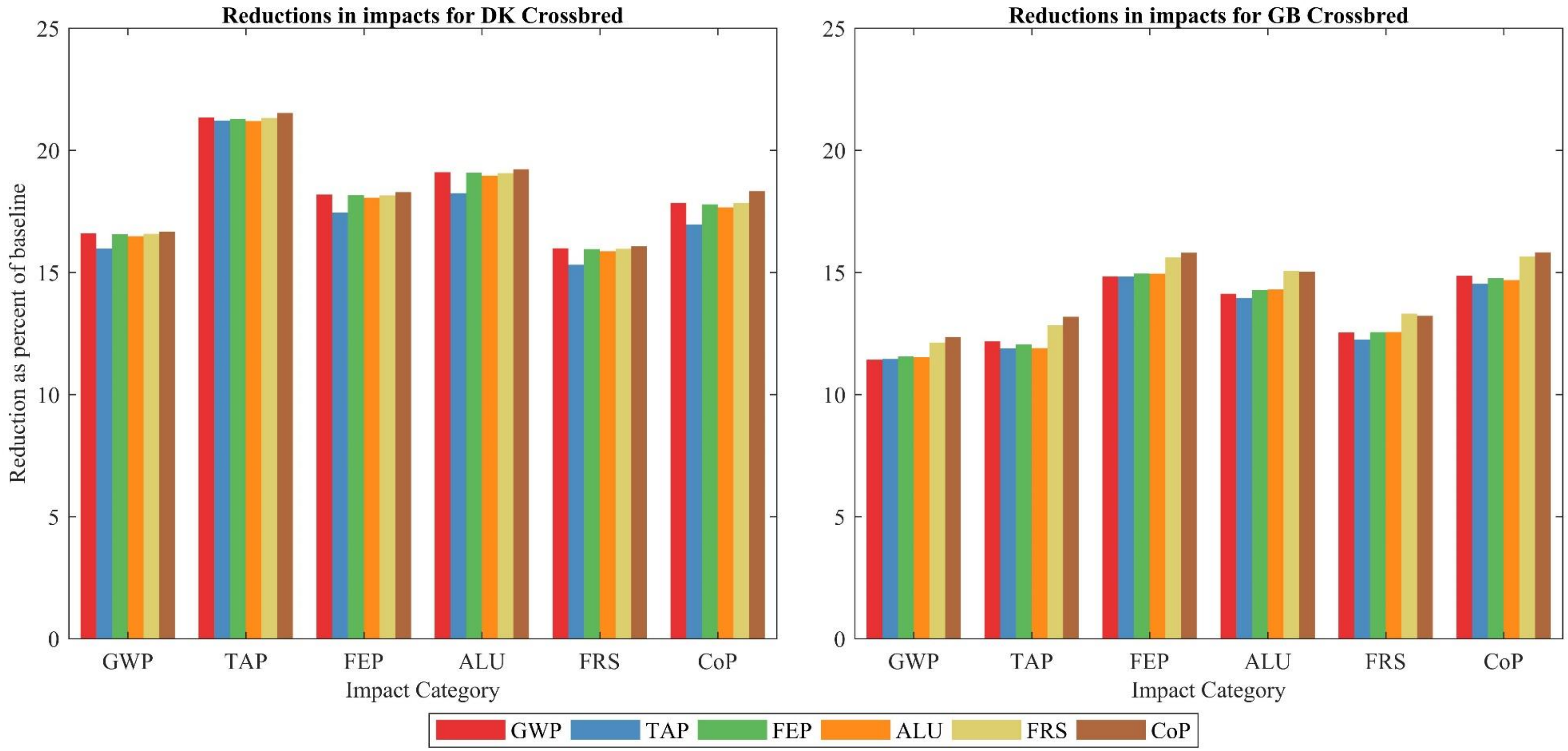

Fig 1: The reduction in impacts in the crossbred pig from the breeding programs after 10 generations relative to the 2017 baseline scenario for each country. Each colour represents a breeding program and each cluster of bars represents an impact category. The breeding programs were aimed to reduce: GWP (Global Warming Potential), TAP (Terrestrial Acidification Potential), FEP (Freshwater Eutrophication potential), ALU (Agricultural Land Use), FRS (fossil Resource Scarcity) and CoP (Cost of Production). The impact categories use the same abbreviations as the breeding programs. The Investigated countries are DK (Denmark) and GB (Great Britain).

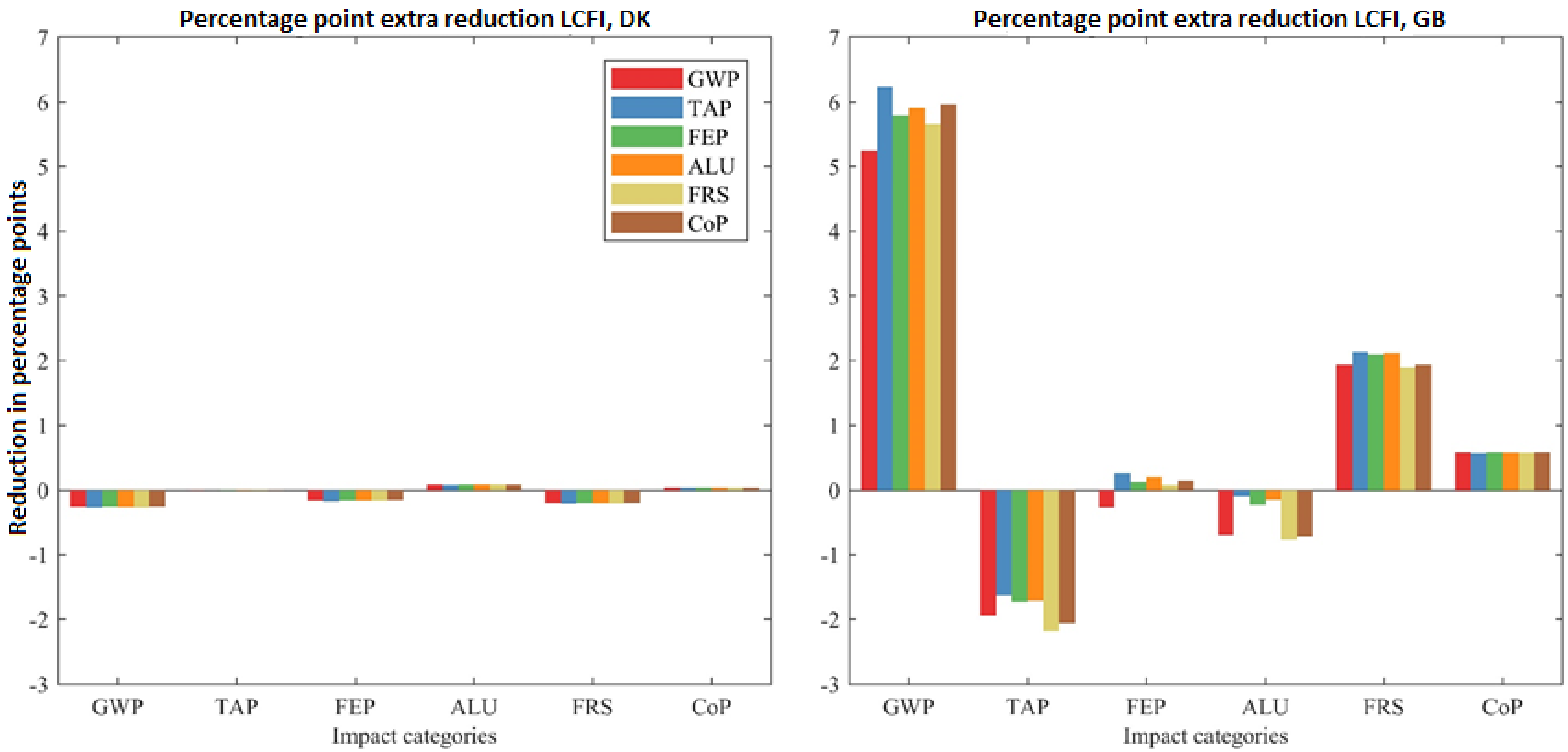

Fig 2:The additional reduction of impacts from the breeding programs of the crossbred pig under Least Cost Feed Intake (LCFI) after 10 generations for each country. Normalised after the same 2017 baseline scenario as Fig 1, and the results from Fig 1 have been subtracted. Each colour represents a breeding program and each cluster of bars represents an impact category. The breeding programs were aimed to reduce: GWP (Global Warming Potential), TAP (Terrestrial Acidification Potential), FEP (Freshwater Eutrophication potential), ALU (Agricultural Land Use), FRS (fossil Resource Scarcity) and CoP (Cost of Production). The impact categories use the same abbreviations as the breeding programs. The Investigated countries were DK (Denmark) and GB (Great Britain).

Abstract code: 208

Sustainability analysis of European pig farms – combining LCAs with environmental multi-criteria analysis

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Abstract

Purpose: To assess a broad range of sustainability aspects of pig farms, we used an analysis tool, which combines quantitative methods such as environmental LCA and cost-benefit analysis with (more qualitative) key performance indicators (KPIs) by using a multi-criteria analysis (MCA).

Methods: Data from pig breeding and fattening farms were collected to integratively assess the sustainability performance of farms in four dimensions: environment, economy, farmer wellbeing including good governance and animal health and welfare. SAFA guidelines (FAO 2013) were used as a basis for the selection of sub-/themes for most dimensions of sustainability. We combined elements of different qualitative and quantitative methods throughout the whole analysis tool (for all dimensions). For the environmental aspects we used (1) LCAs for Global warming potential, Acidification and Eutrophication potential, Cumulative energy demand and Land use and (2) MCA with indicators based on e.g. SAFA for further environmental issues.

Results and discussion: Our method can be used for a comprehensive sustainability assessment of pig farms. An integrative summary of the results (e.g. in spider web and Mekko graphs) shows scores for single indicators which can be summed up for subtheme and theme level. It identifies those indicators with the highest potential to improve the overall sustainability. The tool shows that pig farms have specific strengths and weaknesses and that farm- (production system-) specific solutions are needed to substantially improve the overall sustainability performance.

Conclusions: Our combination of quantitative LCA indicators and more qualitative KPIs (the latter could also be used stand-alone for a rough hot spot analysis) enables a comprehensive environmental analysis without leaving important environmental aspects behind. In a further combination with other dimensions' analyses in the SusPigSys method, this allows for a practical and comprehensive sustainability assessment of pig farms.

Keywords: *Integrative sustainability analysis; life cycle analysis; MCA*

Introduction

Ecological impacts of a farm can be calculated using quantitative LCA methods. Several studies assessed individual pig farms or model pig farms (e.g. de Vries and de Boer 2010; Dourmad et al. 2014; Rudolph et al. 2018). However, as quantitative analyses require a high level of detail and may have various system boundaries and ecological impact categories, these LCA assessments are often of limited use for real world farms. Additionally, environmental issues are often not adequately assessed due to data gaps and uncertainties. A possible solution may be the (additional) use of qualitative indicators and multi-criteria analysis (MCA; Hermann et al. 2007) which yield less detailed but more comprehensive results.

Specific disadvantages are known for both LCA and MCA regarding precise and robust results: while MCAs introduce high uncertainty with more or less subjective indicator weights, the high resolution of life cycle inventories, e.g. regarding different nitrogen fluxes from fertilisers and soil, include emission factors with high uncertainty (Schader et al. 2019). There is no one-size-fits-all solution and different methods supplement each other (Schader et al. 2014).

Therefore, this paper describes a combined (quantitative and qualitative) approach, which requires less data entry than a detailed LCA, but provides comprehensive results for farmers, whilst still including the most important (typical) LCA impact categories. It was developed in the Era-Net SusAn project SusPigSys. Using the example of the ecological dimension, we show that (a) if primary farm data for LCAs are entered, quantitative results for Global warming potential (GWP), Acidification and Eutrophication potential (AP and EP), Cumulative energy demand (CED) and Land use (LU) are calculated, which are interesting for farms' benchmarking and provide specific hints for specific sustainability improvement. (b) These typical quantitative LCA indicators are well complemented by additional KPI indicators in a MCA to identify hotspots and provide further advice to farmers, how to improve sustainability. With this contribution, we want to stimulate a discussion on the embedment of scaled LCA results in a MCA based on the SAFA guidelines.

Material and methods

The integrative sustainability assessment applied in the SusPigSys project addresses four dimensions: Ecology, Economy, Farmer Wellbeing and Animal Health and Welfare. These dimensions were subdivided in themes, subthemes and indicators. In case of the environmental dimension, SAFA guidelines (FAO 2013) were used for the selection of sub-/ themes.

The environmental assessment relates to farm level and input supply chains. For the LCA, three different functional units related to kilogram pig produced were applied for specific farm types (breeding, finishing, farrow-to-finishing), each using a slightly different system boundary. The system boundaries were defined as cradle-to-farm gate. We used background data mainly from two LCA databases for feed, electricity and materials such as fertilisers (Ecoinvent, Wernet et al. 2016; Agribalyse, Koch and Salou 2016). The following methods were applied to assess the LCA impacts: Cumulative energy demand v.1.10, characterization factors from IPCC (2013) for GWP, CML-IA non-baseline V3.04 / EU25 for the AP and the ILCD 2011 Midpoint+ V1.10 / EC-JRC Global for freshwater and marine EP.

For the MCA, additional ecological Key Performance Indicators (KPIs) were assessed for all SAFA sub-/themes. Concerning, for instance, ecosystem, species and genetic diversity, those KPIs analyse the proportion of farm area with plant protectants, the average number of pesticide treatments per year or the use of GMO-feed.

As qualitative indicators can be binary (i.e. 0 or 1) or ordinal (e.g. on a Likert scale), they were transformed into sustainability scores ranging from 0% (worst) to 100% (optimum). The same procedure was applied to LCA results. This scaling was based on the range of values found in literature and in our own data and done by experts of the SusPigSys consortium. For instance, a LCA result of less than or equal to 2 kg CO_2-eq per kg finishing pig (live-weight) was set as optimum (100%) for the LCA indicator "kg CO_2-eq per kg pig", a result of greater than or equal to 5 kg CO_2-

eq per kg finishing pig (live-weight) as worst (0%). LCA results in between were interpolated linearly. When indicators were summarized to the corresponding subtheme, and subthemes to the corresponding theme, their relative impacts were adjusted according to weights applied by 23 experts in a Delphi survey. The experts' weights of LCA indicators and of KPIs on the environmental sustainability subthemes are provided in Table 1 (aggregated) and Table 2 (detailed for a selection of subthemes).

Environmental sustainability results were displayed using spider webs at subtheme level (e.g. "Greenhouse (GHG) gas emissions"; Fig. 1) and theme level and with Mekko charts at indicator level (LCA and KPI by theme; Fig. 2).

Results and Discussion

Only in six out of twelve subthemes, LCA-results are contributing. For our project goal to deliver a practicable on-farm sustainability assessment tool, we were not able to implement LCA indicators for every subtheme. For biodiversity, for instance, we could not identify and integrate a method, which is practical, has a low uncertainty of results and is applicable for farmer recommendations. Additionally, in the other six subthemes, experts always gave a lower sum of weights to the LCA indicators than to the complementary KPIs (Table 1). This suggests, that the overall sustainability is influenced more by KPIs than by LCA results. LCA results derive from several different parameters, but are presented as single values (e.g. CO_2-eq). This could cause problems for farmers to identify the most important parameters for environmental improvement. In contrast, KPIs are less complex and allow farmers to choose measures of improvement more easily. This illustrates, that an assessment of the typical LCA impact indicators for livestock, i.e. GWP, AP, EP or LU, might not be sufficient to comprehensively analyse environmental sustainability of farms and to provide improvement options for farmers.

Important driving factors for improving environmental sustainability identified from preliminary analysis are: reduced pesticide application, adequate nitrogen fertilizer application and minimizing water pollution (no cultivation on riparian stripes or no access of animals to water bodies). This can be seen by indicators, their expert weights and the exemplary performances of ten Austrian and eight German farms in Table 2 for the sustainability theme Water, subthemes Water Withdrawal and Water Quality.

Figure 1 shows overall subtheme-level results of ten Austrian and eight German farms. Similar to previous studies, there was high variation between farms in terms of Biodiversity or Soil Quality indicator results. GHG emissions and Air Quality also varied considerably, which are highly dependent on LCA results (e.g. 45 % and 43 % of the Air Quality and the GHG emission result).

The SusPigSys sustainability analysis tool clearly shows that pig farms have specific strengths and weaknesses, also in the environmental dimension. Thus farm- (production system-) specific solutions are needed, which can be detected with our tool.

In conclusion, the combination of quantitative LCA indicators and more qualitative KPIs enables a comprehensive environmental analyses without leaving important environmental aspects behind. In a further combination with other dimensions' analyses within the SusPigSys method (for Economy or for Animal Health and Welfare), this allows for a practical sustainability assessment of pig farms.

Acknowledgements

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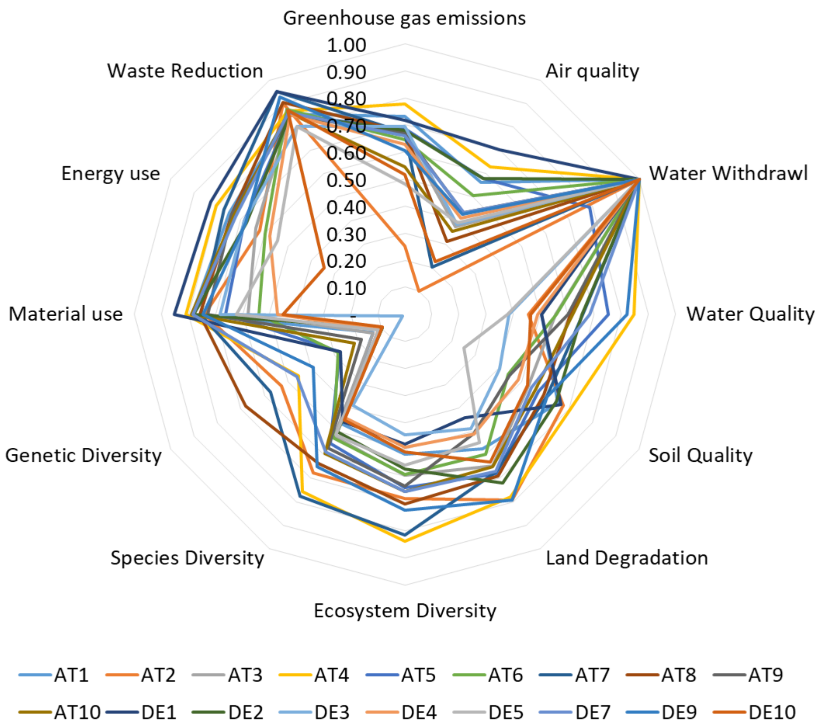

Figure 1. Environmental sustainability (MCA) score results of a selection of ten Austrian (AT) and eight German (DE) farms on subtheme level. Results range between 0% (worst: sustainability goals are not achieved) and 100% (optimum: sustainability goals are fully achieved).

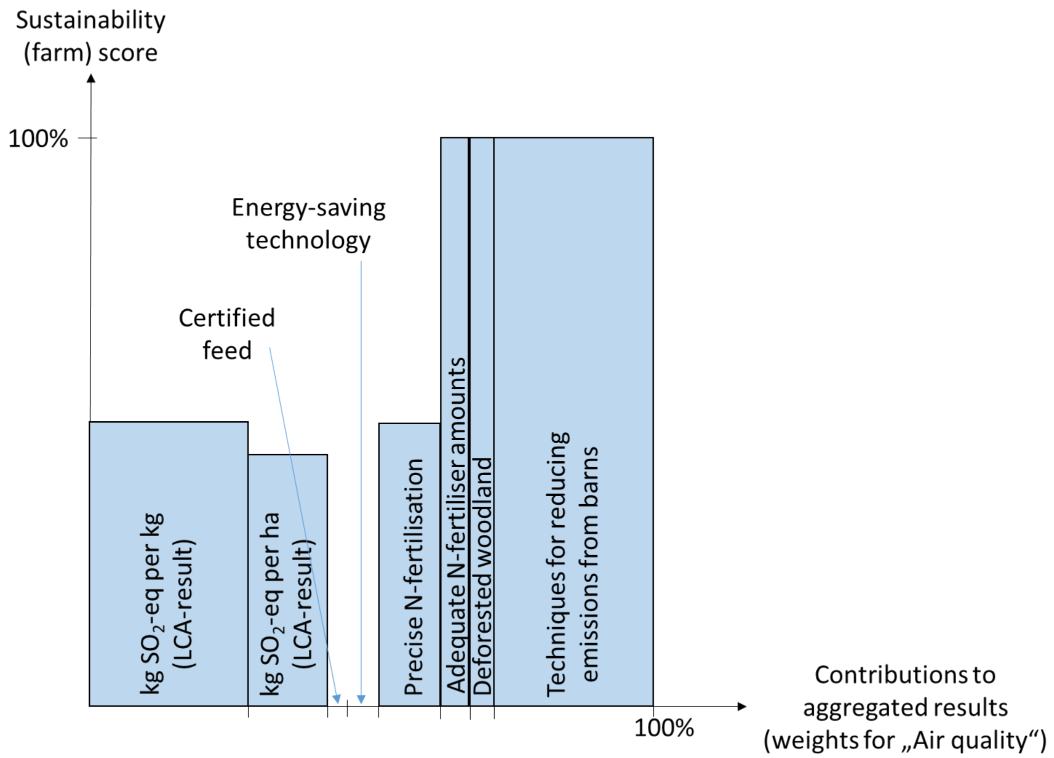

Figure 2. Indicator results for the example of an Austrian farm (AT1) for the subtheme Air quality in a Mekko chart. The height of the columns describes the sustainability score of each indicator (as scaled by the consortium), the width of the columns shows the weights of the indicators for the subtheme (as weighted by the expert opinion).

Table 1. Contribution of quantitative LCA and qualitative KPI indicator weights to subtheme results.

	Proportion of weights			Proportion of weights	
Subtheme	LCA-indicators	KPIs	Subtheme	LCA-indicators	KPIs
Greenhouse Gases	45%	55%	Ecosystem Diversity	-	100%
Air Quality	43%	57%	Species Diversity	-	100%
Water Withdrawl	-	100%	Genetic Diversity	-	100%
Water Quality	30%	70%	Material Use	10%	90%
oil Quality	20%	80%	Energy Use	35%	65%
Land Degradation	-	100%	Waste Reduction	-	100%

Table 2. Indicators for the subthemes Water Withdrawal and Water Quality (selection), their weights provided by expert opinion, sustainability scores (scaling based on literature and our data) and the performance of observed farms.

Indicators	Expert weights	Scales	Performance distribution of selected farms
Water Withdrawal			
Water-saving technology in the barn (high-pressure cleaner, re-use of clean cleaning water, etc.)	0.33	no (0%), partly (50%), yes (100%)	all farms with 100%
Sufficient water supply or storage capacities (e.g. wells, retention basins)	0.20	no (0%), yes (100%)	all farms with 100%
Water-saving technology for irrigation of fields (e.g. drip irrigation)	0.20	no (0%), partly (50%), yes/no irrigation (100%)	17 out of 18 farms with 100%, 1 farm with 50%
Use of information about local precipitation and evaporation rate (in order to adapt your irrigation quantities)	0.12	no (0%), partly (50%), yes/no irrigation (100%)	17 out of 18 farms with 100%, 1 farm with 50%
Field irrigation	0.10	no (100%), partly (50%), yes (0%)	17 out of 18 farms with 100%, 1 farm with 50%
Access to communal (tap) water for a sufficient water supply in the pig barn	0.05	no (0%), yes (100%)	all farms with 100%
Water Quality			
kg P_2O_5-eq per kg piglet / fattening pig live-weight (LCA)	0.15	0% to 100%	4 farms with 75%-100%, 10 farms with 50% to 75%, 2 farms with 25% to 49%, 2 farms with 0% to 24%
kg P_2O_5-eq per ha (LCA)	0.15	0% to 100%	3 farms with 75%-100%, 11 farms with 50% to 75%, 1 farm with 25% to 49%, 3 farms with 0% to 24%
Cultivating harvesting and fertilising crops or pesticide use on riparian strips	0.10	no (100%), yes (0%)	16 out of 18 farms with 100%, 2 farms with 0%
Access of animals (pigs, cows, sheep, etc.) to surface water bodies and/or riparian strips	0.05	no (100%), yes (0%)	16 out of 18 farms with 100%, 2 farms with 0%
Slope of the paddock towards natural water bodies (not interrupted by a buffer strip >5 m)	0.05	no (100%), yes (10%)	16 out of 18 farms with 100%, 2 farms with 0%
Fertilising nitrogen with high precision by using e.g. variable rate application methods, drip irrigation with mineral fertilisers or others	0.05	no (0%), partly (50%), yes (100%)	5 out of 18 farms with 100%, 10 farms with 50%, 3 farms with 0%
N-fertiliser amounts based on demand of soil or plant analyses	0.05	no (0%), partly (50%), yes (100%)	14 out of 18 farms with 100%, 3 farms with 50%, 1 farm with 0%
Application of mineral P- and K-fertilisers based on the results of soil or plant tests	0.05	no (0%), partly (50%), yes (100%)	15 out of 18 farms with 100%, 2 farms with 50%, 1 farm with 0%
Proportion of farmland with synthetic plant protectants	0.05	0% to 100%	4 farms with 75%-100%, 1 farms with 50% to 75%, 13 farms with 0% to 24%
Average pesticide treatment frequency	0.05	no application (100%), 1-3 applications (50%), 4 or more applications (0%)	3 farms with 100%, 14 farms with 50%, 1 farm with 0%
Proportion of land with catch crops	0.05	0% to 100%	1 farm with 100%, 3 farms with 50% to 75%, 9 farms with 25%-49%, 5 farms with 0% to 24%
… [4 minor relevant indicators not shown]			

Topic 6:

Aquatic Models and LCAs

Abstract code: 32

Microalgae for human consumption: A methodological (top-down) approach for the life cycle assessment and techno-economic analysis of microalgae cultivation in tubular photobioreactors

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Abstract

Purpose: The fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) as well as protein are scarce resources in the context of global food security. Specific microalgae species have been shown to be a lucrative source for EPA, DHA and protein and could help reduce the pressure on marine ecosystems. However, microalgae cultivation in colder climatic zones, where closed photobioreactors (PBR) could be more suitable, has only been investigated in few studies regarding their environmental and economic effects.
Methods: This study compared microalgae cultivation in closed PBR with the production of aquaculture and capture fish in terms of environmental impacts. Life cycle assessment (LCA) was conducted according to ISO 14040/44 (2006) using Simapro (v 8.5). The cultivation of *Nannochloropsis sp*. and *Phaeodactylum tricornutum* was considered including detailed satellite climatic data. Different scenarios comprised variations in tube material and diameter, and cultivation season length. Life cycle impact assessment values of selected fish species were obtained from a systematic literature research. The following impact categories were taken into account: global warming potential, acidification, eutrophication, the cumulative energy demand and the water footprint and land use. The economic potential of microalgae was investigated applying the net present value (NPV) and the return-on-investment (ROI) to the cultivation model.
Results and discussion: Even in the cold temperate climate, an extended cultivation season from April to October with a reduced productivity was found advisable. Acrylic glass as a tube material had higher environmental impacts than all other scenarios. Critical processes in all scenarios were the usage of hydrogen peroxide for the cleaning, nitrogen fertilizer, and electricity for mixing, centrifugation and drying. Microalgae biomass was found to have similar or less environmental impacts than fish. Especially fish from aquaculture performed unfavorably compared to microalgae. From an economic point of view, the cultivation of microalgae in a tubular PBR in a cold-weather climate is feasible. On a 30-year time horizon, the facility yields an NPV of 4.5 million euros with a positive ROI in year eleven.
Conclusion: Distinct microalgae seem to be a potential biomass source to close, above all, the gap of EPA+DHA supply. Regarding the recommended daily intake of 250-500 mg EPA+DHA, microalgae are an advisable source of nutrients to lessen the environmental pressure on marine ecosystems while they are also a lucrative economic investment.

Keywords: *Microalgae; Life cycle assessment; Tubular photobioreactor; Environmental impacts; Nannochloropsis sp.; Economic analysis*

Introduction

Protein and the long-chain n-3 polyunsaturated fatty acids (PUFAs) eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are already scarce nutrients in a global context, with the main sources being animal origin (meat and fish), whereby meat in particular causes relatively high environmental impacts (Clune et al. 2017). Fish catch and aquaculture, on the other hand, cannot meet the actual global demand of EPA and DHA. Thus, it is very relevant to investigate additional alternative sources of these essential nutrients.

Some microalgae species contain a high quantity of n-3 PUFAs with concentrations comparable to those found in fish oil (Chacón-Lee and González-Mariño 2010). The quality of proteins from microalgae has been shown to be equal to that of proteins from soybean (Becker 2007). In addition, some microalgae species show a wide range of favorable high-value nutrients such as vitamins, carotenoids, phycobilins, polysaccharides and sterols (Keller et al. 2017). Hence, these species could potentially help compensate for the global deficiency of nutrient supply or to improve health.

The majority of microalgae that are cultivated for human nutrition today is produced in open raceway ponds (ORPs) located in Asia. Large plants moreover operate in Australia and Israel (Borowitzka 2013). However, the evaluation of microalgae cultivation in different geographical and climatic locations is crucial to exploit their true potential in providing nutrients for humans globally. In particular, cultivation in cold areas of temperate climatic zones has only been investigated in a few studies.

The objective of this study was to perform an extensive environmental comparison of microalgae to different fish species regarding the nutritional profile, in particular n-3 PUFAs and protein. Additionally, it was aimed at comparing the modeling of carbon dioxide as an avoided burden to the inclusion of the full burden of carbon dioxide production during microalgae cultivation. Previous studies have often relied on the usage of waste carbon dioxide originating from sources in close proximity to microalgae to ameliorate the environmental cycle of microalgae. However, this approach does not consider the situations in many microalgae facilities. The current comparative study may help gain more insight into the consequences of this methodological choice.

Moreover, it has been shown that from an economic and technical point of view, microalgae cannot compete with fossil fuels and are most profitable for food and feed (Barsanti and Gualtieri 2018). To obtain a profound evaluation, it was furthermore the goal to evaluate the economic potential of microalgae biomass production for food in a tubular photobioreactor in a humid continental climate.

Material and methods

Life cycle assessment (LCA) following ISO Standard 14040/44 (ISO Organisation 2006) was used to compare the environmental impacts of microalgae and fish production. Foreground data were partly acquired from the literature and supplemented with information gained through expert interviews. Data derived from the literature comprised the nutritional composition of the microalgae species used, the photoconversion efficiency (PCE), nutrient inputs during cultivation, cleaning substances, materials for the supporting structures of the PBR and flow velocity in the PBR. Detailed climatic data were obtained from the NASA Data Access Viewer (NASA - National Aeronautics and Space Administration 2019). To assess the relevant input flows for the conduction of the LCA, selected data were drawn from our own calculations.

The Ecoinvent v3.4 'APOS' system model ('allocation at the point of substitution') was used for the calculation of all background processes (Wernet et al. 2016). Concerning microalgae cultivation, a variety of scenarios were selected and tested for their comparability to fish. Thus, cultivation of *Nannochloropsis sp.* in 40 mm (baseline) and 36 mm borosilicate glass tubes was analyzed, along with the usage of acrylic glass in a 3-year and 7-year cycle. Furthermore, the cultivation of *Phaeodactylum tricornutum* in 40 mm borosilicate glass tubes was considered. For every scenario, three different cultivation seasons were assumed, which were then illustrated as a range for each

scenario. Additionally, 15 further scenarios were assessed, which were based on the previously described scenarios, but with the full burden of carbon dioxide production whereas in the first 15 scenarios, carbon dioxide was modeled as an avoided burden.
System boundaries comprised all processes up to the dry microalgae biomass at the store in Germany. In terms of fish products, system boundaries were harmonized to fish fillet at the store by adding data for transportation processes to the farm gate data (the farm gate includes 'landed fish'). Germany was assumed to be the target country for all products. Hence, a cradle-to-store system boundary was applied for this study.
The life cycle impact assessment (LCIA) was first based on the nutritional energy value to compare the results, namely, 100 kcal. Additionally, to obtain a profound comparison, the incorporated amount of protein and polyunsaturated fatty acids (EPA+DHA) was depicted in terms of 50 g protein and 500 mg EPA+DHA, which on average correspond to the daily intake recommendations per person (World Health Organization (WHO) 2007; Salem and Eggersdorfer 2015). Fish are not only the most important source of PUFAs but also a significant food group for the supply of protein, which is why a comparison was chosen that considers both of these nutrients.
Relevant impact categories concerning fish production are global warming, acidification, eutrophication and cumulative energy demand. In terms of aquaculture fish production, water and land use are also significant. LCIA values of fish products were depicted in boxplots according to species and production method including the minimum and maximum value, the median and the 10th and 90th percentile. Regarding land and water use, values for fish were analyzed in boxplots for capture and aquaculture production due to the small range of impact values available for these indicators.
For the compilation of the cost assessment, a net cash flow table for the construction phase and the first thirty years of operation was established in order to calculate the NPV (net present value = discounted cash flow) and the ROI from it. Sensitivity analysis of the economic evaluation comprised variations in commodity prices and selling prices of the final products, different time periods, *Phaeodactylum tricornutum* as an alternative microalgae species, and microalgae oil as an alternative target product.

Results and discussion

It was shown that microalgae production in closed PBR is a feasible option compared to fish as a source of EPA+DHA and protein. The microalgae scenarios with avoided CO_2 mostly had similar or less environmental impacts than capture fish production and always far lower impacts than aquaculture fish production, as can been seen in Fig. 1. When accounting for the full burden of CO_2 production, the environmental impacts increased for all indicators, and approximately doubled the impacts of the global warming potential, acidification potential and CED. However, the scenarios with included CO_2 burden still had similar or lower environmental impacts than aquaculture fish (Fig. 1). In particular, popular fish species such as Alaska pollack, aquaculture salmon and pangasius were mostly highly unfavorable in terms of their environmental impacts.

Fig. 1: Global warming potential according to IPCC 2013 in g CO_2eq FU^{-1} (logarithmic scaling)

Concerning the global supply, fish are almost equally produced from wild capture and aquaculture, with the latter having a share of approximately 47% (FAO 2018). The greatest environmental burden of aquaculture fish production can be traced back to land use due to feed production. Feed crops for aquaculture use far more land and have a lower productivity than microalgae from PBR. Moreover, microalgae can be cultivated on infertile land, which makes them ecologically favorable over aquaculture fish.
If a supply gap of 0.25-0.35 g $capita^{-1}$ d^{-1} is presupposed for Germany, an additional amount of 7,500-

10,500 t EPA+DHA year^{-1} would be required. To produce this amount from *Nannochloropsis sp.,* 179,000-250,000 t year^{-1} dry biomass would be needed, which corresponds to approximately 3,400-4,700 ha of PBR area. It would be necessary to consume approximately 6.0-8.4 g of *Nannochloropsis sp.* dry biomass per day in order to reach the recommended additional intake of 0.25-0.35 g d^{-1}. Consequently, microalgae as a source for EPA+DHA can probably not replace fish but would rather be an ecologically desirable complementation.
The economic evaluation resulted in a positive NPV of EUR 4.5 million after 30 years and positive returns in year eleven with an annualized ROI of 1.87%, which indicates that the investment in the microalgae photobioreactor in this region is profitable. All costs excluding interests and the contingency factor summed up to EUR 9.60 per kilogram dry biomass of which 80% were made up by infrastructure, labor cost and maintenance cost. The effects of the variation of certain technical and economic parameters are shown in Fig. 2. The selling price had a great effect on the NPV with a 5% shift resulting in an NPV change of around 15.5% and a 15% selling price change causing an alteration in the NPV of approximately 47%, which makes the consideration of the selling price a major issue. The effect of the length of the cultivation period on the NPV was also rather substantial. Continuously shorter or longer cultivation periods altered the NPV by almost one third compared to the baseline scenario, which is a significant impact taking into account that, for instance, longer periods implied that production was just two weeks extended in both April and October.

Fig. 2: Effects of parameter variation on the NPV of the photobioreactor

Costs for Atlantic salmon (*Salmo salar*) aquaculture production, the third most consumed fish species in Europe (EUMOFA 2018) and the globally largest single fish commodity by value (FAO 2018), have been increasing over the last years mainly due to higher costs for feed as well as increasing labor costs and depreciation (Iversen et al. 2020). Production costs varied between USD 4.35-5.93 (EUR 3.92-5.35) per kilogram depending on the country of origin (Iversen et al. 2020). Presupposed an EPA+DHA content of 7.43 g kg^{-1} edible salmon (Schade et al. 2020) this results in an EPA+DHA price of 0.52-0.72 EUR g^{-1}. *Nannochloropsis sp.* contains 42 g EPA kg^{-1} dry biomass. If the costs for interests and the contingency factor are added to the production costs, it needs EUR 12.43 to cultivate one kilogram of biomass. Consequently, this accounts for an EPA price of 0.29 EUR g^{-1} in the whole biomass, which makes microalgae a superior source for n-3 PUFAs in economic terms, too.
As a final point, microalgae are able to serve the market for vegan products and as such represent the only extensive vegan source for EPA and DHA.

Conclusion

Compared to fish from aquaculture and partly to fish from ocean fishing, microalgae cultivation in closed PBR in 'colder' temperate climates performs environmentally better. Moreover, it has been shown that the cultivation is also profitable in a humid continental climate like Germany. However, the climatic preconditions can influence the economic profitability, which should be reflected in the selling price of the target product. Given the abundance of essential nutrients in microalgae resulting in beneficial effects on human health, it is probable that their cultivation becomes a major industry even more so since they are still considered a "poorly explored natural source for a healthy diet" (Sathasivam et al. 2019). Regarding the recommended daily intake of EPA and DHA, microalgae represent—from an environmental and economic point of view—an advisable source of nutrients.

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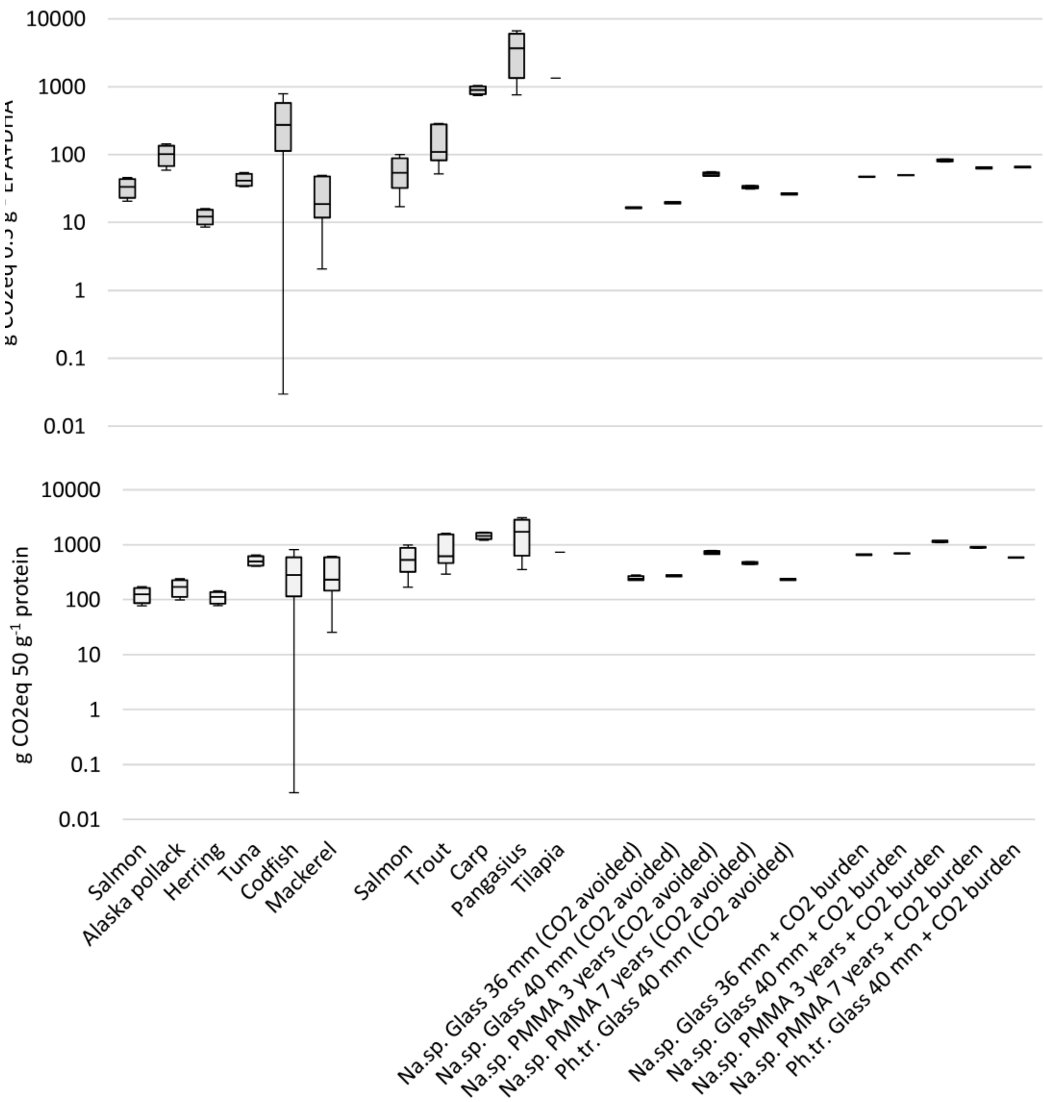

Fig. 1: Global warming potential according to IPCC 2013 in g CO_2eq FU^{-1} (logarithmic scaling)

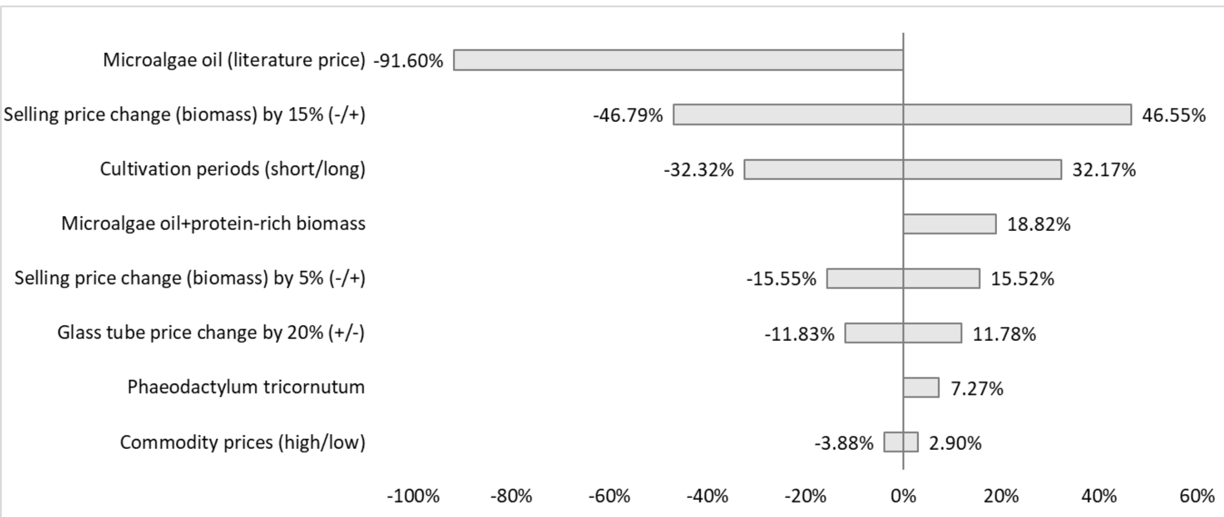

Fig. 2: Effects of parameter variation on the NPV (net present value) of the photobioreactor

Abstract code: 172

Development of an approach to assess overfishing in Europe based on the Ecological Scarcity Method

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Abstract

Purpose One third of the global fish stocks is classified as overfished. Life cycle impact assessment methods for overfishing exist but are not fully implemented and do not allow to compare results of different impact categories. Thus, a new approach based on the ecological scarcity method (ESC) was developed to be applied in life cycle assessment (LCA) and to compare results of overfishing with other categories like climate change and land use.

Methods Based on the ESC and the maximum sustainable yield (MSY) concept, an approach was developed to assess overfishing. The region specific approach considering the overall catch in Europe in relation to the European catch within sustainable limits (MSY) and defines the overfishing indicator as the species-specific characterization factor. The introduced approach was applied to the production of three salmon feed: feed 1 with fish oil and fish meal; feed 2 with VERAMARIS® Algal Oil and fish meal; feed 3 with VERAMARIS® Algal Oil and other agricultural ingredients and compared to the impact categories climate change and land use.

Results and discussion When comparing the three different feed in the categories climate change, land use and overfishing it was determined, that the category overfishing had the highest impacts for feed 1 and 2, because both feed contain fish meal and/or fish oil. For feed 3, where the omega-3 fatty acids come from algae oil and agricultural products only, the overfishing impact was zero. The impacts in the categories land use and climate change increased only slightly with growing amounts of agricultural products. One of the main reasons for the high overfishing impacts is the defined target of having no overfishing, whereas the targets of the other two categories are formulated less ambitious. This result would therefore change, when other more ambiguous targets are considered, for example for climate change.

Conclusions A new approach was developed for the assessment of overfishing in LCA, which allows for the comparison of different impact assessment categories. Its applicability was demonstrated within a case study comparing different fish feed. It was shown, that the use of wild fish in fish feed in Europe leads to high overfishing impacts, whereas the use of algae oil does not significantly increase impacts of land use and climate change.

Keywords: overfishing; algae oil; ecological scarcity approach; maximum sustainable yield; weighting

Introduction

The fishery and aquaculture sector plays a significant role in the provision of food and nutrients. However, overfishing has been a global issue for several decades, because around one third of the global fish stocks are classified as overfished. Overfishing refers to depletion of stocks due to fishery beyond the maximum sustainable yield (MSY); thus, more fish are caught than needed to be able to regenerate. Impacts of overfishing include biodiversity loss, decrease of ecosystem services as well as reduced availability of fish and therefore social and economic consequences. (Food and Agriculture Oganization of the United Nations 2020) Thus, overfishing has been addressed by the SDG 14 (Life below water: conserve and sustainably use the oceans, seas and marine resources for sustainable development) with the goal to end overfishing by 2020 (United Nations 2016). This goal was also translated into many regional goals, e.g. for Europe, where overfishing is to be phased out by 2030 (European Commission 2020).

One strategy to reduce the pressure on overfishing is the use of aquaculture. However, in all aqua cultural systems currently fish meal and oil produced from wild fish is used as feed. In 2018 around 22 millionen tonnes of fish were used to produce fishmeal and fish oil. Thus, adapting aquaculture fish farms by reducing fish meal and oil can be a significant contribution to tackle overfishing. Agricultural products like crops have been a preferred substitute for fishmeal. Their production can lead for example to impacts regarding climate change and land use. As agricultural products do not have the necessary nutrients to replace fish oil, algae oil has been the favored substitute for fish oil, but can just recently been produced in the necessary amounts due to technological advancements in its production (e.g. Shah et al. (2018)).
Thus, one goal of the paper is, to analyze the environmental impacts of the categories overfishing, climate change and land use by replacing fish oil and meal with agricultural products and algae oil.

However, so far no adequate impact assessment methods for life cycle assessment (LCA) exist to measure overfishing. Most methods are based on the primary production, which is an indicator accounting for productivity but not scarcity and therefore does not adequately reflect overfishing (e.g. Emanuelsson et al. (2014); Cashion et al. (2016); Stucki et al. (2018)). Thus, a new approach had to be developed which allows for the assessment of overfishing from a scarcity point of view. Further, this approach had to be able to compare different impact assessment results in order to compare diverse food systems despite existing tradeoffs.

The new impact assessment approach was tested in a case study comparing three salmon feed with different omega-3 fatty acids, and protein sources:

- Feed 1 with fish oil and fish meal
- Feed 2 with the VERAMARIS® Algal Oil, and fish meal
- Feed 3 with the VERAMARIS® Algal Oil and other agricultural ingredients.

Material and methods

The introduced approach is based on the ecological scarcity method (ESC) (Müller-Wenk 1978; Frischknecht and Büsser Knöpfel 2013) and the maximum sustainable yield concept. The MSY concept is the basis for many existing overfishing indicators inside and outside of LCA (e.g. Phillips, Anderson, and Schapire (2006)). The ESC method was originally developed in 1978 to be applied to Switzerland. The method has been continuously updated since then and was further applied to many other countries and regions, e.g. the European Union (Muhl et al. 2019). The ESC sets a current flow (e.g. emission in a region) in relation to a defined target (e.g. allowed emissions) and normalizes the result by the current flow.

The developed approach is a region specific approach, with the following terms (see equation 2):

- Current flow: overall catch in Europe
- Target: European catch still within sustainable limits, which is determined by dividing the overfished catch from the overall catch
- Species specific characterization factor (CF): overfishing indicator based on (Ziegler and Valentinsson 2008; Ziegler et al. 2011)
- Normalization factor: species specific overfishing indicator results for the European catch
- Constant c: mathematical term ($3{,}68*10^3$)

$$Ecofactor = CF_i \times \left(\frac{overall\ catch_{Europe}}{(overall\ catch - overfished\ catch)_{Europe}}\right)^2 \times \frac{1}{\sum(CF_i \times catch_i)_{Europe}} \times c$$

(Equation 2)

Existing ecofactors for Europe from Muhl et al. (2019) are applied to determine the result for the categories climate change and land use.

Results and discussion

Figure 1 shows the results (expressed in ecopoints) for the three different feed in the categories climate change, land use and overfishing.

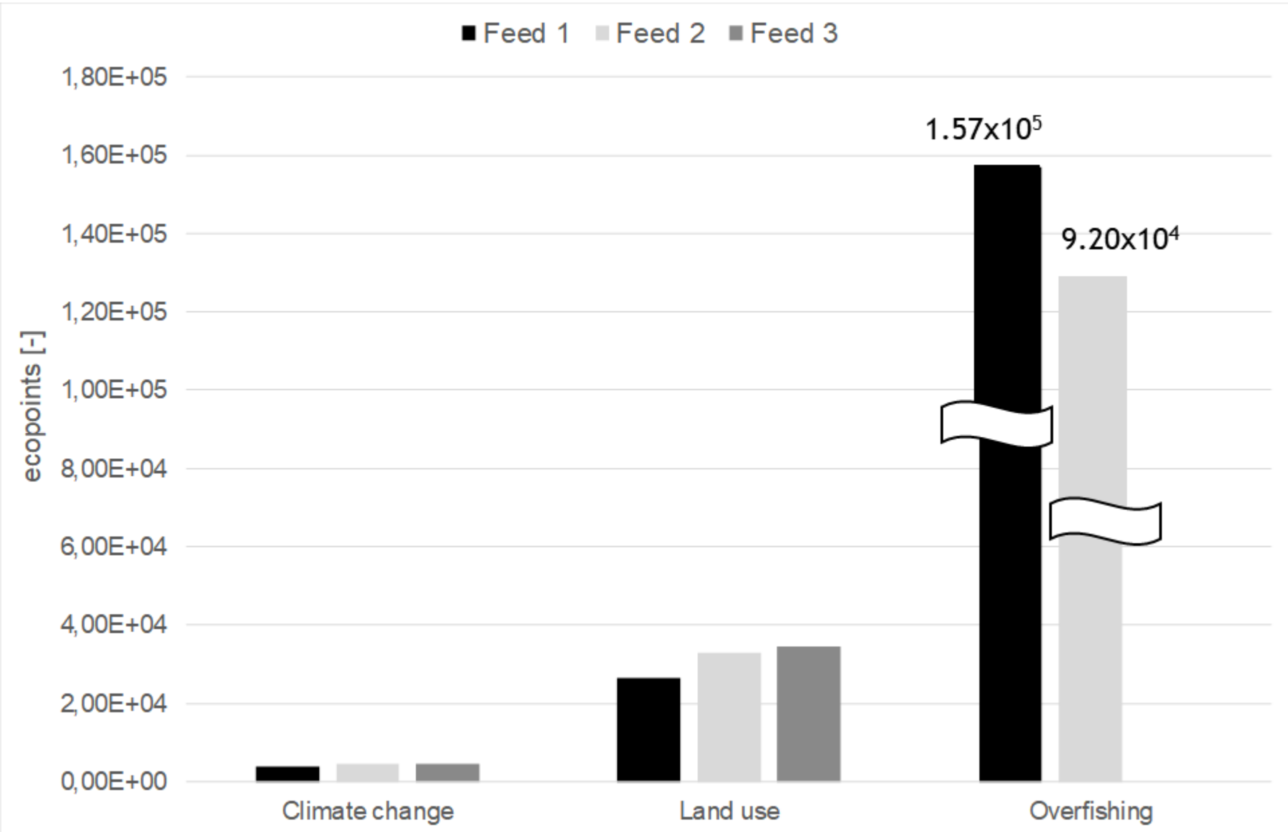

Figure 1: Results of the three different feed for climate change, land use and overfishing

It can be seen that the category overfishing has significantly higher results compared to climate change and land use for feed 1 and feed 2. Both feed contain fish meal and/or fish oil made out of wild fish and therefore contribute to overfishing. For feed 3, where the omega-3 fatty acids come from algae oil and agricultural products replace fish meal, the overfishing impact is zero.

The impacts of the categories land use and climate change are significantly lower compared to the category overfishing and only slightly increase with growing amounts of agricultural products.

One reason for these results is the applied weighting factor of the category overfishing. Compared to climate change and land use the European target of phasing out overfishing by 2030 is much more precise and strict compared to the goals for the other two categories. Even though goals on European level are formulated, they are less ambitious. Thus, for many fish species used in fish meal and oil this target is reached and often exceeded (many fish species are already overfished or at the boarder of being overfished), the goals are not yet reached for climate change and land use. The overall results however, could change significantly if targets for climate change proposed by e.g. NGOs with net zero would be applied instead of targets by the European Commission.

Currently, 67% of the fish species used for the production of fish meal and oil in Europe are overfished. To determine how a decrease in use of overfishing species would influence the results of the considered product system, the breakeven point of the categories overfishing and land use was determined. Therefore, the share of overfished species used in feed 2 were modified to be at 10%, 20%, 30% and so on. As shown in Figure 2, only around 10% of the fish species need to be overfished for the category overfishing being more significant than land use. This underlines the conclusion that using algae oil instead of fish oil in salmon feed contributes to tackling overfishing.

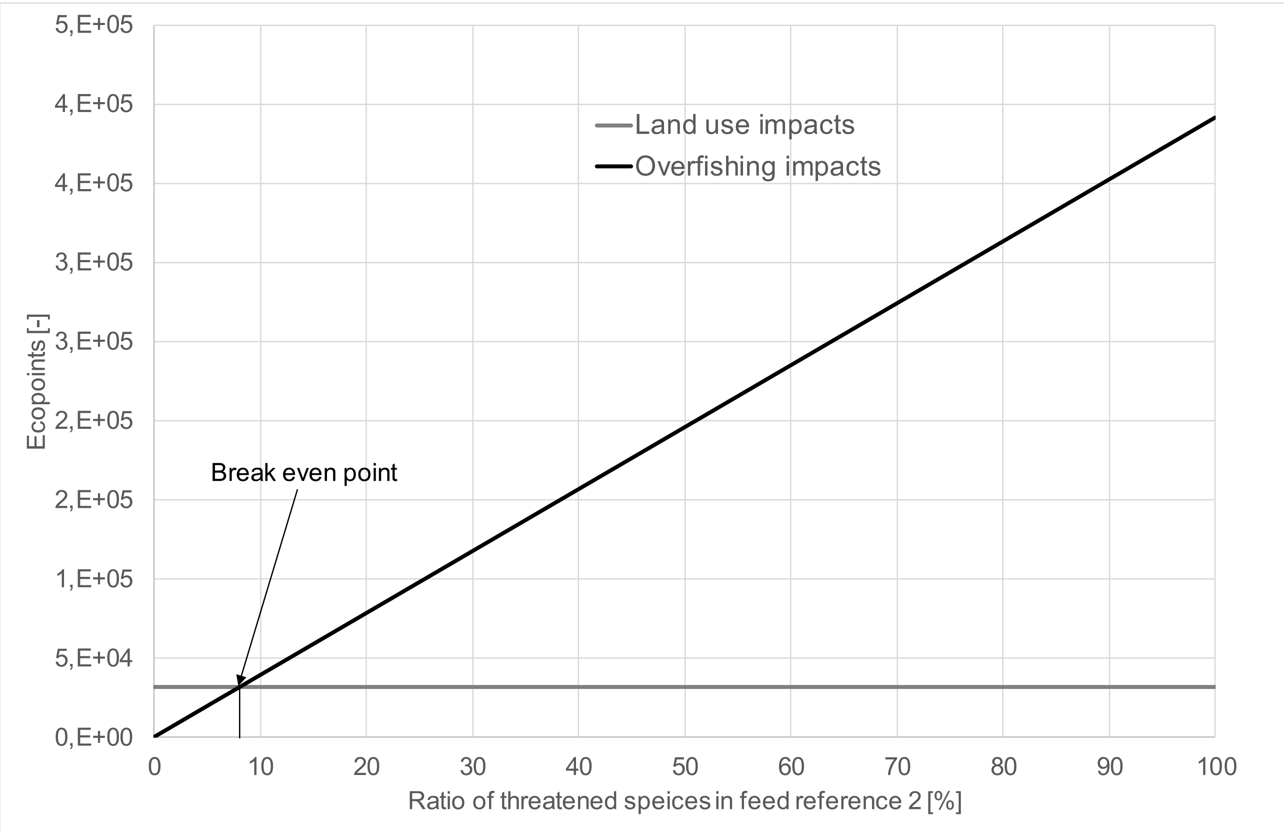

Figure 2: Break-even point of the categories overfishing and land use

The developed approach for overfishing is new and has only be applied for this one case study presented here. To make sure that it provides reliable results, it has to be tested on more case studies. Another challenge is the data availability, as data for many species is not regularly collected. For some species like boar fish it has only been collected for the last five years. Further, several environmental conditions can influence the availability of species in the ocean, e.g., El Nino events cause an increase in air and water temperature, which can lead to extinction of e.g. cold-water anchoveta.

Conclusion

The newly developed approach to account for overfishing was applied in a case study for salmon fish feed. It could be shown that the approach is applicable and leads to adequate results. It allows for a comparison of different impact assessment methods and can therefore assess the tradeoffs when replacing fish meal and oil with agricultural products and algae oil. When such a replacement takes place, the overfishing impacts can be reduced to a higher extend than the increasing climate change and land use impacts.

Acknowledgements

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Abstract code: 405

Improving LCI data collection methodologies for novel food systems: A case study on microalgae cultivation for phycocyanin production

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Abstract

Algae are a sustainable and promising feedstock for the development of novel food systems with a reduced carbon footprint. Life Cycle Assessment (LCA) is a common tool used to assess environmental impacts of algae systems and facilitate their improvement. Although several limitations have been identified (e.g. functional unit definition, co-product handling), only a few studies have investigated Life Cycle Inventory (LCI) methodologies. This case study evaluates the importance of foreground and background data in algae system modelling. An attributional LCA was performed on a pilot scale *Spirulina* cultivation and biomass processing facility located in Italy. The impacts were calculated for the 'IPCC 2013, Climate change, GWP100a' category using ecoinvent v3.6 as background database. A contribution analysis on foreground processes identified the main contributors to the total environmental impact of dried *Spirulina* biomass production. The background system was further analysed with a focus on electricity generation. A second LCA study was performed on the same algae system using the ecoinvent v3.6 database depleted of electricity production activities. The LCA results of the reference scenario show that cultivation and drying contribute to 65% and 22% of the total impact, respectively. The comparison with the scenario using the depleted ecoinvent v3.6 database highlights the importance of electricity production in algae system modelling. 66% of the overall impact originates from direct and indirect electricity consumption. Since changes in the background system influence LCA results, data collection and system modelling approaches should be expanded to the whole supply chain. A better understanding of background data would support the integration of dynamic algae growth models in LCIs.

Keywords: *Life Cycle Inventory*; *Spirulina*; *system modelling*; *data collection*; *background changes*; *electricity generation*

Introduction

The SpiralG project (BBI, H2020) aims to build the first algal biorefinery capable of producing 10 metric tons of phycocyanin per year. This high-value biomolecule is synthesised by *Spirulina*, a well-known cyanobacterium cultivated in outdoor open raceway ponds. Phycocyanin is a natural blue pigment approved in the US, Europe, and Asia, and mainly used to replace synthetic blue dyes in the food and feed industries (Mejia et al. 2020). To demonstrate the economic and environmental feasibility of biorefining EU produced *Spirulina* biomass, the SpiralG industrial partners intend to cut the production costs, valorise the residues obtained after phycocyanin extraction to reach additional markets, use new technologies at each process step, and reduce the overall carbon footprint. SpiralG creates a new value chain for *Spirulina* biomass by diversifying the product portfolio and proposing new applications in the agri-food, feed, and cosmetics sectors.

LCA is a standardised tool which has been used for more than 15 years to assess environmental impacts of algae systems. According to the ISO14040/44 standards (ISO 2006), LCA consists of four interrelated phases: Goal and Scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation. Recent reviews of the literature have found that methodological choices made in the different phases affect LCA results. Collotta et al. (2016) showed that LCA studies are unique in terms of functional unit (FU) and system boundaries. According to Sills et al. (2020), FU definition and co-product handling methods are a source of variability in LCA of algal biorefineries. Moreover, Morales et al. (2019a) highlighted the difficulty in comparing LCA studies of algal biofuel production due to their specificities. There is a need for guidelines to improve comparability.

LCI is an important stage which consists in collecting raw data, modelling the product system, and performing inventory calculations. The product system is divided into foreground and background systems. The foreground includes processes that are specific to the system studied i.e. directly linked to the functional unit. In contrast, the background system comprises all processes in the supply chain of the product system (Wolf et al. 2012). Primary data, i.e. data collected on-site, are preferred in the foreground system. Background data are provided by databases such as ecoinvent v3.6 (Wernet et al. 2016) and are considered as secondary sources. Although LCI methodologies have recently received considerable research interest, only a few studies analysed algae system modelling and data collection procedures. This case study on *Spirulina* biomass production for phycocyanin extraction investigates the contribution of foreground and background processes to the total environmental impact. The influence of the background system is further analysed with a focus on electricity production. Finally, the influence of changes in the background system on LCA results serves as basis to issue recommendations concerning data collection procedures.

Material and methods

The study is based on a pilot scale *Spirulina* cultivation and processing facility located in Sardinia, Italy. *Spirulina* is cultivated in six open raceway ponds under a greenhouse. The harvested algae broth (0.1% dry weight) is concentrated via filtration, dewatering, and drying to obtain the final product, dried *Spirulina* biomass (97% dry weight). An attributional LCA is conducted on the cradle-to-gate system including the construction of the facility, *Spirulina* cultivation, broth filtration, slurry dehydration, paste shaping, and wet sticks drying. The goal of the study is to assess the environmental impacts of dried *Spirulina* biomass production for phycocyanin extraction. The FU was defined as 1 kilogram of dried *Spirulina* biomass. Data for the foreground system were collected on-site in July 2019, over six working days. The ecoinvent v3.6 database (cut-off system model) (Wernet et al. 2016) is used to model the background system. Country specific data for Italy are used for electricity production. No transportation is considered since cultivation and processing units are located in the same geographical area. The raw data used to calculate the inventory are daily averaged. The analysis is performed using the Brightway2 software (Mutel 2017) complemented with the Activity Browser (Steubing et al. 2020), graphical interface built on Brightway2, to model the algae system. The analysis is focused on climate change and environmental impacts are calculated using the global warming potential (GWP) with a horizon of 100 years. The characterisation factors were defined according to the IPCC 2013 method (Stocker et al. 2013).

An extensive contribution analysis was performed on the LCA results to identify the foreground processes responsible for the largest share of the total environmental impact. The supply chain was manually traversed considering the foreground system only. Impacts were recalculated for each input and output process exchange. Various studies have shown that electricity use is a major drawback in algae cultivation and biomass processing (Bussa et al. 2020). Therefore, the background system was further analysed to evaluate the importance of electricity production in system modelling. A second attributional LCA study is performed using the same foreground as in the reference scenario with a modified background database. The ecoinvent v3.6 database was depleted of electricity inputs to remove all electricity production activities from the algae system model. The Wurst software, an extension of Brightway2, is used to set all electricity input values to zero. The results of the two system model scenarios are compared to evaluate the influence of electricity activities in the foreground and background system on LCA results.

Results and Discussion

The cultivation and drying processes are the main contributors to the environmental impact of dried *Spirulina* biomass production for the category 'IPCC 2013, Climate change, GWP100a'. Figure 1 shows the contribution of each foreground process to the total environmental impact for the reference scenario. Cultivation is the main contributor with 65% of the total LCA score. This result confirms the findings of previous studies showing that cultivation could represent more than 80% of the total score, depending on the impact category analysed (Pérez-López et al. 2017; Morales et al. 2019b). Further analysis of the cultivation stage indicates that sodium bicarbonate (45%), water (33%), potassium nitrate (13%), and electricity (5%) are the main contributors to this process. Moreover, drying contributes to 22% of the total impact due to electricity consumption for the drying chambers. Since nutrients, water, and electricity use depend on technical choices, their contribution to the total impact could be reduced using alternatives sources. Growing algae in wastewater reduces the use of inorganic nutrients. However, the restricted number of wastewater treatment plants and variations in the mineral content make its implementation in algae systems challenging (Morales et al. 2019a). Sodium bicarbonate is an alternative carbon source and pH stabiliser that replaces carbon dioxide supply in algae growth medium. The choice of carbon source is discussed as their environmental impacts depend on production processes (Kim et al. 2019).

The second system modelling scenario is based on the use of the ecoinvent v3.6 database depleted of electricity activities. The LCA results highlight the importance of electricity production in both foreground and background systems. Electricity is responsible for 66% of the total environmental impact of the *Spirulina* cultivation and biomass processing facility. Used in most background processes and responsible for indirect greenhouse gas emissions, electricity is also used in the foreground system as direct source of energy. Cultivation and drying are the most energy intensive processes due to algae broth mixing with paddlewheels, broth pumping from ponds to the processing facility, and the use of drying chambers. Bussa et al. (2020) emphasised the potential of integrating algae cultivation into a regional economy to lower environmental impacts. The use of local biobased waste streams could reduce the dependency on national electricity production mixes and inorganic nutrients. Furthermore, as shown in prospective LCA studies, changes in the background system influence LCA results (Mendoza Beltran et al. 2020). The adaption of the electricity production mix to specific regions (e.g. Sardinia) and the use of temporally differentiated electricity data to support the integration of dynamic algae growth models into LCI are two possible changes.

Conclusions

This case study on dried *Spirulina* biomass production identifies cultivation as the main contributor to the total environmental impact on climate change. A further analysis of the background system reveals that electricity production activities are responsible for the largest share of the LCA score. Electricity is integrated in foreground and background systems as direct and indirect source of energy, respectively. Its impact could therefore be reduced by expanding data collection procedures and system modelling approaches to the whole supply chain. Furthermore, algal biomass productivity in outdoor cultivation systems strongly depends on seasonal variations. The use of dynamic algae growth models in LCI could be complemented by seasonally differentiated electricity production mixes. Seasonal variations could influence LCA results depending on the time resolution chosen. Implementing dynamic LCA at a reduced time scale (e.g. day, week, month) should be consistent with LCIA methods. Regarding climate change, global warming potentials have a minimum time scale of a year (Collet et al. 2014). Therefore, including time variations in fast-growing algae systems remains challenging.

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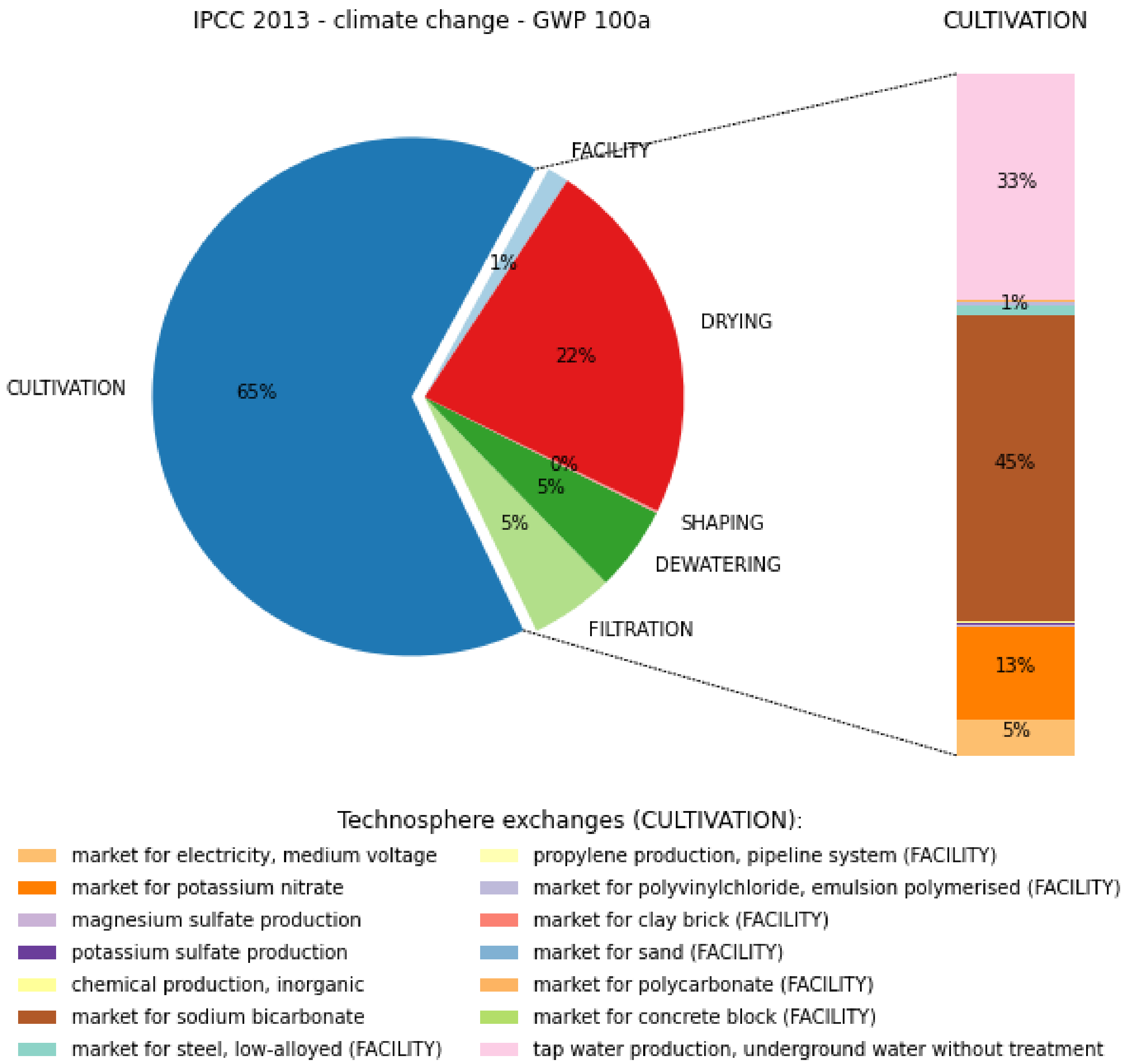

Figure 1: Contribution of foreground processes to the total environmental impact of dried *Spirulina* biomass production for the reference scenario. Ecoinvent v3.6 was used as background database. The contribution analysis was performed using the Brightway2 software. The supply chain was manually traversed and LCA scores were aggregated per foreground process.

Abstract code: 31

Wild-caught versus farmed salmon: what are the impacts on biodiversity?

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Abstract

Purpose – Introduced as a solution to partially solve the environmental issue linked with meat production, the fish production industry is currently in the spotlight. In order to assess the ecological impacts of fisheries and aquaculture, we conducted a study on the case of Norwegian Atlantic salmon (*Salmo salar*). This study considers the impacts on biodiversity, through the Millennium Ecosystem Assessment (MEA) drivers: on one hand, habitat change, pollution and climate change and, on the other hand, overexploitation and invasive species.

Methods – Out of the MEA drivers, we considered that pollution, climate change and habitat change are addressed (although not completely) through Life Cycle Assessment (LCA). We used ReCiPe 2016 to compare the environmental impacts of fishery and aquaculture for those drivers. For overexploitation, we adapted existing methods to evaluate the situation of overexploitation of the Atlantic salmon stock compared to the one of the Peruvian anchoveta stock which is fished to feed farmed salmon. For invasive species, we developed a general semi-quantitative impact scoring method and used it to characterize the impact of escaped farmed salmon on wild ecosystems. This work, oriented by biodiversity drivers, adds information for decision making to an LCA approach.

Results and discussion – Our results show that the global ecological impact of aquaculture is superior to that of fisheries. The LCA results suggest higher midpoint and endpoint impacts of farmed salmon. From the overexploitation point of view the results go the same way, pointing out that, even if the Atlantic salmon stock is vulnerable, it is sustainably managed as opposed to the Peruvian anchoveta stock that feeds the farm salmons, and which is overexploited. On the invasive species aspect, the threat of invasion (of escaped farmed salmon) is low compared to other well-known marine species; nonetheless, the results are aligned with ecological knowledge. Additional case studies on other fish species and invasion pathways could enable to refine the thresholds levels we use in our method.

Conclusions – Considering the impact of the MEA drivers covered by the LCA and our additional study on overexploitation and invasive species, we conclude that salmon aquaculture has a higher impact on biodiversity compared to salmon fishing. Such results should not lead to an increasing fishing pressure but encourage research and innovation on the way to produce farmed salmon without damaging the environment with a major focus on their feed, hence finding alternatives to Peruvian anchoveta which is overexploited.

Keywords: *Life Cycle Assessment, Atlantic salmon, Aquaculture, Fisheries, Biodiversity loss.*

Introduction

Background – For a few decades, an overall loss of biodiversity has been observed worldwide [1]. Amongst all biodiversity threats linked with human activities, food production plays a significant role. To achieve the goal of feeding 10 billion human beings by 2050, more sustainable food production methods need to be developed. The meat industry has been singled out for its high emissions of greenhouse gases, and observers recommend undertaking a diet transition towards less meat and more fish [2]. However, current fish production methods, namely fishery and aquaculture, are faced with fierce environmental criticism.

Life Cycle Assessment, opportunities and gaps – Being able to compare marine food production methods' impact on the environment is the first step toward a more sustainable management of marine resources. Such impacts can be apprehended through the five relevant drivers identified by the Millennium Ecosystem Assessment (MEA) project: habitat change, pollution, climate change, overexploitation and invasive species [3]. These factors are to be used to assess threats on ecosystems. Out of these drivers, pollution, climate change and habitat change are addressed (although not completely) through Life Cycle Assessment (LCA). As for the overexploitation and invasive species drivers, they are needed to complete LCA impacts on ecosystems, and this is especially (but not only) manifold for marine fish.

Aim – This study is under the auspices of the Product Biodiversity Footprint (PBF) project, which objective is to enable to compare the impact of products on biodiversity, combining knowledge and skills from LCA and ecology. Within this project, developments have already been conducted on terrestrial biodiversity [4]. The aim of this study is to add on this work with a case study on marine life. We answer the question: *Do fisheries and aquaculture have different ecological impacts, with respect to the MEA drivers?* In light of a concrete case study, "the food production of Atlantic salmon", we assess the impact on ecosystems through 'mainstream' LCA, complemented with additional overexploitation and invasive species assessment.

Material and methods

LCA – We conducted a life cycle assessment using SimaPro software tool with background inventory data from the ecoinvent 3.5 database. Midpoint and endpoint impacts were assessed with ReCiPe 2016 v1.1 method, hierarchical version [5]. Impacts were calculated per live-weight kilogram of salmon (functional unit) i) at farm gate for aquaculture and ii) at harbor for fishing, considering downstream impacts to be the same. For fishing, we took into account the fuel needed to get the boat to the fishing area and the fuel needed to handle the nets; in addition, we accounted for the manufacture of the nets. Farmed salmon are nursed in fresh water and then transferred to sea water cages. We chose to discard the events before transfer as this period is short and juveniles are a lot lighter than adult salmons.

Overexploitation – In order to quantify the impact of overexploitation of biotic resources on the ecosystem, two methods are currently used. One is based on the Biotic Resource Extraction study [6] whereas the other is based on the Lost Potential Yield study which is an anthropocentric point of view [7]. We adapted these methods to six fish stocks: i) four fish stocks' overexploitation status is known: overfished (Atlantic cod – 2 population zones; European hake) or not (Atlantic horse-mackerel) and ii) two fish stocks of interest in our study: Atlantic salmon in Norwegian Sea and Peruvian anchoveta in Peru, as it is the main fish feed of farmed salmon.

Invasive species – Several impact categories have already been identified to assess threats of invasive species on ecosystems, in terms of both economic and ecological impacts [8]. Focusing exclusively environmental impact assessment, we identify the following categories as relevant: impacts through i) predation, ii) competition, iii) transmission of diseases or parasites, iv) hybridization, v) ecosystems. For each of them, we proposed a semi-quantified indicator with threshold levels and applied it to escaped farmed salmon.

Results and Discussion

LCA – Regarding fishing, midpoint LCIA points out that the main impact is due to the use of diesel. For aquaculture, most of the impact can be traced back to feeding. According to the normalized endpoint results, farmed salmon has a greater impact on ecosystems than wild caught salmon (4,9E-5 compared to 8,96E-6, see Figure 1).

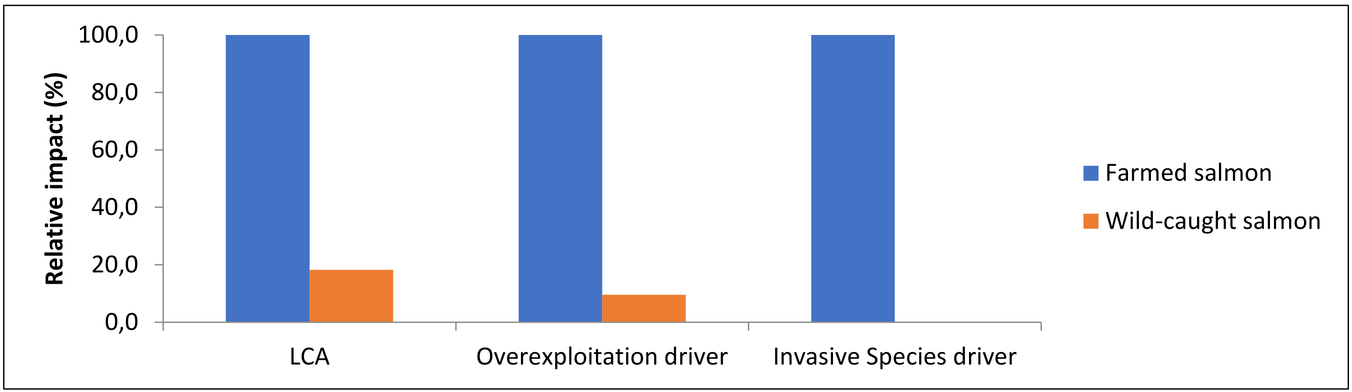

***Figure 1: Relative impact (Percentage) of wild-caught salmon compared to farmed salmon**. LCA method is ReCiPe 2016 endpoint value for "ecosystem quality". The overexploitation impact corresponds to the LPY 30 years [10] after the last census.*

Overexploitation – The two methods show different impacts for Atlantic salmon and Peruvian anchoveta. Figure 2 displays the results for the LPY method [10].

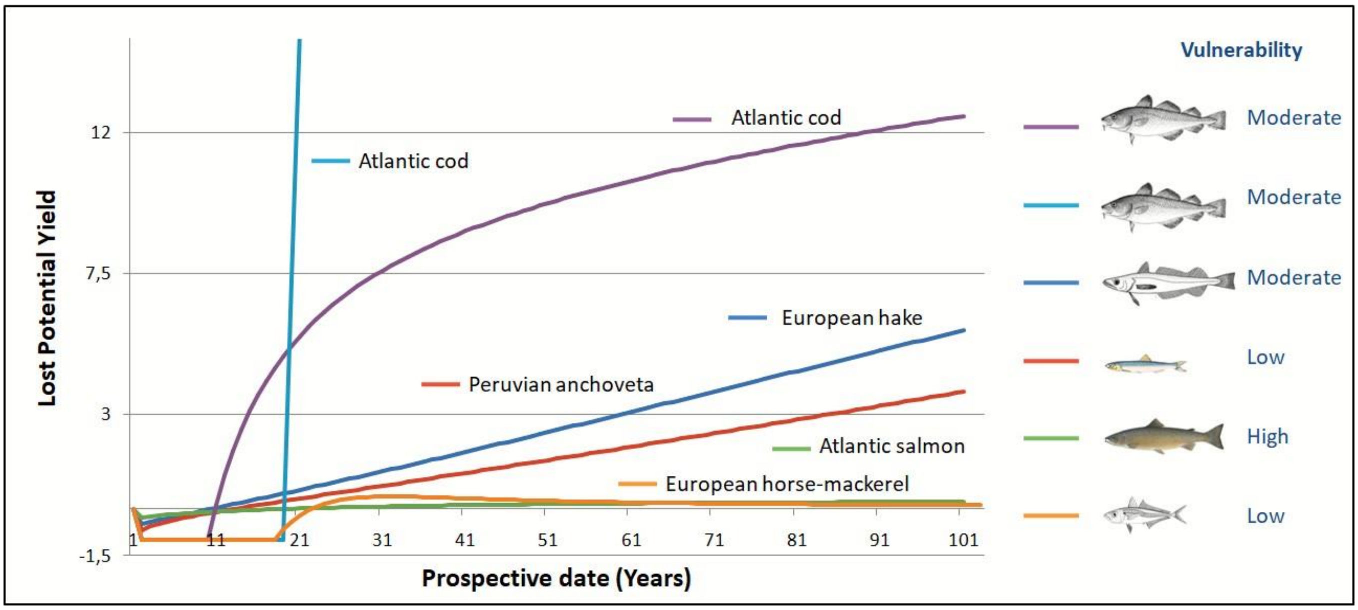

***Figure 2: Lost Potential Yield and vulnerability of six fish stocks.** The X axis represents the prospective date at which the yield is potentially lost. The Y axis represents the value of this lost in proportion of the current catch* [7]. *Negative LPY values correspond to the period of recovery which is needed to sustainably manage the stock. Each stock is linked to a single color. The vulnerability of the stock represents the impact of an overexploitation on its ecosystem.*

Vulnerability of the stock is mainly correlated with the trophic level [6] whereas Lost Potential Yield is linked to the management of the stock [7]. Exploitation of Atlantic salmon is currently sustainable as opposed to Peruvian anchoveta, which is currently used as the main fish feed for farmed salmon. Based on those results, both stocks should stop being exploited. Up to now, overexploitation of the Peruvian anchoveta has not been so much highlighted, but these results are an invitation for action to reduce or reverse its overexploitation.

Invasive species – For each of the impact sub-category, we applied the method to the escaped farmed salmon, as the invasive species. The overall impact score is equal to 6, on a scale ranging from 0 to 25, hence a fairly low impact of escaped farmed salmons on Norwegian marine ecosystems.

Conclusion

Our results indicate a higher environmental impact of aquaculture according to the LCA midpoints and endpoints. The low impact of overexploitation driver illustrates the benefits of the Norwegian regulation of wild Atlantic salmon fishing. It does, however, highlight the shift from overfishing of wild salmon to overfishing of anchovies used to produce farmed salmon. As for the invasive species driver, our method shows a low impact of escaped salmons on wild salmons which is aligned with the low invasiveness of escaped salmon compared to other marine invaders. Production of feed for farmed salmon remains a major issue for improvement. Further research is needed to look at more sustainable feed such as insects or plant proteins. Finally, the impact of salmon as an invasive species is low, but further research with contrasted (known invasive and non-invasive) fish species should be conducted to refine our thresholds.

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Global and regional impacts of fisheries on ecosystem quality

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Abstract

Purpose. Life cycle assessment (LCA) is used to quantify the use of land by human activities and its consequences on the environment (the ecosystem quality area of protection (AoP)). On the other hand, the impact of sea use on ecosystems appears poorly assessed by the LCA community. The purpose of this study is to address this situation by proposing operational characterization factors (CFs) for global fisheries, both regionally and globally.

Methods. The ecosystem quality impact is commonly assessed using CF = FF × EF, with the fate (FF) and effect (EF) factors. In recent work, we define CFs for AoP natural resources for fisheries, based on the fraction of the stock that is depleted. We show that these CFs correspond to the EF for the ecosystem quality AoP. FF represents the duration of the impact by specifying how long the intervention has an effect and are then defined as the inverse of the growth rate of the fish species. This leads to CFs at the ecoregion level, assessing the losses of intrinsic ecosystem functions at the regional scale. The global (and irreversible) loss is defined from the regional loss using a vulnerability score at the species level.

Results and discussion. The regional and global CFs have been calculated for 5 000 fish stocks from FAO data. CFs are provided both for ReCiPe (species.year) and LCI guideline (potential disappeared fraction of species for a year PDF.year) units. As illustration, four fisheries are presented and compared to livestock productions.

Conclusions The use of the sea by fishing activities leads to a loss of marine biodiversity. The work presented here proposes operational CFs dedicated to this, for all the global fisheries, in accordance with LCI guidelines. It allows quantifying the impacts of fisheries in LCA.

Keywords: *Fisheries, ecosystem quality, characterization factors, vulnerability score, FAO data.*

Introduction

This paper outlines the main aspects of a more detailed article (Hélias and Bach 2020). With life cycle assessment (LCA), practitioners often quantify environmental impacts, leading to three areas of protection (AoP): human health, natural resources and ecosystem quality. On the one hand, LCA makes it possible to quantify the use of land by human activities and its consequences on ecosystems (the third AoP). On the other hand, the impact of sea use on ecosystems seems to be poorly assessed by the LCA community. With the current impact assessment method, the causal effect of fishing on the quality of ecosystems cannot be represented, i.e. its impact is equal to zero. The objective of this work is to resolve this situation by proposing operational characterization factors (CFs) for global fisheries. These factors are in accordance with international guidelines that convert the inventoried mass into a unit of ecosystem quality and are in line with recent work on the depletion of fish biotic resources (Hélias et al. 2018).

Material and methods

In its guidelines, the Life Cycle Initiative (LCI), recommends CFs for the ecosystem quality AoP expressed in Potentially Disappeared Fraction of species for a year (PDF.year). For land use, CFs address the potential species loss due to the human used area per ecoregion. This leads to regional CFs (expressed in PDF/m^2 for occupation and PDF.year/m^2 for transformation) assessing loss of the intrinsic function of ecosystems at regional scale (Frischknecht and Jolliet 2016). Global CFs (expressed in global PDF/m^2 for occupation and global PDF.year/m^2 for transformation) are also provided. They assess the global (and irreversible) lost, addressing the proportion of endemic species in the ecosystem by the use of a vulnerability score (Verones et al. 2015).

In a recent work (Hélias et al. 2018) we propose an approach addressing global fisheries in terms of resource depletion. It is based on a marginal approach with a dynamic of population models, to link the inventory (the withdrawal of fish) and the impact (the depletion of the stock). The approach is briefly reported here. The often-used in fish stock dynamics Schaefer model shape (Schaefer 1954) serves as a basis of this work

$$\frac{dB}{dt} = -C + rB \times DSF \qquad (1)$$

where B is the fish biomass (ton), C the annual catch (ton.year^{-1}), r the growth rate (year^{-1}), and DSF the depleted stock fraction. The latter varies from 0 for a plentiful stock to 1 for an exhausted one. This model shows the growth where the exponential expansion (rB) is limited by the available habitat represented by DSF. In Hélias et al. (2018), eq (1) is used at steady state with a marginal approach. The CF is defined as the partial derivative of the impact (∂DSF) according to the inventory (the mass of fish removed from the biomass stock, $-\partial B$).

$$-\frac{\partial DSF}{\partial B} = \frac{C}{rB^2} \qquad (2)$$

Recently in Hélias and Heijungs (2019), consistency in modelling has been shown between this approach and the abiotic depletion potential (Guinée and Heijungs 1995) (the most used approach to assess abiotic resource depletion in LCA).

The impacts leading to ecosystem quality are often addressed with $\mathrm{CF} = \mathrm{FF} \times \mathrm{EF}$. For a given intervention, the characterization of the impact is the product of the fate factor (FF) with the effect factor (EF).

For a biotic resource, we have an analogy between the depletion of the resource and the impact on biodiversity. Thus, fishing leads to a loss of biodiversity, due to the withdrawal of part of the living biomass. The DSF represents the disappeared fraction of the stock (a given species in its habitat) and the unit of eq (2) is therefore the species lost/kg. Eq (2) is used as EF. Most of the impacts affecting ecosystem quality (e.g. ecotoxicity, acidification, eutrophication, etc.) result from substance emissions. In this context the fate factor represents the persistence of the involved substance in the media (Cosme et al. 2018). It is usually expressed in years or days. It can be assimilated to the inverse of the sum of the removal rates (Cosme et al. 2018) or to the residence time (Rosenbaum et al. 2007). The FF for an impact on ecosystems of fisheries is reversed since it results from a resource withdrawal, but the principle remains the same: defining $\mathrm{CF} = \mathrm{FF} \times \mathrm{EF}$, the effect factor represents the impact and the fate factor defines its duration. In USEtox®, fate factors are determined as the inverses of exchange- and removal-rate constants (Bijster et al. 2018). By analogy, we defined the fate factor as $\frac{1}{r}$, the inverse of the growth rate.

The regional CF for the impact on ecosystem quality due to fish catches ($\mathrm{CF}_{\mathrm{EQ,reg}}$, expressed in species.year/kg of fish) is therefore determined as follows

$$\mathrm{CF}_{\mathrm{EQ,reg}} = \frac{1}{r} \times \frac{C}{rB^2} = \frac{C}{(rB)^2} \qquad (3)$$

The species.year unit corresponds to the ReCiPe method (Huijbregts et al. 2017) and the fishery impacts on ecosystems can be directly added in this method. The conversion from species.year /kg to regional PDF.year/kg can be easily done with the division of $\mathrm{CF}_{\mathrm{EQ}}$ by the number of species in the marine region (Horton et al. 2019). Note that the reverse approach was used in the ReCiPe method to convert PDF.year into species.year.

With the LCI guidelines, global CF is also expected. From a modeling perspective, the main difference between land use and fisheries is the level of intervention. The impact of land use affects all species in the corresponding area. For fisheries, if more than one species can be caught simultaneously in an ecosystem, the corresponding impacts are additive and assessed separately through inventory flows and associated CFs in the LCA. The CF is defined for a specific species in a given ecosystem (i.e. population). In contrast to land use, human intervention through fishing a fish does not affect all communities in the ecosystem, but only one of the species in the ecosystem. However, to this must be added the direct impacts on the ecosystem related to fishing techniques such as the destruction of the seabed (Woods and Verones 2019), but this goes beyond the purpose of this study.

At the population (fish stock) level, the conversion factor to obtain the global PDF from the regional PDF should only quantify the extent to which the species concerned is endemic to the region, and only it. With the same reasoning as for the vulnerability score or the global extinction probability but at the species level, the endemic conversion factor to express global-PDF from regional-PDF is $B_j / \sum_{j^*} B_{j^*}$, the proportion of the global biomass in the ecoregion *j*.

CFs are computed for 5000 FAO datasets describing fisheries as detailed Hélias et al. (2018). The reader can refer to this article for more details. As illustration, four fisheries are presented (Atlantic bluefin tuna (*Thunnus thynnus*, Scombridae) in the Eastern-Atlantic, Yellowfin tuna (*Thunnus albacares*, Scombridae) in Atlantic, Alaska pollock (*Theragra chalcogramma*, Dadidae) Northwest Pacific and European seabass (*Dicentrarchus labrax*, Moronidae) Northeast Atlantic) and compared to livestock production (chicken, pork and beef from the ecoinvent database). The purpose is not to provide an exhaust and accurate LCA, but to illustrate how CFs can be used by practitioners and to highlight some of the outcomes. For this purpose, a simple functional unit is used without considering protein content nor other nutritional aspects. All systems are assessed for one metric ton of the fresh product.

Results

Figure 1 focuses on the land (transformation and occupation) and sea (fisheries) use of the different systems. If we consider the regional PDF (Fig 1.a), bluefin tuna is then the worst-case scenario. The LCI guidelines provide confidence intervals for CFs. It is then possible to take into account all the uncertainties related to the impacts. With the confidence intervals, Alaska pollock and yellowfin tuna have a much lower impact than sea bass, but no other results can be shown. This is due to the large uncertainty in the bluefin tuna assessment and the fact that land-based productions have very wide confidence intervals, the lower limit of which is negative (i.e. a positive effect of land use on biodiversity).

The impacts assessed with the global PDF (Fig 1.b) provide different results. The impacts in global PDF are about ten times lower for terrestrial systems (beef, pork and chicken), Alaska pollock and yellowfin tuna. At the opposite, impacts decrease only slightly for seabass (from 32×10^{-11} PDF_{reg}.year to 25×10^{-11} PDF_{glo}.year) and bluefin tuna (from 47×10^{-11} PDF_{reg}.year to 40×10^{-11} PDF_{glo}.year). This leads to higher impacts for these two fish stocks than the other systems. Based on the confidence intervals, the difference is significant for seabass with respect to Alsaka pollock, yellowfin tuna and land-based productions (i.e. no overlapping of the confidence intervals), significant for bluefin tuna with respect to yellowfin tuna and chicken and almost significant between bluefin tuna and Alaska pollock, beef and pork due to the reduced overlap in the confidence intervals.

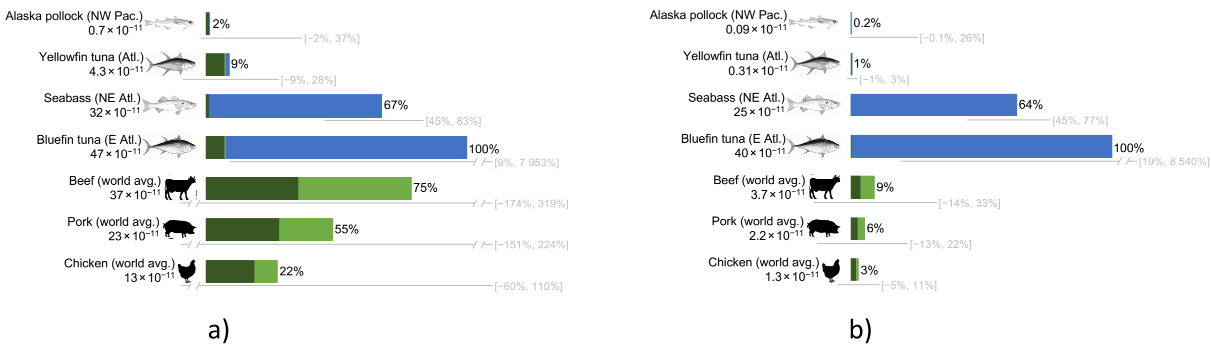

Figure 1.a) Regional and b) global impacts on ecosystems of the four fisheries and the three terrestrial meat production systems. Results are expressed in the percentage of the worst system and impact of each of them are given below the names (in pdf.year). Green: Land transformation (dark) and use light) impacts. Blue: Fishery impact on fish stocks. Grey line: uncertainty range associated with the fishery impact.

Discussion

The application case emphasizes the relevance of the evaluation to the global PDF. According to the data, Atlantic bluefin tuna is quite endemic in the eastern Atlantic, where 91% of the global biomass is found, with the remaining 9% in the western part. The status of European seabass is similar, with 81% of the biomass in the northeastern part of the Atlantic Ocean (seabass are also found in the Mediterranean Sea, rarely in the central-eastern Atlantic). As these species cannot be easily found elsewhere, their CFs expressed in global PDF are close to the regional PDF CFs. Yellowfin tuna is a global species, distributed in all temperate oceans. The Atlantic population accounts for only 11% of the global population, so its global PDF value is ten times lower than the regional PDF. The Alaskan Pollock, in the Pacific Northwest, is the main population of this species. It accounts for 66% of the global biomass (with the remaining portion in the northeast Pacific), so the variation between the regional and global PDFs is not significant. However, since the CFs are very low, the results are mainly determined by land use and the overall result of the global PDF is an order of magnitude less than the regional global PDF.

The inventories involved in this case study are not the result of a detailed description of the systems but are only generic data sets available. The conclusions of these comparisons cannot be extrapolated. However, it shows that marine production is of the same order of magnitude as land-based production and highlights large variations in impact between fish stocks. This case study illustrates how the ecosystem impact associated with fishing can be combined with the ReCiPe result and the land use of the LCI guidelines, the units being the same. This illustrates the introduction of fisheries impact into the current LCIA methods.

Conclusions

The use of the sea by fishing activities leads to a loss of marine biodiversity. The work presented here proposes operational CFs dedicated to this, for all the global fisheries, in accordance with the ICM guidelines. It allows quantifying the impacts of fisheries in LCA.

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Fish should swim, not fly—The role of air freighting in seafood supply chain emissions

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Abstract

Purpose: Seafood is the most internationally traded food commodity globally with many perishable products shipped by air. Though life cycle greenhouse gas (GHG) emissions have been assessed for hundreds of seafood supply chains, few studies to date have included consideration of emissions that arise from air freight. We explore the role of air freight and the methodological challenges in modeling air freight drawing on findings from recent seafood case studies.

Methods: We undertook four case studies of seafood products that included distribution by air freight and compared the relative role of air freight in the GHG results of each case study. Case studies included: Atlantic salmon farmed in Norway and flown to China; Chinook salmon farmed in New Zealand and flown to both domestic and international markets; Red king crab fished in Norway and flown to South Korea; and American lobster fished in Canada and flown to Sweden.

Results and discussion: Air freight accounted for between 17 and 76% of total life cycle GHG emissions, despite each system generating relatively high production-related emissions. System characteristics and methodological choices that influenced results included distance from production to destination, type of flight (dedicated cargo or passenger plane), number of takeoffs involved, and load utilization. Inclusion of transport within the system boundaries of future studies would facilitate comparison between products at the point of sale or consumption. If studies include air freight, they should consider these important factors in undertaking modeling.

***Keywords**: Air freight; Seafood; Fisheries; Aquaculture; Trade; Greenhouse gases*

Introduction

International trade is an integral component of many seafood supply chains: 38% of combined fisheries and aquaculture production was traded internationally in 2018 (FAO, 2020). Increasingly globalized access to markets, demand for high-quality seafood, improved technologies and logistics, and cheaper transport have allowed seafood trade to rapidly expand in recent decades (Asche *et al.*, 2020). However, the extent to which seafood products are shipped by air is unclear.

Despite the role of air transport in seafood supply chains, few seafood life cycle assessments (LCA) have included distribution in their system boundaries, and fewer still have included air freight (Parker, 2012, updated with new studies). These have included live lobster flown from Canada to Las Vegas (Driscoll *et al.*, 2015) or from Australia to Hong Kong (van Putten *et al.*, 2016), and salmon flown fresh from Norway to the United States (U.S.) (Liu *et al.*, 2016). Though air freight is often identified as an important driver of GHG emissions and other impacts when it is considered, it is surprising that it has not received greater attention to date. Here we draw on findings from four recently undertaken studies to explore the role of air freight in seafood supply chains. All studies involve high-value products and unique logistical journeys to lucrative markets.

Methods

We assessed four case studies of seafood products shipped internationally by air. These included Atlantic salmon (*Salmo salar*) from Norway to China; Chinook salmon (*Oncorhynchus tshawytscha*) from New Zealand to Australia, Japan, and the United States; Red king crab (RKC, *Paralithodes camtschaticus*) from Norway to South Korea; and American lobster (*Homarus americanus*) from Canada to Sweden. System boundaries included production, processing, packaging, storage, and distribution. We compared each case study based on the total GHG emissions, the contribution of air freight to GHGs, the identified factors that influenced the role of air freight in results, and the effect of alternative transport scenarios. We compared contribution results to several previous seafood studies which also included air freight in their systems.

Results

Case 1 – Atlantic salmon, Norway to China: Fresh head-on gutted farmed Atlantic salmon is the most important seafood export product from Norway, with over 800,000 tonnes exported at a value of 51 billion NOK (5 billion USD) in 2017. Although most is destined for European markets, salmon is increasingly flown to distant markets in Asia and the U.S. This case study modelled salmon farmed and processed in Norway and trucked to Oslo before being flown to Shanghai via direct flights with full load utilization. Logistics required routing of half-empty cargo flights from Brussels to Oslo to make planes available. Total life cycle GHG emissions of salmon delivered to Shanghai was 19.4 kg CO_2-eq per kg, of which over half resulted from air freight (Figure 1). Frozen products delivered to markets in Europe and Asia by road and sea instead resulted in less than half the emissions. Modelling alternative air freight scenarios indicated that avoiding the need to route aircraft from Brussels to Oslo would reduce emissions by 13%, while using passenger flights instead of dedicated cargo flights would, with average load factors, increase emissions by 93%.

Case 2 – Chinook salmon, New Zealand to various markets: New Zealand is the world's leading producer of farmed Chinook salmon, producing ~12,000 tonnes per year primarily from marine net pens. Fresh head-on gutted salmon is sold domestically and flown internationally to markets in Australia, Japan and the U.S. Given New Zealand's geographic remoteness, transport of fresh salmon to these overseas markets can require multiple flights and variable routings. Weighted across all 2013-2015 production and markets, average fresh head-on gutted salmon travelled 9,100 km by air and 600 km by road. Despite relatively substantial GHG emissions up to farm gate (11.3 kg CO_2-eq per kg), arising from higher feed inputs and high rates of livestock product inclusion in diets, air freight still drove emissions for most distribution scenarios. Air freight related emissions for salmon delivered domestically to Auckland and internationally to Australia, Japan, and the US, ultimately accounted for 6, 17, 47, and 59%, respectively, of total GHG emissions up to the point of arrival (Figure 1). A scenario in which product is instead frozen and transported by a combination of truck and sea freight to the same markets indicates that distribution would account for less than 5% of life cycle GHG emissions.

Case 3 – King crab, Norway to Korea: Red king crab, although a small volume fishery, is one of Norway's highest value seafood exports with a large portion of harvest currently being shipped live to South Korea. RKC are fished by small coastal vessels in northern Norway using baited traps and requiring substantial fuel use. RKC are maintained alive in chilled water tanks before being packed dry in polystyrene containers for shipping. Air freight from Norway to Seoul involved a three-leg journey on passenger flights. GHG emissions up to the point of landing totalled 6 kg CO_2-eq per kg edible meat, and subsequent air freight from Norway to Seoul resulted in a three-fold increase in overall emissions up to the point of delivery (total emissions of 28.6 kg CO_2-eq per kg edible meat upon delivery in Korea). Air freighting accounted for almost 75% of total emissions (Figure 1). A scenario in which RKC are first processed and frozen prior to transport to Korea using a combination of truck and sea freight resulted in a ~72% reduction in total GHG emissions up to delivery (7.8 kg CO_2-eq per kg frozen edible meat).

Case 4 – American lobster, Canada to Sweden: American lobster is fished almost exclusively in Canadian and American baited trap fisheries in coastal waters of the northwest Atlantic. In both countries, lobster is one of the most valuable fished species with animals destined for well-established domestic markets and, increasingly, international markets. We used Stockholm, Sweden as a representative destination locale for live and frozen lobster exported from Halifax, Canada. Logistical journeys followed typical product-form specific routes and modes of transport (*e.g.* live lobster air freighted via London or Copenhagen; frozen lobster sea freighted via Rotterdam). Despite relatively high fuel use and resulting GHG emissions during fishing, transatlantic air freight represented 73% of total emissions. Shipping frozen lobster by sea rather than air would reduce overall emissions by ~70%. Flying live lobster to Europe but subsequently replacing intra-European air freight with truck transport would reduce life cycle emissions by 17%. Replacing all air freight with a specifically modified sea freighting technology which includes keeping lobsters alive in a shipping container would reduce overall emissions by 50%.

Discussion

Common challenges encountered when undertaking LCAs that include air freighting include identifying appropriate emissions factors, differentiating between dedicated cargo flights and passenger flights, and in the latter case how to allocate emissions between passengers and freight. The IATA (2019) recommends using mass allocation to apportion emissions between passengers and cargo, assuming 100 kg of total person and luggage per passenger. Emissions factors used here for air freight range from 0.48 to 1.47 kg CO_2-eq per tkm, and are influenced by the type of flight, load utilization, distance travelled, and the number of intermediate stops as a disproportionate amount of emissions are experienced during takeoff (Winther *et al.,* 2020).

Each of our case studies was associated with relatively high emissions from production prior to distribution. Yet the disproportionate impact of air transport still drove the overall life cycle GHG emissions for most cases and scenarios (Figure 1). This reflects previous findings which also assessed relatively high impact products and found the distribution stage to still drive overall emissions (van Putten *et al.,* 2017; Driscoll *et al.*, 2015). In comparison, distribution has typically accounted for less than 20% of life cycle GHG emissions in seafood LCAs which included distribution by other transport modes (Parker, 2012, updated with new studies). Opportunities to reduce emissions from air freight in seafood supply chains include using frozen product forms, prioritizing dedicated freight over passenger flights, limiting the number of legs or limiting air freight to intercontinental legs, and optimizing flight logistics to avoid the need for empty flights.

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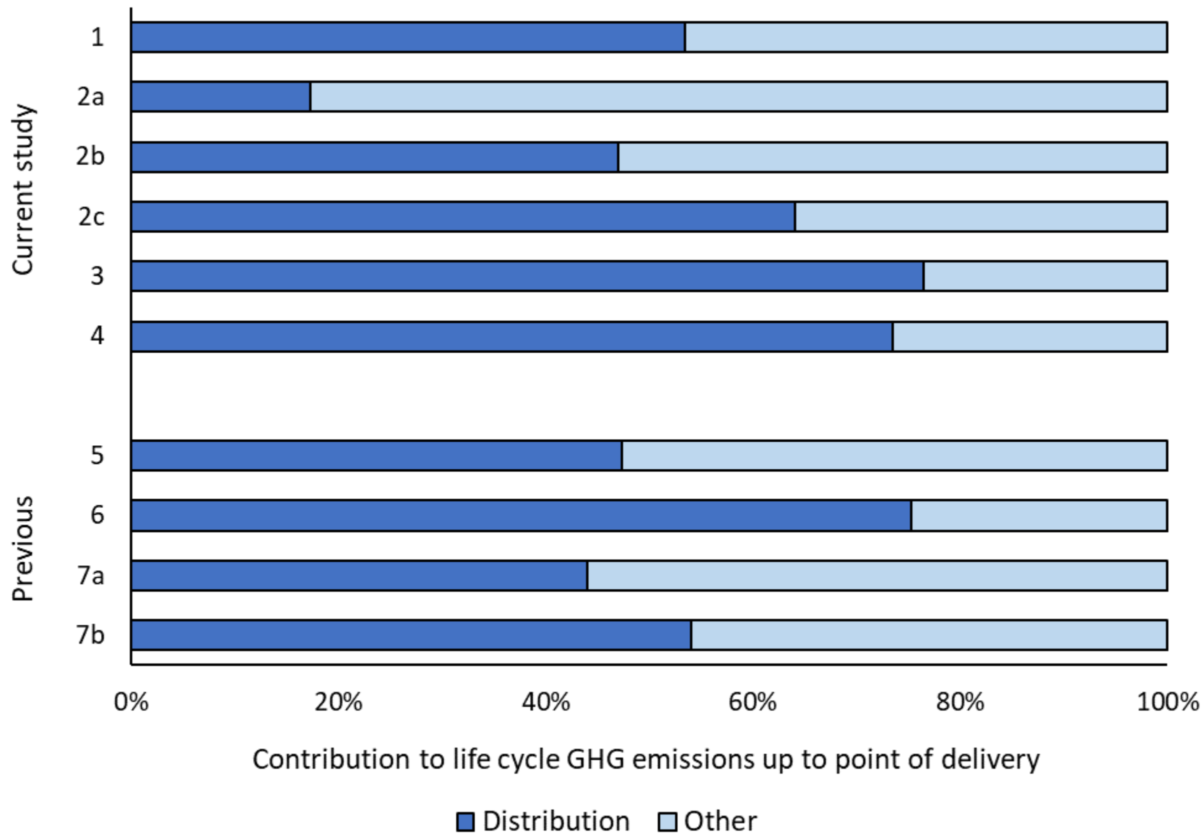

Figure 1. Percent contribution of distribution by air freight to total life cycle greenhouse gas emissions up to the point of arrival at destination market. **1** Farmed Atlantic salmon from Norway to China; **2** Farmed Chinook salmon from New Zealand to Australia (a), Japan (b), and the eastern United States (c); **3** Trapped Red king crab from Norway to Seoul; **4** Trapped American lobster from Canada to Sweden; **5** Trapped American lobster from Nova Scotia to Las Vegas (Driscoll *et al.*, 2015); **6** Farmed Atlantic salmon from Norway to the U.S. (Liu et al., 2016); **7** Trapped Southern rock lobster (a) and diver-caught Tropical rock lobster (b) from Australia to Hong Kong (van Putten *et al.*, 2016).

Abstract code: 143

Integrated multi-Trophic Aquaculture in ponds: what environmental gain? An LCA point of view

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Abstract

Aquaculture faces a double challenge produce more to sustain growing demand for aquatic products and respect the environment. For several years, Integrated MultiTrophic Aquaculture (IMTA) has gained worldwide attention. IMTA is based on integrated cultivation of aquatic organisms from different but complementary trophic levels. The objective of this study was to assess environmental performances of pond-IMTA systems based on freshwater polyculture experiments in earthen ponds conducted in Romania, France and Indonesia that explored different ways to combine fish and plants. In each experiment, the IMTA system was compared to a conventional or traditional system for the country (carp polyculture in Romania, intensive polyculture in France and gourami monoculture in Indonesia). Environmental impacts of IMTA systems differed among case studies. In Romania, environmental impacts also differed between years: IMTA system had higher impacts than the traditional one in 2016 but has lower impacts in 2017. In France, conventional system had lower cumulative energy demand, eutrophication and net primary production use than semi-intensive and IMTA system, the latter had the highest values of these impacts. However, for climate change the conventional system has higher impact than IMTA and semi-intensive system. In Indonesia, IMTA system had lower impacts than the traditional one. The environmental impacts estimated in this study illustrate the variability in the responses of IMTA systems. Impacts of agricultural systems depend on system productivity and the amounts of inputs embodied in the system. IMTA is expected to provide improvements such as a decrease in input use such as feed, increase in fish yields, and/or decrease in emissions per unit mass of fish produced. Depending on the practices, increasing the number of species or their organization through IMTA practices can decrease environmental impacts, especially local impacts such as eutrophication, compared to classic practices. Production and use of fish feed is one of the main causes of environmental impacts. Based on our results, IMTA practices can improve resource use and decrease the overall impact of aquaculture. Any increase in inputs used to improve nutrient recycling must also increase productivity to ensure a decrease in impacts per unit mass of fish. Certain impact categories that can describe consequences of IMTA systems more completely are lacking, especially those related to diversity, particularly biodiversity.

Keywords: aquaculture, ponds, multi-trophic

Introduction

Market demand for seafood products and stagnating production volume from fisheries have combined to increase aquaculture production for the past several years (FAO, 2018). Consequently, aquaculture faces a double challenge: i) produce more to sustain growing demand for aquatic products and ii) respect the environment. Freshwater pond aquaculture remains the main system worldwide for producing fish (FAO, 2018). Nonetheless, intensification of practices in these systems has had increasing drawbacks, and new perspectives must be sought. Although the number of aquatic species used in aquaculture increased from ca. 72 in 1950 to more than 500 at present (of which fish species increased from 43 to 219 in 2005), 90% of global aquaculture production depends on only 20 fish species (Teletchea, 2019). For several years, Integrated MultiTrophic Aquaculture (IMTA) has gained worldwide attention. IMTA is based on integrated cultivation of aquatic organisms from different but complementary trophic levels. Inorganic and organic wastes from fed aquaculture organisms are assimilated by autotrophic and heterotrophic species, respectively, that are co-cultured with the fed organisms (Neori et al., 2004). IMTA systems are designed to i) decrease dependence on external inputs and increase system efficiency by optimizing use of nutrients and energy in production, ii) decrease impacts of waste and bio-deposition by decreasing nutrient loss (to water, sediments and air), iii) diversify aquaculture products and generate a more robust source of income (less dependent on single-product markets) and iv) generate and use different types and levels of ecosystem services. The objective of this study was to assess environmental performances of pond-IMTA systems based on experiments launched at a commercial scale.

Material and methods

a) System design: The study was based on freshwater polyculture experiments in earthen ponds conducted in Romania, France and Indonesia that explored different ways to combine fish and plants (Figure 1). In Romania, experiments compared two systems of common carp and four species of Chinese carp (bighead, grass, crucian and silver) in 2016 and 2017. A traditional extensive polyculture (TEP), with all five species fed by a cereal mixture, was compared to a semi-intensive monoculture of common carp fed the cereal mixture and separated by nets in the same pond from a polyculture of the Chinese carp (IMTA_EP). The Chinese carp relied solely on the natural productivity of the pond, which was sustained by emissions from the common carp monoculture. In France, experiments compared a classic unfed extensive polyculture (CEP) to i) a semi-intensive polyculture using formulated feed (SEF) and having double the fish density and ii) a SEF connected to a planted lagoon with the same area (IMTA_SEF). The polyculture was composed of common carp, perch and roach. The ponds had the same water area, and pumps were used in SEF and IMTA_SEF to increase water circulation. In Indonesia, experiments compared a giant gourami monoculture (GM) fed by artificial feed to the same giant gourami culture with the added culture of a floating plant (red Azolla) in the same pond separated by nets (IMTA_G). The Azolla produced in the pond was used to supplement the Gourami diet.

b) Environmental assessment: Life Cycle Assessment (LCA) was performed according to the main recommendations of ISO (2006 a & b) but applied at the farm gate. The functional unit was 1 kg of total fish biomass produced during one production cycle. The processes included covered the production of feeds, fingerlings, equipment and buildings. The electricity mix was adapted to the country, if necessary. The ecoinvent v3.4 database was used for background data and the Ecoalim data set (Wilfart et al. 2016) for feed ingredients. Impact categories were selected based on previous studies and recommendations for aquaculture LCA (Aubin et al., 2009; Bohnes & Laurent, 2019; Papatryphon et al., 2004; Wilfart et al., 2013): climate change (kg CO_2-eq), potential eutrophication (kg PO_4^--eq), Net Primary Production Use (NPPU, kg C) showing the pressure on terrestrial and aquatic primary production, and cumulative energy demand (MJ) according to CML IA v3.05 and cumulative energy demand v1.10. Impacts were estimated using SimaPro ® software v8.5.4.0. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described.

Results

Environmental impacts differed among the systems in the case studies (Figure 2). In Romania, environmental impacts also differed between years: IMTA system had higher impacts than the traditional extensive system (TEP) in 2016 (except eutrophication), but lower impacts than TEP in 2017. In France, the classic unfed extensive polyculture had lower cumulative energy demand, eutrophication and NPPU than the semi-intensive polyculture using formulated feed system and the IMTA system, the latter of which had the highest values of these impacts. However, the classic unfed extensive polyculture system had higher climate change than IMTA and semi-intensive polyculture using formulated feed systems. In Indonesia, the IMTA system had lower impacts than the gourami monoculture one.

Discussion

The environmental impacts estimated in this study illustrate the variability in the responses of IMTA systems. Impacts of agricultural systems depend on system productivity and the amounts of inputs embodied in the system. IMTA is expected to provide improvements such as a decrease in input use (especially feed), increase in fish yields, and/or decrease in emissions per unit mass of fish produced. In Indonesia, the giant gourami culture associated with Azolla decreased consumption of formulated feed per unit mass of fish and nutrient emissions to water by recycling them into Azolla production, which also feeds the fish. This "virtuous" system decreased all selected impacts by ca. 70%.

In Romania, the IMTA system decreased eutrophication by increasing recycling of the nutrients from the common carp monoculture. However, the associated Chinese carp polyculture did not grow sufficiently in 2016 due to the initially low weight of individual fish. Consequently, since the use of formulated feed did not decrease, the lower yields resulted in higher energy demand per kg, climate change and NPPU compared to those of the traditional extensive system. In contrast, better management of the Chinese carp in 2017 generally increased their yields and consequently decreased impacts compared to those of traditional extensive system.

In France, the classic unfed extensive polyculture system had the lowest impacts because it used biomass produced naturally in the pond. Its higher climate change impact was due to natural methane emissions from the pond itself, which were compensated by high fish yields in the semi-intensive polyculture using formulated feed and IMTA systems. In the IMTA system, the planted lagoon captured some nutrients, which decreased the natural biomass available for fish and thus decreased fish yield. The decrease in yield was not compensated by a significant decrease in nutrient emissions in the water when ponds were drained. Moreover, since the plants were not considered as co-products of the lagoon, the increase in inputs was not compensated by an increase in production, which increased the impacts.

Conclusions

Depending on the practices, increasing the number of species or their organization through IMTA practices can decrease nutrient emission and therefor environmental impacts compared to classic practices. Production and use of fish feed is one of the main causes of environmental impacts. Based on our results, IMTA practices can improve resource use and decrease the overall impact of aquaculture. Any increase in inputs used to improve nutrient recycling must also increase productivity to ensure a decrease in impacts per unit mass of fish. Certain impact categories that can describe consequences of IMTA systems more completely are lacking, especially those related to diversity, particularly biodiversity.

Moreover, IMTA covers a broad spectrum of practices based on the complementarity of productive compartments and can involve many groups of species from different ecological niches. Combining LCA with another assessment method, such as Emergy Accounting or food-web models, could improve understanding of these promising aquaculture systems.

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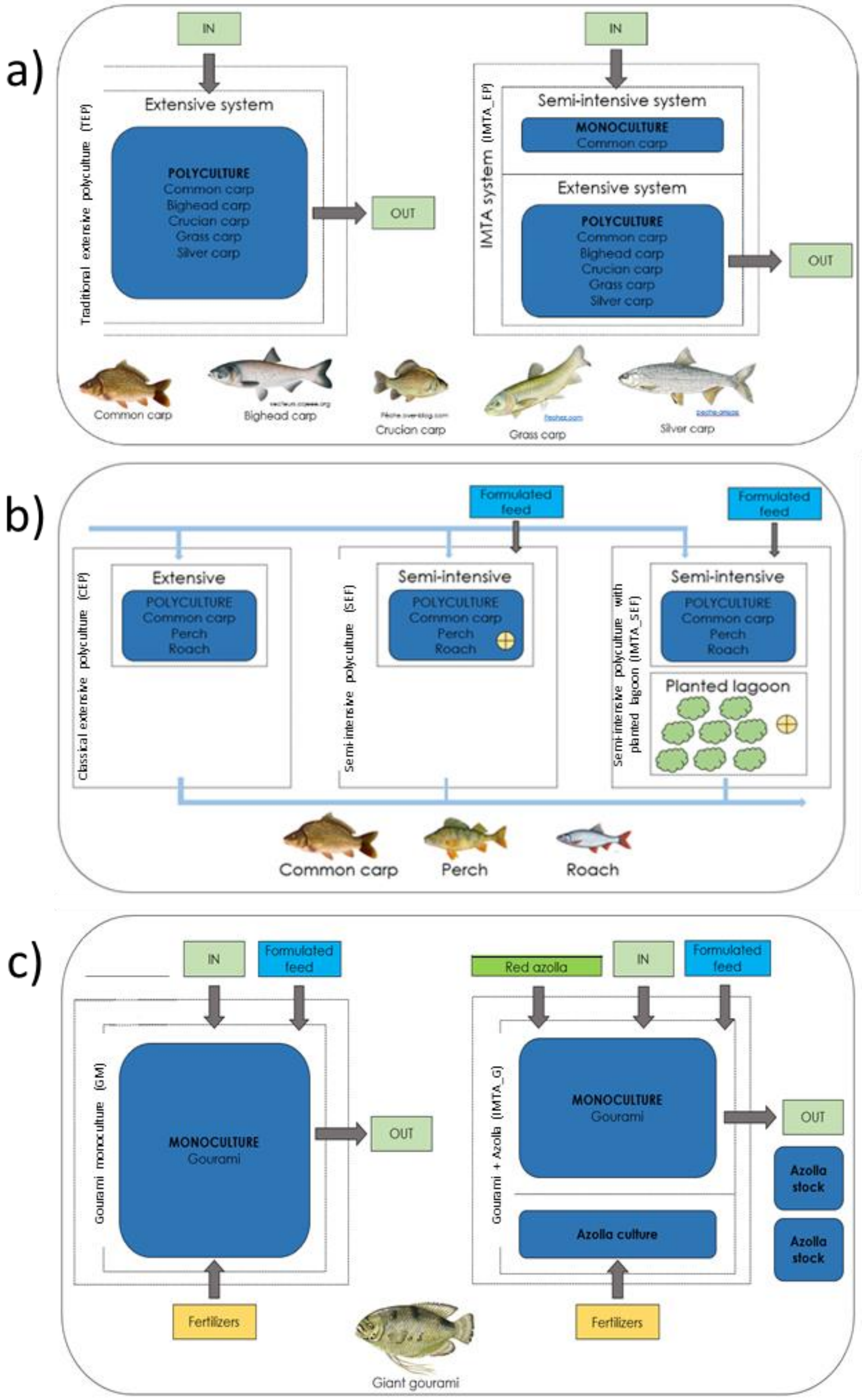

Figure 1. Experimental design of (a) Romanian experiments for a traditional system (TEP) and the IMTA system (IMTA_EP); (b) French experiments for a classic extensive polyculture (CEP), a semi-intensive polyculture using formulated feed (SEF), and a SEF coupled with a planted lagoon (IMTA_SEF) and (c) Indonesian experiments for a classic giant gourami monoculture (GM) and a IMTA system based on co-culture of gourami and azolla (IMTA_G). In (b), the crossed circle indicates the use of a pump, and the three ponds with fish had the same water area.

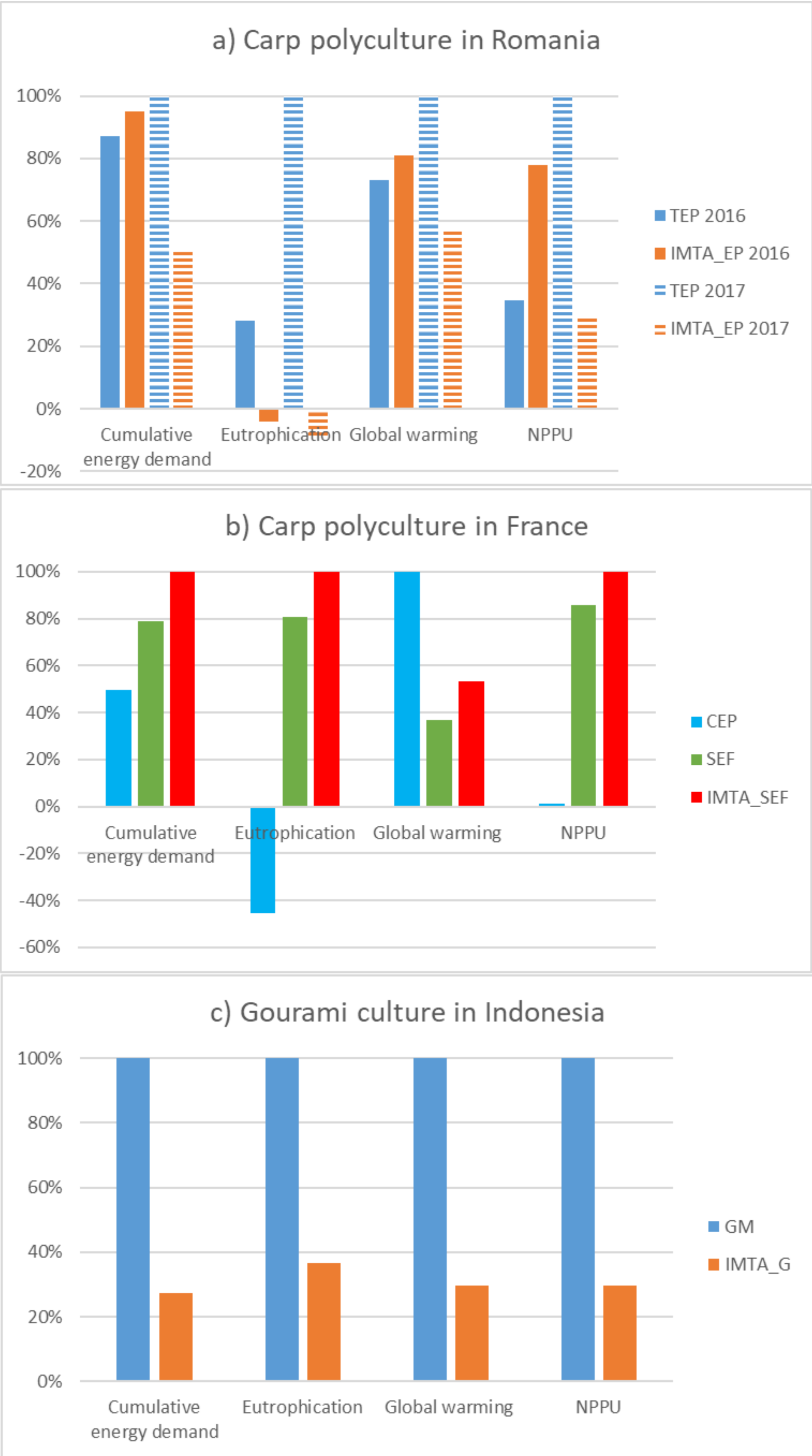

Figure 2. Comparison of environmental impacts of classic and IMTA systems in the case studies from (a) Romania, (b) France and (c) Indonesia. Results are expressed as a percentage of the largest value per impact.

Topic 7:
Novel Technologies
and Protein Production Systems

Abstract code: 147

Environmental assessment of new European protein sources for pig feeds

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Abstract

Purpose. European pig production aims at reducing its environmental impacts with various mitigation strategies. Among them, the replacement of Brazilian soybean meal (BSM) associated to deforestation with European protein sources (EPS) combined with the genetic improvement of feed efficiency was tested in the H2020 Feed-A-Gene project. The goal was to estimate the environmental impacts of pig production resulting from incorporating EPS in fattening feeds.

Methods. Four EPS were examined: fine fraction of rapeseed meal, partly defatted soybean meals obtained from crushing of dehulled or non-dehulled soybeans, and protein paste extracted from biomass. Environmental impacts per ton of protein for feedstuffs and per kilogram of pig at the farm gate were estimated using life cycle assessment. Benefits were calculated by comparing each EPS scenario with a reference using BSM and traditional protein sources. Least cost formulation defined feed compositions. For current feedstuffs, prices come from four European countries for four contrasting years. Prices of BSM and EPS were considered zero respectively in reference and innovative scenarios in order to maximize their incorporation. Improved genetic was assessed thanks to the comparison of two lines respectively with low and high feed efficiency.

Results and discussion. At feedstuff level, the EPS reduce climate change impact more than twice compared to BSM but other impacts could be increased as acidification, eutrophication and land occupation. At pig level, the average incorporation of BSM in the reference fattening diet was 13%. Compared to this baseline, EPS scenarios reduce climate change impacts (by 8-9% for the European soybean meal and by 3-4% for the protein paste and the fine fraction of rapeseed meal) but still with a transfer of impact to land use (increase of 13%). With an additional improved genetic, the reduction on climate change with EPS rises 12-16% and limits the increase of land occupation below 5%. These results show a potential interest of EPS.

Conclusions. EPS can't be considered competitive as a replacement for BSM in the current context in which less than 5% of BSM was currently used in fattening diets due to the relative prices of protein sources. EPS seem interesting for climate change in a context economically favorable to BSM. But because of the transfer of impacts, there is a need for more macroscopic analyses to capture indirect land use effects.

Keywords: *pig, feed, innovations, LCA, environment, impacts.*

Introduction

The production of feedstuffs for pigs explains a huge part of the animal product's impacts at farm gate (expressed in kilogram of live weight for pigs): from 60 to 67 % of the climate change impact and from 68 to 71 % of non-renewable energy consumption impact (Dourmad et al., 2014). Brazilian soybean meal (BSM) is one of the most impactful feedstuffs on climate change because of its partial contribution to the local deforestation of primary forest. Almost 80% of the global soybean is cultivated on the American continent where 24 million hectares of forest (including primary one) and grassland were converted to arable lands between years 2000 and 2010 (WWF, 2014). 75% of the soybean world production is used for animal feeding. The high interest for this feedstuff is due to its rich protein content (between 46 and 48%) and its profile in amino acids adapted to animal requirements. However, its use is questioned because of genetically modified organism and environmental impacts. Thus, an alternative could be a substitution of Brazilian soybean meal by European protein sources (EPS). The goal of this study is to assess the environmental incidences of such application by Life Cycle Assessment.

Material and methods

Four EPS were considered to replace BSM (Figure 1): a fine fraction of rapeseed meal (FRM) which increases protein content and reduces fiber content of rapeseed meal, European soybean meal processed by flaking-cooking-pressing with or without previous dehulling (respectively EUSM D and EUSM) (Quinsac et al., 2012), and a protein concentrate (PC) extracted from biomass as ryegrass or clover (Hermansen et al., 2017). The environmental impacts were calculated with attributional Life Cycle Assessment (LCA) for energy consumption (EC in MJ, CED V1.8), climate change (CC in kg CO_2-eq, ILCD), acidification (AC in molc H+-eq, ILCD), eutrophication (EU in kg PO_4^{3-}, CML 2001) and land occupation (LO in m².year, CML 2001) impacts using the model developed by Cadero et al. (2018). The functional units were the ton of protein for feedstuff (BSM and EPS) and the kilogram of live weight pig at farm gate. The pig farm used in the model was with fully slatted floor in building and storage of manure under the animals, followed by an external storage of manure in uncovered pit. We considered three genetic lines for pigs: a current one representative of conventional pig (Large White x Landrace) x (Large White x Piétrain) (Brossard et al., 2014), and two genetic lines selected for divergent residual feed intake, high (RFI+) and low (RFI-). The difference between RFI+/- represents genetic progress or diversity of expression of genetic potential in commercial farms. RFI- pigs reach on average better performance than the RFI+ pigs with a feed conversion ratio improved by 12%, nitrogen excretions reduced by 23%, and volatile solid excretions decreased by 14% (Gilbert et al., 2017). At feedstuff level, the impacts of EPS were compared to those of BSM. At pig level with conventional genetic, benefits due to EPS were calculated by difference between innovative scenario (one for each EPS) and reference scenario using BSM and traditional protein sources. For RFI genetic lines, the comparison was made between EPS and RFI- to reference RFI+ in order to cumulate the benefit of EPS and genetic improvement. Feeds were formulated at least-cost under constraints relative to possibilities of incorporation rate and final nutritional requirements. In innovative scenarios, EPS were integrated at their potential level in growing and finishing feeds of a two-phase strategy. Their nutritional profiles were given by Carré et al. (2017), Lærke et al. (2019) and Melo et al. (2020) (Table 1). The prices of SBM and EPS, respectively in reference and innovative scenarios, were set to 0€ in order to maximize their incorporation but with a maximal rate of 15% for fine fraction of rapeseed meal and protein concentrate. For the other current feedstuffs, economic contexts of four countries (France, Germany, Spain and the Netherlands) and four contrasting years were considered. LCA impacts of pig production were subjected to variance analysis (ANOVA) using a generalized linear model (glm) to assess effects of protein sources used in feed. Fixed effects were tested using each of the 80 scenarios for conventional genetic, crossing five protein sources, four countries and four economic contexts, as the statistical units; and 20 scenarios for RFI lines, crossing protein sources and economic contexts. We used the stats package and the glm function of R software for this analysis.

Results and discussion

Per ton of protein, FRM, EUSM and EUM D have an interesting potential in reducing climate change compared to BSM (>50%) (Table 1). This is also the case for EC, which is higher for BSM because of the transportation from Brazil to Europe. The AC and LO impacts were higher for some EPS compared to BSM. Indeed, soybean is not fertilized with nitrogen (legume) compared to rapeseed, and its production in Brazil has two harvests per year instead of only one usually in Europe. At pig production level each EPS can replace BSM but their respective digestible Lysine to net energy ratios are lower (Table 1), so the complement with other feedstuffs is done differently to offer final feeds with equivalent nutritional characteristics (in terms of energy content, protein content…). With current conventional genetic, the EPS result in a potential reduction of CC (by 8-9% for European soybean meal and by 3-4% for protein concentrate and fine fraction of rapeseed meal) compared to a reference in which BSM would be the main protein source (i.e., incorporation of 13% in the fattening diet). However, as shown at feedstuff level, LO is increased (by 12% for the European soybean meals). When combining EPS and genetic improvement, the environmental reduction is mainly due to genetic for AC and EU. The reduction of impact for CC is enhanced compared to what was obtained with the only EPS. In our study, it achieves a reduction around 15% for the European soybean meals and 12% for the fine fraction of rapeseed meal and the protein concentrate. The reduction of EC is also improved thanks to combination of both factors.

The results show the importance of considering the life cycle of animal production to assess feeding strategies. A feedstuff is not equal to another because of its own nutritional characteristics (protein content, amino acid profile, energy content…). Thereby, it is not possible to simply replace one feedstuff by another and the impacts between two protein sources per ton of feedstuff could change per ton of the mixed diet because of feedstuffs substitutions. Animal feed optimization is based on least-cost formulation and a wide range of ingredients are available. Furthermore, diet compositions can change easily, resulting in different environmental impacts. Therefore, environmental assessment of feeding strategies should include a sensitivity analysis on economic contexts to make the results more robust. However, the feed level is not enough because the feeds are part of feeding strategies and several feeds are used in monogastric productions. Just as a set of feedstuffs defines the nutritional profile of a feed, a set of feeds and their use in a feeding plan define nutritional input of animals and result in animal performance depending also on the genetic. A feeding strategy that uses feeds with lower impacts but leads to reduce animal performance is not favorable. Thereby all these nested scales (feedstuff, feed, animal product) are confirmed necessary to assess the environmental interest of innovative feeding strategies.

Results indicate a transfer of impact on LO. What would be the result for the planet? Indeed, no new fertile land is available to expand crop areas. On the contrary, the general trend is a reduction of exploitable surfaces because of global warming and increase of artificialized surfaces. Any extensification of production is therefore done to the detriment of another production that must be reduced or stopped. These indirect consequences could be called rebound effects and must be considered at a larger assessment scale in order to see the net environmental impact of a potential feeding strategy (Van Zanten et al., 2017). Espagnol et al. (2018) confirmed this need by assessing rebound effects associated to the production of eco-feed (feed with lower environmental impacts) for a virtual territory that produced feed ingredients for a pig farm. Attributional LCA was performed using multiple functional units and system perimeters: kg of pig live weight at the farm gate, ha of land used, economic value produced and number of people fed. The situation in which eco-feeds are produced can appear better or worse than the situation in which standard feeds are produced. These studies highlighted the necessity to complete ALCA by more global study at a larger perimeter. This has to be done to complete the result of this work.

Conclusions

In a context economically favorable to BSM, it is possible to reduce climate change impact of pig production by using EPS, especially European soybean meal, but with an increase of land use. Because of this, it is necessary to consider the rebound effects in the perimeter of analysis especially in France where the ambition is to rise the French soybean production from 150 000 ha to 250 000 ha. EPS are currently not competitive as a replacement for BSM because currently a low content of BSM is used in pig feeds (less than 5% in fattening diets). This is due to the relative prices of the different protein sources, which makes rapeseed and sunflower meals more competitive than BSM. The environmental interests of EPS depend on the economic context and the resulting initial incorporation rate of BSM in feeds.

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Figure 1: Production processes of alternative European protein sources to Brazilian soybean meal

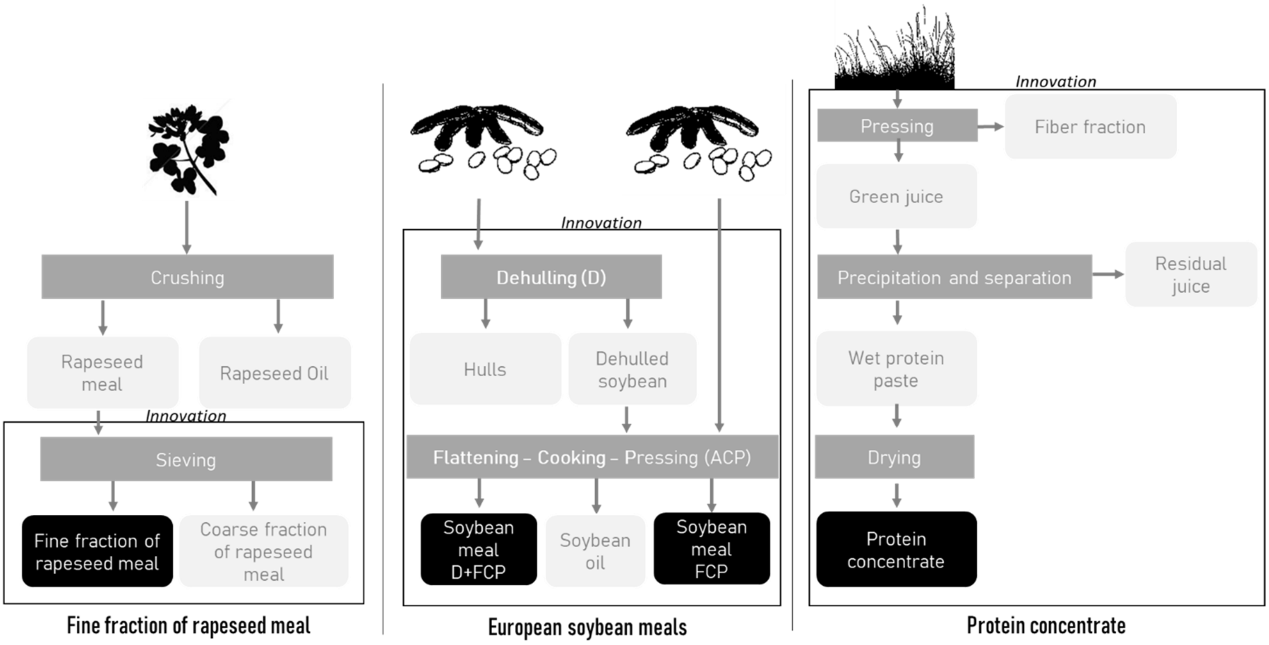

Table 1 – LCA impacts per ton of protein for feedstuffs (BSM and EPS), and per kilogram of live weight pig at farm gate considering feeding strategies with BSM or EPS for conventional genetic and contrasted genetic lines on feed intake (RFI+ for BSM and RFI- for scenarios with EPS)

		BSM	Protein concentrate	Fine rapeseed meal	EUSM	EUSM D		
		Nutritional characteristics of EPS and BSM per kg of feedstuff						
Protein (g)		463	337	385	466	505		
Fiber (g)		59	205	72	51	32		
Fat (g)		16	63	17	78	59		
NE for fattening pig (MJ)		8,3	5,1	7,1	9,6	9,6		
Dig. Lys. / NE (g/MJ)		3,12	2,59	2,16	2,72	2,96		
		Impacts per ton of protein for feedstuff						
	CC (kg CO2 eq)	2499	1588	1161	888	881		
	AC (molc H^+ eq)	15,42	91,72	24,26	8,76	8,77		
	EU (kg PO_4^{3-} eq)	10,43	21,42	8,91	13,50	13,64		
	EC (MJ)	19156	12991	8623	16708	16562		
	LO (m^2.year)	3300	8869	3582	8047	8145		
		Impacts per kilogram of live weight pig						
							RSD[1]	*P-value*
Conven-tional genetic	CC (kg CO2 eq)	2.38[c]	2.31[b]	2.30[b]	2.17[a]	2.19[a]	*0.019*	*<0.0001*
	AC (molc H^+ eq)	0.0726[b]	0.0692[a]	0.0744[d]	0.0735[c]	0.0741[cd]	*0.00089*	*<0.0001*
	EU (kg PO_4^{3-} eq)	0.0189[a]	0.0190[ab]	0.0190[a]	0.0192[ab]	0.0193[b]	*0.00032*	*0.008*
	EC (MJ)	20.3[b]	20.1[ab]	19.8[a]	19.7[a]	19.7[a]	*0.456*	*0.001*
	LO	3.82[a]	4.07[b]	3.86[a]	4.29[c]	4.30[c]	*0.131*	*<0.0001*
RFI-/RFI+	CC (kg CO2 eq)	2.67[c]	2.35[b]	2.33[b]	2.24[a]	2.26[a]	*0.0205*	*<0.0001*
	AC (molc H^+ eq)	0.0875[c]	0.0691[a]	0.0747[b]	0.0744[b]	0.0751[b]	*0.00059*	*<0.0001*
	EU (kg PO_4^{3-} eq)	0.0220[b]	0.0197[a]	0.0195[a]	0.0199[a]	0.0200[a]	*0.00040*	*<0.0001*
	EC (MJ)	21.5[b]	20.1[a]	19.8[a]	20.2[a]	20.2[a]	*0.295*	*<0.0001*
	LO (m^2.year)	4.27[ab]	4.29[ab]	4.04[a]	4.50[b]	4.52[b]	*0.156*	*0.004*

[1]RSD: residual standard deviation of the model.
[a, b, c, d, e, f, g, h] Means followed by same letter do not differ (P >0.05) according to Fischer's test.

Abstract code: 136

Reducing environmental impacts of Danish milk production with plasma treatment of manure

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Abstract

Purpose
N2 Applied is a novel technology to treat animal slurry with plasma. The technology has several features, which includes reducing of methane emissions, reduction of ammonia losses, increasing the fertiliser efficiency of slurry when applied to land, increased nitrogen content in slurry, which increases the substitution of mineral fertiliser. The purpose of the study is to compare the environmental impact of N2 Applied treatment with other slurry treatment options.

Methods
Danish milk production in 2012 is used as a case study. The study makes use of a very detailed model of Danish milk production, which enables for modifying all relevant parameters affected by the N2 Applied technology. The functional unit is 1 kg of energy corrected milk (ECM). The impact assessment includes 16 impact categories. The study compares the impacts of the Danish milk production system in 2012 with and without the N2 Applied technology. Further, this is supplemented with scenarios of different technology setups in the slurry treatment.

Discussion and conclusion
The comparison of average Danish milk production in Denmark in 2012 without and with the N2 Applied technology shows that the N2 Applied scenario is associated with 27% lower GHG emissions. If the N2 Applied technology is combined with biogas capture for the slurry treatment, the GHG emissions are 36% lower than the baseline scenario.

Keywords: Fertiliser, Manure treatment, Dairy, Emission reductions

Introduction

N2 Applied is a novel technology to treat animal slurry with plasma, reducing methane emissions and ammonia losses. During 2019, a detailed LCA study has been carried out in accordance with the ISO 14044 standards (Astudillo and Schmidt 2019). The purpose of the study is to compare the environmental impact of N2 Applied treatment with other slurry treatment options.

How it works: A plasma unit uses electricity and atmospheric N2 to produce NO_x, which is applied to animal slurry. Nitrogen oxides react with water in the slurry, and nitric acid is formed, which neutralizes the liquid. The oxides react with ammonia to form a stable (involatile) ammonium nitrate. The treatment inhibits bacterial activity in manure, which in turn eliminates methane emissions from manure storage. Besides this, the technology increases the nitrogen available for plant uptake for manure applied to land: 1) reduced ammonia loss leads to more nitrogen for plant uptake, 2) the reaction of oxides with ammonia forms ammonium nitrate which can easier be uptaken by plants, and 3) the N-content of the slurry is increased by ~60% from the absorbed NO_x from the N2 Applied plasma unit.

Material and methods
Danish milk production in 2012 is used as a case study, using the Arla FarmTool model developed by 2.-0 LCA consultants (Dalgaard et al. 2016). Different parameters of the model are modified to model the effects of the alternative treatments. The functional unit is 1 kg of energy corrected milk (ECM). Since the objective is to understand the potential effects of introducing the N2 Applied technology, the study uses a consequential approach. Therefore, the substitution method is used to model by-products. The impacts of the Danish milk production system with and without the N2 Applied technology is compared under different technology setups in the slurry treatment: Without and with biogas capture. Furthermore, the Danish average is assessed with sulphuric acid acidification technology. The following five scenarios are compared in the study:

Scenarios without biogas

1. **N2 Applied**: N2 applied technology is applied to cattle slurry.
2. **Baseline**: farm practices remain as defined by the Arla FarmTool.
3. **Baseline + acidification (H_2SO_4)**: cattle slurry is treated with sulphuric acid.

Biogas scenarios

4. **N2 Applied + biogas**: Cattle slurry is treated with anaerobic digestion and resulting digestate is treated with N2.
5. **Baseline + biogas**: anaerobic digestion is applied to cattle slurry

The life cycle impact assessment is performed using the Stepwise 1.6 method (Weidema 2009; Weidema et al. 2008).

Results
The life cycle impact assessment is introduced with a weighting to help identifying the most significant impact categories. The most significant impact categories for Danish milk production are identified as global warming, respiratory inorganics and nature occupation, i.e. biodiversity impacts caused by land use. The relative differences between the assessed scenarios and the baseline are presented for these impact categories in Figure 1.

The results for the comparison of the baseline and the N2 Applied scenarios without biogas show that the N2 Applied scenario has the lowest contribution to global warming at 0.549 kg CO_2-eq against 0.757 for the baseline, i.e. 27% lower. Conventional acidification with H_2SO_4 reduces the GHG emissions by 12% compared to the baseline. When combined with biogas, the impact of the N2 Applied scenario reduces to 0.483 kg CO_2-eq and the baseline reduces to 0.636, i.e. a 24% reduction.

The relative differences for respiratory inorganics are more or less similar to those of global warming. Nature occupation is not affected in any of the compared scenarios.

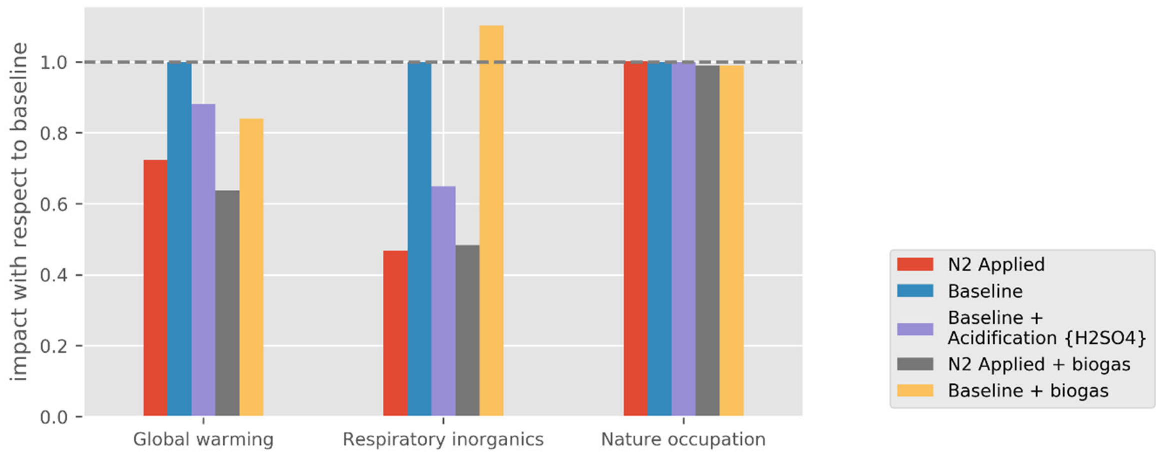

Figure 1: Difference between scenarios relative to the baseline for the three most significant impact categories.

Figure 2 shows a contribution analysis of the difference between the N2 Applied and the baseline scenario for GHG emissions. The contributions are normalized to 1 kg NO_x-N, which is plasma from the N2 Applied unit that is applied to the slurry. The contribution analysis shows that the largest GHG savings from the N2 Applied technology are reductions in CH_4 from manure storage, substitution of manufacture of mineral N-fertiliser. Reductions in N_2O from slurry land application are also significant.

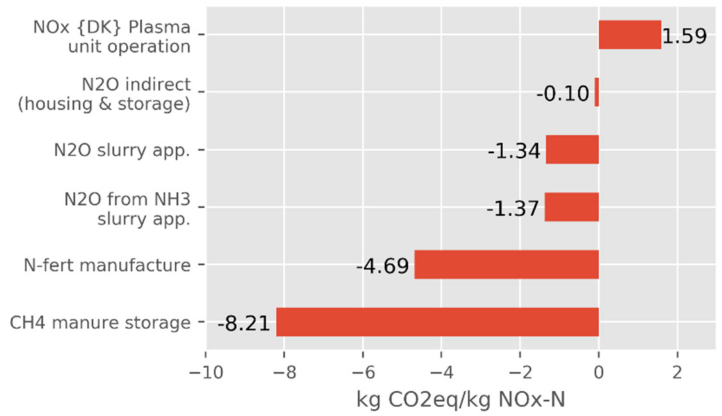

Figure 2: Contribution to CO_2-eq emissions per kg NO_x-N applied.

Discussion and conclusion

There are two main mechanisms by which N2 Applied reduces the GHG emissions of milk production. The first one is the reduction of methane emissions in manure storage. The second is the improved characteristics of treated slurry as fertiliser, which reduces field N_2O emissions and the need to manufacture synthetic fertilisers. Most of the greenhouse gas emissions of N2 Applied are due to the emissions of electricity production and therefore the use of low carbon electricity is necessary to obtain the calculated gains.

Concluding, the study shows that the N2 Applied technology has the potential to reduce the impacts of the Danish milk system significantly. Compared to the baseline without biogas, N2 Applied reduces the GHG emissions by 27%, and compared to the baseline with conventional H_2SO_4 acidification, N2 Applied reduces the GHG emissions by 18%. Also, when the N2 Applied system is implemented in a system with anaerobic digestion, the GHG emissions are significantly reduced by 24%.

Acknowledgement
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Abstract code: 170

Comparative life cycle assessment of plasma-based and traditional decontamination strategies on Norwegian ready-to-eat fresh spinach

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Abstract

Purpose
The goal of this study was to determine the environmental life cycle impacts of fresh spinach and potential benefits reducing food waste using three proposed treatment methods. The investigated processing methods included rinsing with either tap water (reference scenario), or the novel food processing technology Plasma Activated Water (PAW scenario), as compared to not rinsed products (untreated scenario). The study applied comprehensive life cycle inventory for the entire fresh spinach value chain.

Methods
The life cycle assessment follows the ISO14044 guidelines. The following impact categories were included: global warming potential, ozone layer depletion, acidification, eutrophication, abiotic depletion potential, abiotic depletion fossil and water use. The reference flow of fresh spinach was calculated by means of material flow analysis. The functional unit was set up as 1 kg fresh spinach consumed raw by end-users. A "cradle to grave" approach was implemented, with Norway as target geographical area. Consumer related impacts (except wastage) were not considered in this study. Activity data (e.g. food waste, processing technology life cycle inventories, transport distance, etc.) were case specific whereas process data (e.g. lorry inventories, energy production, waste treatment, etc.) were derived from the Ecoinvent 3.5 database.

Results and discussion
According to current industrial practices, production of 1.35 kg spinach is required per 1 kg eaten by consumer. The food waste impact according to current practices accounts for 18-22% within the assessed environmental burdens. The PAW and untreated scenarios were assumed to reduce, respectively, 50 and 25% food waste through shelf-life extension. For the PAW and untreated scenarios, the avoided environmental burdens ranged 6-8% and 5-6% respectively. Although it is uncertain whether prolonged shelf-life can reduce food waste, the potential of labelling strategies such as "best before" and "close to expiry date" has been demonstrated in this regard.

Conclusions
Both untreated and PAW scenarios led towards decreased environmental burdens and annual costs by food waste reduction compared to the reference scenario. PAW rinsing showed the greatest cut potential both environmentally and economically. For PAW, the most significant decreased impact category was eutrophication potential. Further research is needed to establish a direct connection between shelf-life extension and food waste reduction throughout the spinach value chain.

Keywords:
Fresh spinach, LCA, PAW, MFA, food-waste, shelf-life

Introduction

Providing sustainable, safe and high-quality nutritious foods is of major concern within the food industry. Ready-to-eat, fresh-cut spinach are products within the fresh produce category, with high wastage rates (Kasim and Kasim, 2017; Stensgård et al., 2019). Spinach salads reached the seventh largest revenue in Norway in 2018 (about 9 million EUR), corresponding to 6.7% of the total salad revenue (OFG, 2019).

Rinsing with tap water (reference scenario) is a common industrial post-harvest treatment for fresh produce, including spinach (Sousa-Gallager and Mahajan, 2011). Such a rinsing process makes the product visually appealing, contributes to the removal of pesticides and dirt, and reduces the indigenous microflora. Plasma Activated Water (PAW) is an emerging non-thermal technology alternative to traditional sanitizers applied in the fresh produce industry. Vaka et al. (2020) reported a significant disinfection potential of PAW on baby spinach leaves, as compared to tap water. Additionally, PAW inhibited bacterial growth during an 8-day refrigerated storage, conditions set to mimic the product shelf-life, while a significant increase in microbial levels was observed when rinsing with tap water. Although not rinsed spinach presented higher initial bacteria load than both PAW and tap water rinsed spinach, microbial levels remained unaffected during storage, most likely due to the limited water availability, and thus, significantly lower than the bacterial load in reference samples rinsed with tap water (Vaka et al., 2020). Microbial and enzymatic degradation is the main driver for spinach spoilage, and thus a key factor towards shelf-life extension (Sousa-Gallager and Mahajan, 2011). Moreover, a correlation between increased shelf-life of fresh produce and reduced food waste has been established (Soethoudt et al., 2013; Stensgård et al., 2019).

There are a few LCA studies on fresh spinach, but they are limited to GWP and/or cumulative energy demand (Büsser et al. 2008; Seo et al. 2017; Stoessel et al. 2019). However, no relevant food LCA studies has been found on processing technologies of spinaches or on PAW.

The aim of this study was to investigate the overall environmental performance of PAW disinfection on fresh spinach, as compared to typical rinsing with tap water and untreated products. The scenarios were based on the results reported by Vaka et al. (2020) related to microbial inactivation and quality retention, and thus shelf-life extension. The outcomes of this study shall expand the state-of-the-art on potential environmental benefits and/or limitations of PAW to aid in decision-making for further industrial implementation. Thus, it is of utmost importance to estimate the overall environmental burden contribution of food waste within current practices in spinach processing.

Material and methods

A "cradle to grave" approach, with Norway as target geographical area, was implemented (Figure 1), where final transport to end-users and consumer practices (e.g. cooking) were excluded. The LCA methodology was applied according to the ISO14044:2006 guidelines, and further calculations were carried out in SimaPro 9.1 software with the support of the Ecoinvent 3.5 database. Output driven material flow assessment (MFA) (Brunner and Rechberger, 2003) enabled estimation of accumulated spinach waste throughout the entire value chain. The following impact categories were included; Global Warming Potential (GWP), Ozone Layer Depletion (ODP), Acidification (AP), Eutrophication (EP), Abiotic Depletion Potential Elements (ADPE), Abiotic Depletion Potential Fossil (ADPF) and water use. Applied life cycle impact assessment methods are presented in Table 1. The functional unit was defined as 1 kg raw fresh spinach consumed at end-user level.

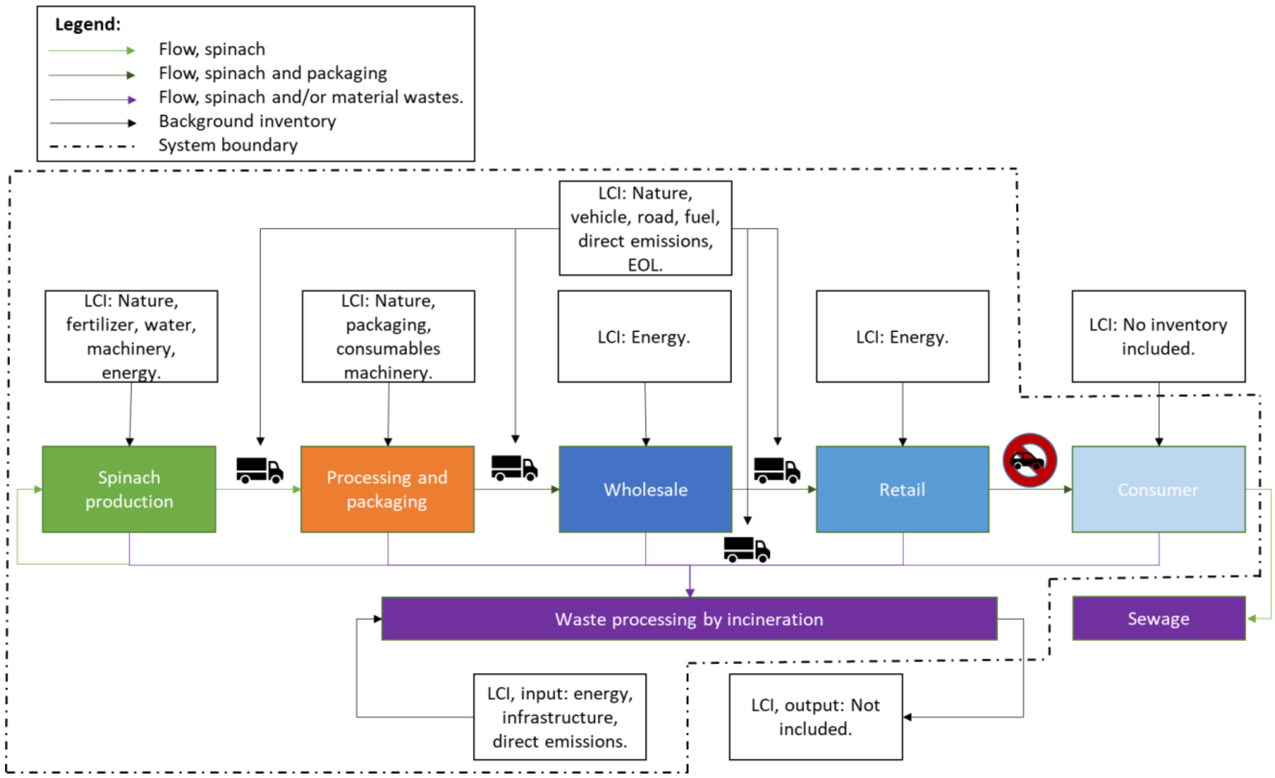

Figure 1 System boundary of included activities in the LCA of fresh spinach with life cycle inventory (LCI) descriptions and excluded stages.

Alternative food processing approaches have been studied and compared to current practices:

- Reference scenario (current industrial practice), with food waste recorded throughout the entire value chain.
- Reference scenario without food waste.
- Untreated scenario, with a 25% shelf-life related food waste reduction after sorting of fresh spinach.
- PAW scenario, with a 50% shelf-life related food waste reduction after sorting of fresh spinach.
- PAW sensitivity scenario, with a 50% shelf-life related food waste reduction only at retailer level.

Data for spinach production were based on the Life Cycle Inventory (LCI) presented in Stoessel et al. (2019), where the electricity source was changed to Norwegian grid mix. Direct and indirect emissions from nitrogen fertilizer at the farm level were based on IPCC emission rates (De Klein et al., 2006). The weight of consumer packaging (polyethylene), distribution packaging (cardboard) and pallets (HDPE, 58 uses) was estimated, respectively, as 49.6 g, 70 g and 5.5 g per 200 g spinach. The transport LCI's were adapted to specific capacity utilization, fuel consumption, and B20 fuel blend.

Specific LCIs for each processing strategy were determined:

- Reference scenario: 2 L tape water per kg fresh spinach.
- PAW scenario: 2 L water, 0.24 kWh electricity and 14.4 mg NO_2 (emission) per kg fresh spinach.

Determining food waste throughout the value chain is key to understand the metabolism of any system (Brunner and Rechberger, 2003). In this study, specific food waste rates for fresh spinach were found to be 6% at retailer level. For the remaining value chain stages (Figure 1), data from the product group vegetables/fruits/ berries, as reported by Stensgård et al. (2019), were used for waste estimations in fresh spinach as follows; waste from sorting (13%), wholesaler (0.4%) and consumer (9%). Stensgård et al. (2019) found that the causes for food waste at wholesale level was related to expiration date (64-78%), product damages (28%), wrong items (5%) and customer returns (3%). At retail level, vegetable wastage has been mainly attributed to reduced quality (e.g. yellowing) (Kasim and Kasim, 2017) or expiration (Stensgård et al., 2019). The causes for food waste found in Stensgård et al. (2019) combined with the experiment findings in Vaka et al. (2020) have been the background information used to semi-quantitatively develop the proposed food waste reduction rates in the above-mentioned scenarios. Using different data sources has been acknowledged to increase the uncertainty in LCA studies (Clavreul et al., 2019). As a mean to counter uncertainty, scenario development, material flow consistency and dataset adaptation have been implemented.

Results

The total production of fresh spinach produce required to meet the functional unit was estimated as follows: 1.35, 1.29 and 1.24 kg, respectively, for the reference, untreated scenarios and PAW. The costs associated to food waste within the reference scenario were estimated to 3.1 million EUR per year. However, PAW and untreated scenarios could save respectively 0.96 and 0.51 million per year due to just food waste reduction (investment and operation costs excluded).

The avoided environmental impacts by excluding food waste form the reference scenario was 17.6 to 22.8 % as seen in the nether part of Table 1. The implementation of PAW technology and its increased processing efforts for spinach decontamination contributed to a minor increase in environmental impacts (0.6 to 3.0%). However, the net effect of the PAW's food waste reduction potential led to a decrease in environmental impact of 6 to 8%. The untreated scenario also showed potential to diminish environmental impacts, ranging from 4 to 6% within the assessed impact categories. In the PAW sensitivity scenario, the environmental impact reductions ranged from 0.4 to 3.0%.

Tables

Table 1: Life cycle impact assessment of the five spinach treatment scenarios

	Environmental impact results for each of the five scenarios					
Impact categories	**Reference**	**Reference without food**	**Untreated**	**PAW**	**PAW sensitivity**	**Unit**
GWP (IPCC2013 GWP 100a v1.03)	1.13	0.92	1.08	1.04	1.10	kg CO2 eq./FU
ODP (CMLIAb v3.05)	1.79E-07	1.47E-07	1.71E-07	1.65E-07	1.74E-07	kg CFC-11 eq./FU
POCP (CMLIAb v3.05)	2.07E-04	1.67E-04	1.98E-04	1.92E-04	2.03E-04	kg C2H4 eq./FU
AP (CLIAb v3.05)	4.18E-03	3.35E-03	3.99E-03	3.87E-03	4.10E-03	kg SO2 eq./FU
EP (CMLIAb v3.05)	1.66E-03	1.29E-03	1.57E-03	1.52E-03	1.62E-03	kg PO4 eq./FU
ADPE (CMLIAb v3.05)	4.64E-05	3.77E-05	4.44E-05	4.30E-05	4.54E-05	kg Sb eq./FU
ADPF (CMLIAb v3.05) LHV	16.03	13.18	15.34	14.75	15.57	MJ LHV / FU
Water use (AWARE v1.02) scarcity	0.23	0.18	0.22	0.22	0.23	m3/FU

	Avoided environmental scenario impacts relative to reference				
	Reference	**Reference without food**	**Untreated**	**PAW**	**PAW sensitivity**
GWP	0 %	18.5 %	4.4 %	7.8 %	2.6 %
ODP	0 %	17.6 %	4.4 %	7.9 %	2.8 %
POCP	0 %	19.3 %	4.5 %	7.3 %	2.0 %
AP	0 %	19.9 %	4.5 %	7.3 %	2.0 %
EP	0 %	22.2 %	4.9 %	8.0 %	2.1 %
ADPE	0 %	18.8 %	4.3 %	7.2 %	2.1 %
ADPF	0 %	17.8 %	4.3 %	8.0 %	2.9 %
Water use	0 %	21.8 %	5.9 %	5.9 %	0.4 %

Discussion

The PAW and untreated scenarios were set to 50% of shelf-life related food waste. However, the accumulated food waste reduction in the untreated and PAW scenarios are estimated to 17 and 31% compared to todays practice. This means that food waste cannot be reduced by one single factor, e.g. shelf-life, even if this factor is highly uncertain.

The LCA results show that both PAW and untreated scenarios present slight to significant environmental benefits within the assessed environmental impact categories (Table 1). Even in the PAW sensitivity scenario, significant reduction potential was found (Table 1). Since each alternative scenario yielded reductions in all impact categories, no danger for problem shifting is assumed. The results show that there is a clear connection between avoided impacts and economic benefit for the two alternative spinach processing approaches. Thus, potential infrastructure investment and operation costs for PAW implementation might be partially or fully covered by the achieved food waste reduction.

Independently of the scenario, the GWP estimates in the present study are higher than the results reported by Seo et al. (2017) but lower than those found in Büsser et al. (2008). This has been attributed to differences in LCI datasets, age and representativity. In these studies, transport within distribution has been reported as a major factor for GWP, which was also confirmed in the present work.

In order to achieve more robust estimations, it is recommended to assess further scenarios and collect specific data for Norwegian fresh spinach production and specific fresh spinach wastage rates. Since it is difficult to document the effect of extended shelf-life as a quantitative reduction in food waste, semi-qualitative estimates have been used and more research is needed to close this knowledge gap. Novel processing technologies such as PAW may create skepticism among Norwegian consumers since they are typically unaware of their advantages/applicability, as well as the health consequences of unsafe products (Altintzoglou and Heide, 2020). Thus, Norwegian consumers might replace fresh spinach with other food products that may lead to increased spinach waste or reduced production.

Conclusions

Overall, the reference scenario has been demonstrated to cause the largest environmental impacts for a broad range of impact categories, as compared to the alternative PAW and untreated scenarios. PAW rinsing has shown the greatest potential to reduce environmental burdens caused by fresh spinach, as well as the most significant reduction in food waste related costs. No environmental problem shifting was identified by implementing the alternative processing approaches on fresh spinach. Further research is needed to establish a direct connection between shelf-life extension and food waste throughout the food value chain. More representative and updated food waste datasets are recommended for new studies on fresh spinach.

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Attributional and Consequential Life Cycle Assessment of Insect Production in Europe

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Abstract

Purpose

The lack of protein sources in several parts of the world is triggering the search for flexible and sustainable protein production technologies. Insect production in Europe is currently recognized as a potential solution. Production and processing of insect biomass remain at its early stages resulting in a diversity of production scales (small pilot to automated industrial). This study is aimed to define the potential of food and feed production and processing technologies transfer for the design of sustainable insect production chains. It includes the identification of production requirements of insect technology suitable to be applied in a variety of conditions and feeding sources.

Methods

Two insect species were considered as a case study (*Hermetia illucens* and *Tenebrio molitor*). The study is based on theoretical modelling approach with reliance on industrial data covering nineteen-month period (2015–2017) of *H. illucens* production and processing with measured variables of water use, feed inputs, electricity and heat consumption, production yields from an industrial producer (Protix, Dongen, The Netherlands). Production of *T. molitor* was modelled based on literature data. The design allowed for the economic analysis and Life cycle assessment (LCA) of insect-based technology applied for utilization of food and feed side streams. LCA was both attributional and consequential, IMPACT2002+ and IMPACT World methodologies are applied with ReCiPe used for sensitivity analysis.

Results and discussion

The results indicated that if attributional LCA rules are applied (feed is a free waste material with zero negative burden) both industrial and pilot scale technologies are impacting the environment in the range of 38.83-77.67 mPt (mPt – millipoint, 1 kPt is annual impact of one European person, IMPACT2002+ Methodology) with each tonne of feed material consumed. If substitution of conventional waste treatment technologies (composting, anaerobic digestion) is considered with related market effect through substitution of chicken meat, protein feed or fertilizer (consequential LCA approach) then industrial insect production results in positive environmental impact in the range of -155.34 to -233 mPt for each tonne of treated material.

Conclusions

Insect production technologies are economically and environmentally viable option to produce food and feed. The efficiency and level of impact depends on the scale of production, type of feed (waste vs. by-product, physical and chemical properties of feed), insect species. Further research for variations in insect species, production technologies and feed materials are required.

Keywords: *insects; alternative food; environmental impact; LCA.*

Introduction

Insects are considered as less environmentally impacting source of proteins than meat products. However, in certain cases their environmental impact might be in the range of impacts similar to chicken and pork products: nitrous oxide emissions (Oonincx 2017), land use (Smetana et al. 2016). However, the level of impact highly depends on the diet, production system and species, as some of them lead to the increased emissions compared to others (Oonincx 2017). Insects, containing high amounts of proteins, are also perceived as a potential substitute for meat (van Huis et al. 2013; Smetana et al. 2015, 2016).

The goal of this study is the assessment of the determinants of the environmental impacts of insect based intermediate products (usable for feed and food) and to provide guidance on how the industry should move forward to exploit the potential of insects to minimize its environmental impact with specific attention on the potential use of non-utilized biomass from food and feed industries. This study relies on a systemized dataset of *H. illucens* and *T. molitor* production. These data are analyzed by applying attributional (A-LCA) (identification of the optimal production and allocation between products) and consequential life cycle (C-LCA) assessment approaches for the definition of more sustainable options. The outcomes of the study indicate the most promising scenarios for sustainable insect production for food and feed producers, policy makers and scientists.

Material and methods

The assessment followed the standard LCA approach (ISO 14040 2006; ISO 14044 2006) and used professional SimaPro v8.2.0.0 software (PRé Consultants B.V., Amsterfoort, The Netherlands) and adapted ecoinvent 3.1 datasets (ecoinvent, Zurich, Switzerland) for background data (electricity and water supply, heat generation, etc.). The study also relied on integrative methodology for life cycle impact assessment: IMPACT2002+ (Jolliet et al. 2003) for most impact categories (IMPACT World+ Midpoint V0.04 for Water footprint after (Boulay et al. 2011)). Further results for the impacts were checked for the uncertainty (Monte Carlo simulation analysis with 1000 runs performed for mid-point and end-point categories) and integrated for the single score representation (IMPACT 2002+).

The A-LCA required the allocation of environmental impact between co-products at the stages of feed production, insect growing and harvesting. Economic allocation was applied unless otherwise mentioned. The main allocation factors based on the price of the final products followed the ratios of 3.08:1 fresh insects to fertilizer and 4:1 insect meal to fat with further adjustment according to the relative weight of the product. Waste treatment impacts were allocated to the products accordingly or avoided in relevant cases of C-LCA.

The C-LCA followed established practices (Weidema et al. 1999; Weidema 2000; Ekvall and Weidema 2004) to define the decisions between scenarios for: (1) application of protein-rich side-streams of food processing for insect diets (with increased demand for other protein feed sources); (2) potential reactions of the market to the increased production of insect meal as a source of feed and food proteins. Multifunctionality was dealt by the substitution method and only marginal suppliers were included within the system boundaries. The identification of marginal suppliers was based on the guidelines for stepwise market-based system delimitation (Weidema 2003), however, due to the lack of information for the future progress of insect-based products on the market, it was assumed that the average market producer of relevant products (feed for insects and insect products analogues) would be affected. Foreground and background system modelling were performed using the consequential approach described in the guidelines of ecoinvent (Weidema et al. 2013).

The study relied on cradle-to-gate LCA approach, and a few functional units (FU): 1 kg of dried and pelletized organic fertilizer; 1 kg of fresh biomass (puree); 1 kg of protein concentrated meal; and 1 kg of insect fat. C-LCA modelling was performed on the basis of a single product (fresh biomass or protein concentrate meal). It included increased demand on the market for three main scenarios: (1) market demand increase for fresh insect biomass as a substitute for fresh chicken meat; (2) for insect protein concentrate as a substitute for soybean meal and for fishmeal (3). Additionally, the sensitivity analysis for short-term (ST), mid-term (MT) and long-term (LT) were computed for HP and HM. It was assumed that HP substituted chicken meat on the market (HP_M), while HM avoided soy meal (HM_S) and fishmeal (HM_F) since they are both common protein sources in feed.

Results and Discussion

Production of insects was based on the side-streams (commercially available side-streams from the food industry - milling, alcohol production, potato processing and brewery) and food wastes. Allocating the food side-streams as co-products identified them as valuable biomass sources rather than as wastes. In Figure 1, A-LCA impact results are presented for *Hermetia* puree (HP) and *Hermetia* protein meal (HM). The greatest sources of impact in all categories were feed production and energy use.

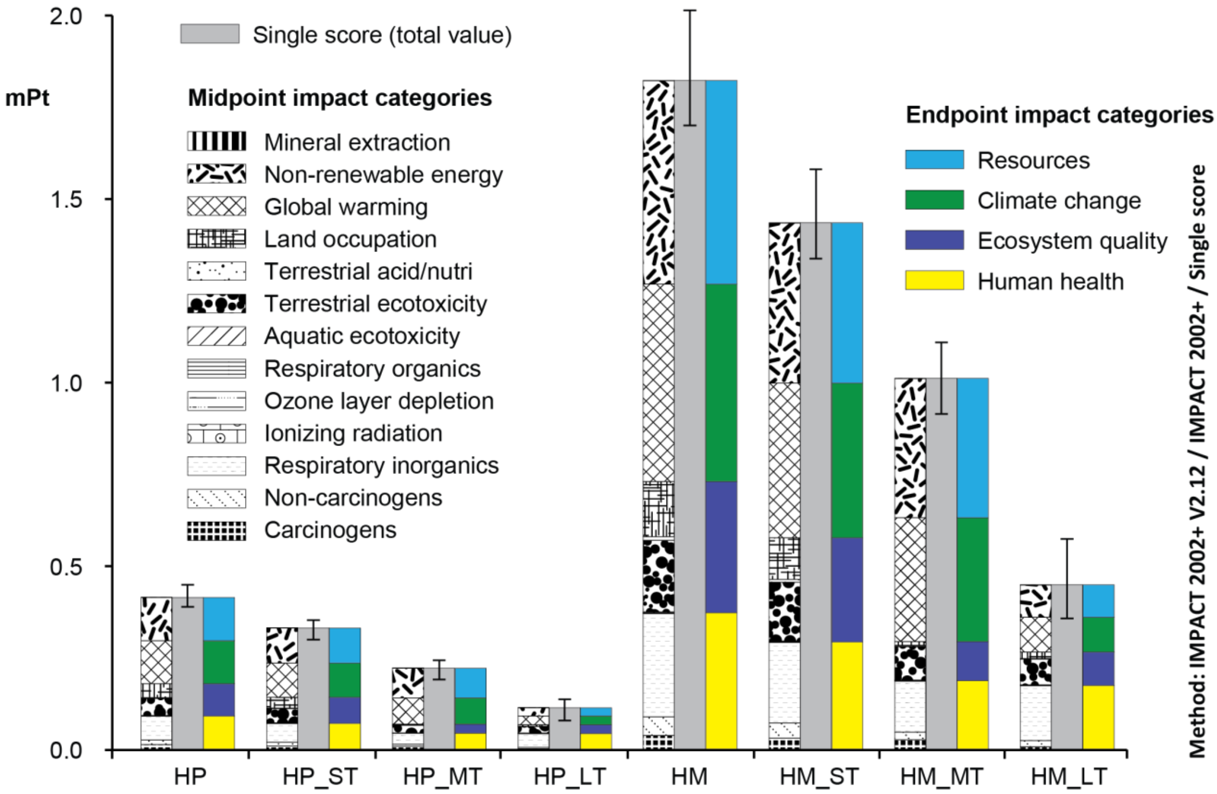

Fig. 1. Environmental impact of insect products (Smetana et al. 2019) (HP – *H. illucens* puree scenarios (fresh insect production); ST –25% feed conversion efficiency and energy use; MT – application of non-utilized side-streams; LT –energy supplied from renewable sources; HM – *H. illucens* meal (de-oiled protein concentrate) scenarios; Methodology IMPACT2002+, FU 1 kg of product, error bars – standard deviation; Pt – ecopoints, relative measure of environmental impact with 1 kPt equal to the annual impact of one European person).

Application of *T. molitor* for sidestreams and waste utilization, was limited due to the low-moisture diet requirement of the species. *H. illucens* on the other hand demonstrated wide range of application possibilities even in small mobile unit (Ites et al. 2020).
The C-LCA included the potential changes to the feed and food markets as a reaction to the changes caused by insect production. In addition to the baseline case, two sensitivity analyses were performed for HP and HM involving a transition to non-utilized side-streams as feed. Figure 2 displays the results of these analyses. *H. illucens* fertilizer caused the avoidance of organic fertilizer production (IF_F).

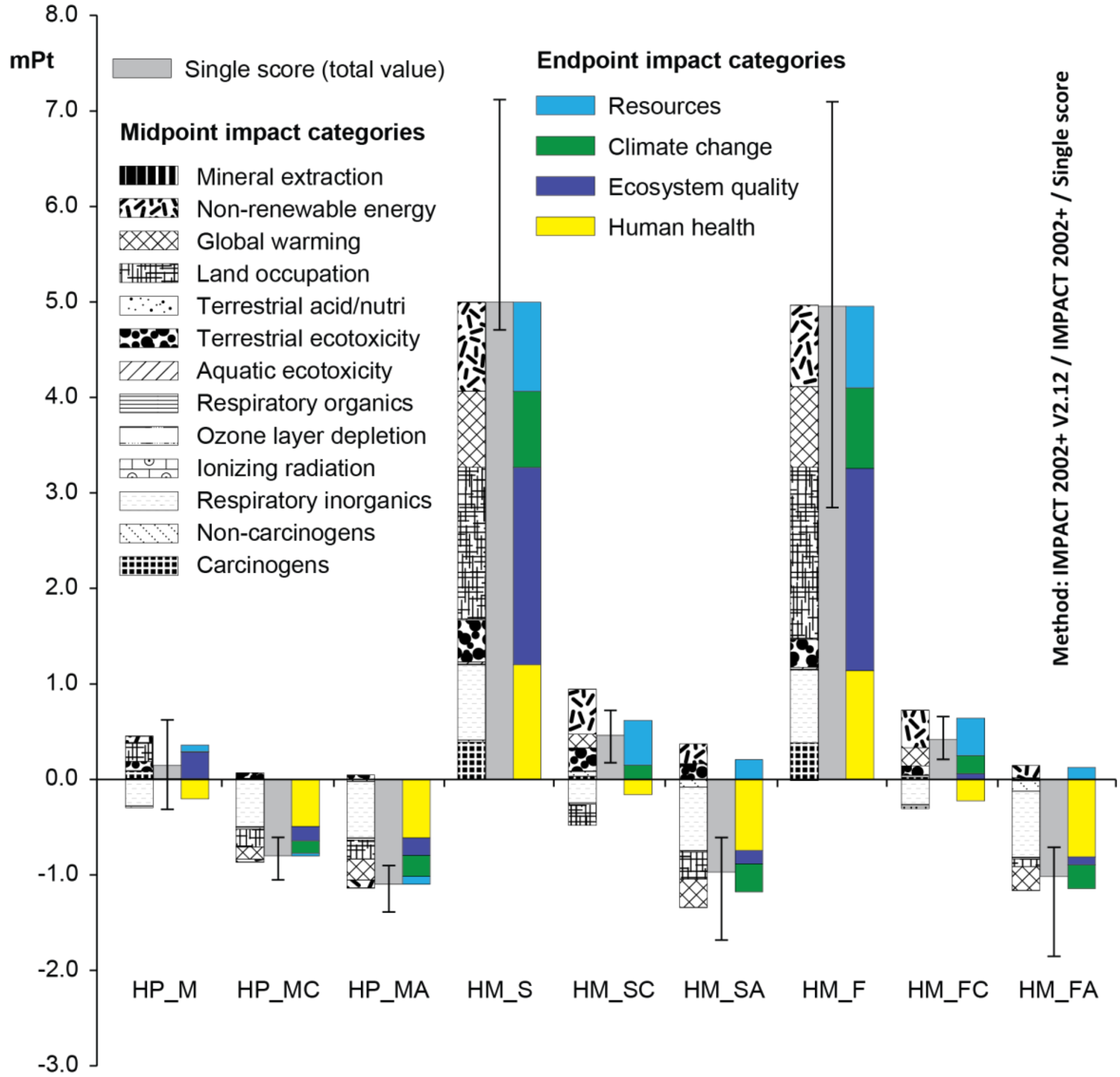

Fig. 2. Environmental impact of insect products with accounting of consequences of market changes (Smetana et al. 2019) (HP_M – *H. illucens* puree (fresh insect production) with chicken production (live weight) substituted; C –with avoided need to compost non-utilized side-streams used as feed for insects; A –with avoided need to treat non-utilized side-streams used as feed for insects (anaerobic digestion); HM_S – *H. illucens* meal (de-oiled protein concentrate) with soybean meal production substituted; HM_F – *H. illucens* meal (de-oiled protein concentrate) with fishmeal production substituted; Methodology IMPACT2002+, FU: increase in market demand for 1 kg of product with the substitution of alternative benchmark product, error bars – standard deviation; Pt – ecopoints, relative measure of environmental impact with 1 kPt equal to the annual impact of one European person).

Conclusions

Attributional LCA of a high productivity pilot industrial scale of *H. illucens* production indicated its lower environmental impacts than similar sources of animal biomass for food. The results of this study showed that current insect production offers the potential for more sustainable protein, fertilizer and lipid production. Fertilizer production, even at the pilot scale was more environmentally favorable compared to conventional organic fertilizer. Insect fats and proteins, if used in human food applications were environmentally preferable to many animal-based food sources, and on some impact types like water and land usage they were favorable to plant based proteins. However, to assure the environmental benefits expected from insects, the industry will need to consciously make

additional steps.
Upscaling of insect production (improved efficiency of feed conversion and processing) reduced environmental impact making *H. illucens* biomass competitive to feed protein sources. Further application of non-utilized side-streams or alternative sources of energy for processing will result in a more beneficial source of proteins than most known alternatives. A consequential LCA indicated that transforming organic residuals into *H. illucens* biomass results in lower environmental impacts than composting or anaerobic digestion.

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Insects to feed the future? A comprehensive perspective on mealworm as an alternative trout feed protein, using attributional and consequential approaches

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Abstract

Purpose With increasing stress on agricultural and natural systems that provide food, the race is on to find sustainable protein solutions. Yet, investigation of the environmental impacts of this growth are limited. This study focuses on the opportunity of using insects for animal feed. It aims to develop a representative Life Cycle Inventory (LCI) for mealworm and provides the assessments of the environmental impacts of using mealworm as trout feed on the global market.

Methods Two attributional and a consequential LCA were conducted to grasp mealworm environmental impacts in a comprehensive manner. The first attributional LCA was based on primary data from an insect growing and mealworm manufacturing company and the corresponding mealworm LCI dataset is compatible with *ecoinvent* and the World Food LCA Database. The functional unit (FU) of one kilogram of insect meal for trout. The second attributional LCA, with the FU of one kilogram of edible protein for humans, compared the impacts of animal meat produced using various feeds, including trout fed with mealworm. Finally, the consequential LCA was performed by extending the system and including the effects on the market, the FU being a projected annual production of insects' coproducts. Various environmental impacts indicators were considered.

Results and discussion Preliminary results per kilogram of mealworm suggest a global average of a carbon footprint of 7 kg CO2-eq, human health impacts of 9 DALY, ecosystem quality impacts of 17 PDF.m2.y, resource impacts of 90 MJ, and water consumption of 0.05 m3. A sensitivity study for France demonstrated results are mostly sensitive to the electricity mix and feed origin, meaning mealworm raised in France and fed with bran can have lower impacts compared to a global average (for all indicators except resources). The second LCA iteration shows a lower carbon footprint for one kilogram of trout protein that was produced using insect meal in comparison with one kilogram of proteins from other animal sources such as chicken, beef, eggs, pork and trout fed with conventional feed.

Conclusions The study provides a full picture of the environmental performance of insects' coproducts. First, the attributional LCA provides mealworm ecodesign levers such as a local production in France. Then, the comparison of edible protein for human reveals that insect feed has less impact than other protein sources. Finally, the consequential LCA provides a wider comprehension for a sustainable business development, highlighting a decrease of 32'332 tCO2-eq/year with the current projection of production levels.

Introduction

With a growing global population and increasing stress on agricultural and natural systems that provide food, the race is on to find sustainable protein solutions. Some stakeholders expect that insect protein could be a key solution as an alternative protein source for both animal feed and human food. The rapidly expanding insect market is expected to grow nearly tenfold between 2018 and 2029 and to achieve billion-dollar revenues. Yet, investigation of the impacts of this growth on the environment are limited. This study focuses on the opportunity of using insects for animal feed. It aims to develop a representative Life Cycle Inventory (LCI) for mealworm and provide the assessments of the environmental impacts of using mealworm as animal (trout) feed on the global market.

Material and methods

Primary data from an insect growing and mealworm manufacturing company were gathered to build a mealworm LCI dataset. The developed dataset is compatible with *ecoinvent* and the World Food LCA Database. LCI iterations were necessary, from 2015 to 2020, to integrate the rapidly evolving processes. Two attributional LCAs were performed to quantify the environmental impacts of mealworm production, both using 2018 LCI data. Both are based on 'small-scale' industry (up to 20t of insect meal per year). Conversely, the consequential LCA relies on 2019-2020 data coming from a 'large-scale' industry (over 20t of insect meal per year). *Ecoinvent* 3.4 has been used along these studies, and Impact 2002+ was considered as an aggregation method.

The first attributional LCA was designed to support insect meal production ecodesign. The functional unit is one kilogram of insect meal for animals. Economic allocation based on market prices data was used to split the impacts between the three products produced by the insect feed production plant: insect oil (Pet feed ingredient), meal (insect feed ingredient) and frass (Fertilizer).

The second attributional LCA compared the environmental impacts of animal products fed using various feeds (including trout fed with mealworm). It uses one kilogram of edible protein for humans (e.g. as trout or beef) as functional unit. The tables below reference the study relevant *ecoinvent* datasets (table 1) and main hypotheses (table 2).

	Dataset	Meat/alive weight ratio
Chicken	1 kg Chicken for slaughtering, live weight {GLO}| chicken production | Cut-off, U	0,62
Beef	1 kg Beef, fresh meat, at slaughterhouse (WFLDB 3.4)/GLO U	NA
Egg	1 kg Chicken egg, in barn single tiered, at farm (WFLDB 3.4)/GLO U (QLL18.1.0) (of project Quantis LCI Library)	NA
Pork	1 kg Pork, fresh meat, at slaughterhouse (WFLDB 3.4)/GLO	NA
Trout	1 kg Trout, from aquaculture {GLO}| market for trout, from aquaculture | Cut-off, U	0,78
Clean Fresh Larvae (CFL) - GLO	Mealworm clean fresh larvae, at plant (WFLDB 3.5)/GLO U	NA
Clean Fresh Larvae (CFL) - FR	Mealworm clean fresh larvae, at plant (WFLDB 3.5)/GLO U – Global electricity mix replaced by French electricity mix	NA

Table 1: LCA dataset used in the study

	Kg of protein/kg of meat	Source
Chicken	0,228	https://www.intechopen.com/books/meat-science-and-nutrition/nutritional-composition-of-meat
Beef	0,2	https://www.intechopen.com/books/meat-science-and-nutrition/nutritional-composition-of-meat
Egg	0,1258	https://fdc.nal.usda.gov/fdc-app.html#/food-details/173424/nutrients
Pork	0,181	https://www.intechopen.com/books/meat-science-and-nutrition/nutritional-composition-of-meat
Trout	0,2123	https://fdc.nal.usda.gov/fdc-app.html#/food-details/175181/nutrients
Clean Fresh Larvae (CFL) - (GLO)	0,187	Farine/CFL (1:4) ; 0,748 kg protéine/kg farine (https://www.mdpi.com/2076-2615/9/5/258/pdf)
Clean Fresh Larvae (CFL) - FR		

Table 2: Amount of protein per kilogram of meat and hypotheses source

Finally, a consequential LCA is being finalized to extend the system and to integrate effects on the market, in the scope of the analysis. This study is currently undergoing a critical review to validate its outcomes. As a first step, a market analysis of insect meal, oil and frass allowed to assess their prices and potential substitutes. Insect oil was assumed to influence the poultry fat market, insect frass mineral fertilization market and insect meal fishmeal market for trout feed production (50% and 100% as substitution rates for fishmeal were considered in mass).

Furthermore, trials made by an insect manufacturer showed that trout fed with insect meal have a higher survival rates than trouts fed with alternative feeds. A 50% substitution of fishmeal by insect meal leads to an increase of trout growth rate of 11%, and a 100% of 34%.

As a disruptive input for this study, soil carbon sequestration due to frass spreading on field was considered on rapeseed. This work is based on the C-sequ guidance to be published shortly (by Quantis as the technical lead, together with a consortium of seven dairy and beef companies). According to a study (Houben D 2020), rapeseed production using Frass instead of mineral fertilizer leads to an increase of 20% of the rapeseed yield.

Results

The first attributional LCA (with one kilogram of mealworm as functional unit) suggests a a global carbon footprint average of 7kg CO2-eq, human health impacts of 9 DALY, ecosystem quality impacts of 17 PDF.m2.y, resource impacts of 90 MJ, and water consumption of 0.05 m3.
A sensitivity study demonstrated that the results are mostly sensitive to the electricity mix and feed origin, meaning mealworm raised in France and fed with bran can have lower impacts (for all indicators except resources) compared to a global average.

The second attributional LCA iteration showed a lower carbon footprint for one kilogram of trout proteins that was produced using insect meal in comparison with one kilogram of proteins from other animal sources such as chicken, beef, eggs, pork and trout fed with conventional feed (figure 1).

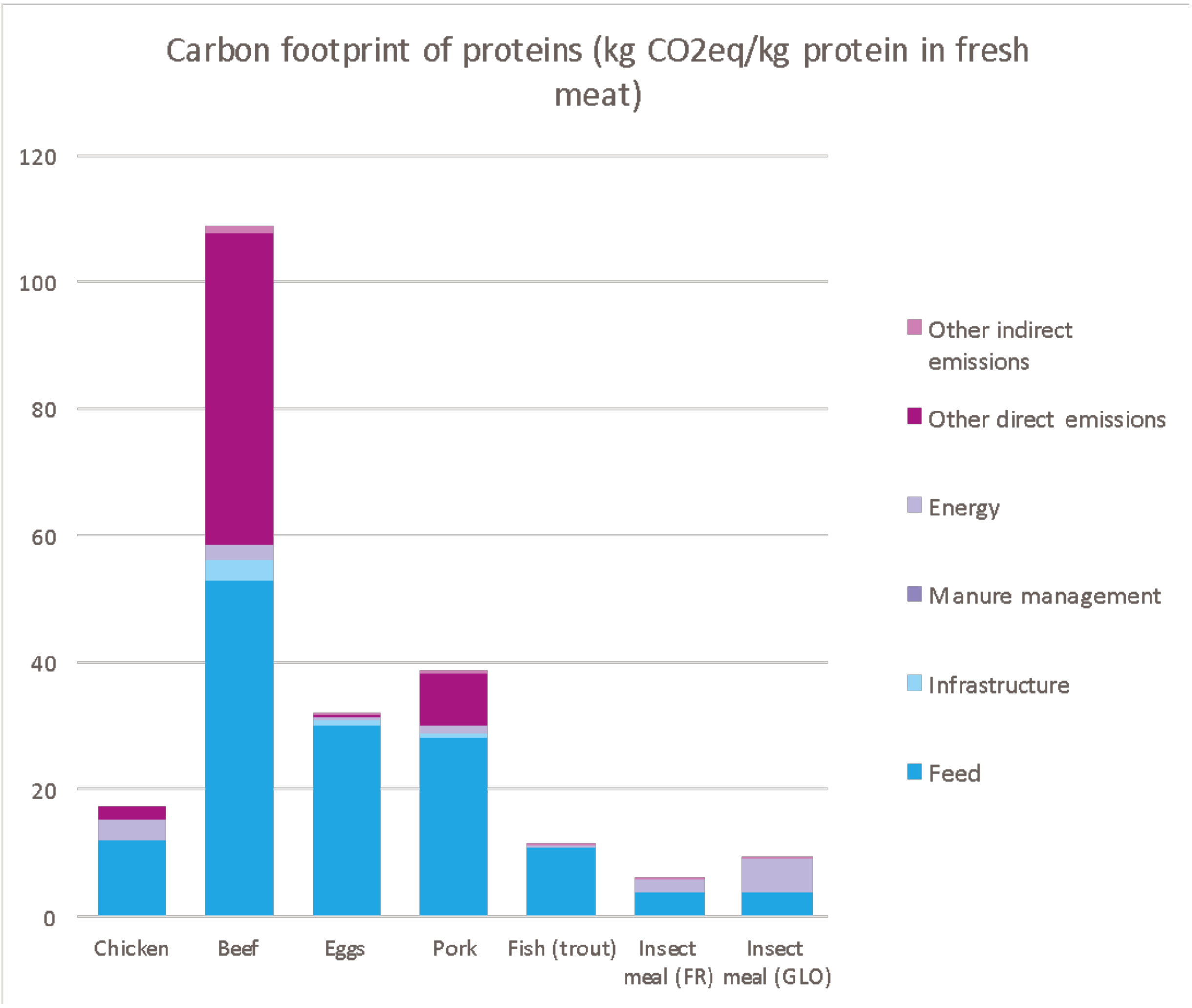

Figure 1. Comparison of total carbon footprint and contribution to the footprint for various proteins such as insect meal for France and a Global average in comparison to other average edible protein sources for human.

Consequential LCA:

The consequential LCA underpins the environmental and market dependency of key raw ingredients for the insect feed such as wheat bran and sunflower. The consumption of such raw materials by insect manufacturers taking into account the upscale of their activity may lead either to an increase of the current dedicated cultivation area or to a substitution for the other markets previously targeted, such as the animal feed one with other ingredients with higher environmental impacts. Moreover, As trout production market is growing rapidly, demand for trout feed is proportionally increasing. Being an efficient trout food ingredient, insect meal is fostering this trend. The insect feed production (sunflower and wheat) would increase as well, and the consequential LCA takes into account this potential market evolution, quantifying the total emissions. Figure 2 below presents the results.

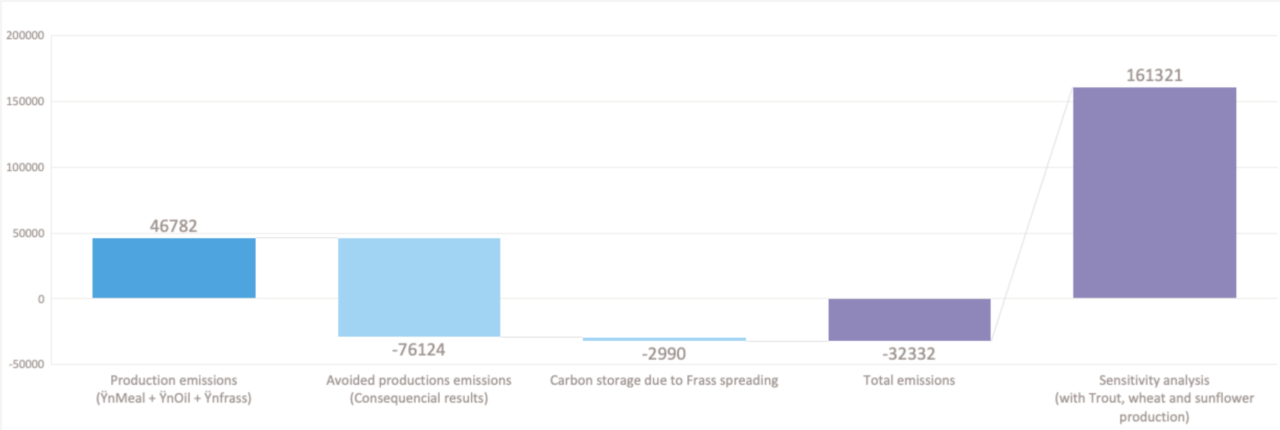

Figure 2: Consequential LCA results overview (t CO2-eq)

Including all the consequences and taking into account the GHG emissions linked to the production, the activities of the insect product plant leads to -32'332 t CO2-eq/year, i.e. a carbon storage, comparing to an attributional LCA of the production (46'782 t CO2-eq/year). This is mainly due to the increase of growth rate due to the insect meal introduction into trout feed (avoided emissions from the avoided production of fishmeal replaced by insect meal), and, to a lesser extent, to the soil carbon sequestration due to frass spreading on field indicates a sequestration of 2'990 t CO2-eq.

Finally, a sensitivity analysis demonstrates that if the expected trout, wheat and sunflower markets evolutions are considered, + 161 ktCO2-eq are emitted. However, this is not a very likely scenario and other consequential LCAs available in the literature do not take into account the fish production as the increasing production of trout corresponds to less than the expected trout market increase.

Discussion

Using a functional unit based on protein as human food for the second LCA provides interesting insight into the impacts of different protein sources. Protein is composed of various amino acids that can be bio-assimilated differently depending on many factors, thus having various biological functions when used as animal feed or human food. Furthermore, comparing different products as egg, beef and trout is difficult using protein as FU, since they provide very different amount of other critical nutrients. Therefore, future work can focus on using various functional units (e.g. amino acids, other nutrients, or a wider scope including specific diets or meals) to test the robustness of the results and to improve methods to assess insects' proteins as feed and food. A relevant scenario could be to evaluate the proteins based on a specific market need for example for a given protein type or mix for humans or animals.

Conclusions

The study provides a full picture of the environmental performance of insects' coproducts. First, the attributional LCA gives insights for a B2B perspective (mealworm sold to pet food manufacturers), providing mealworm ecodesign levers such as a local production in France. Then, the comparison of edible protein for human, incl. protein produced with insects, considers the final client perspective and reveals that insect feed as a protein source has less impact than other protein sources (In comparison with chicken or beef fed with alternative animal feeds). Finally, the consequential LCA provides the insects products manufacturer a wider comprehension for internal discussions, among which the orientation of the business model, highlights a decrease of 32'332 tCO2-eq/year with the current projection of production levels.

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The consistency of protein sources' environmental performance across LCI data sources and impact assessment methods?

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Abstract

Purpose

What protein source would be chosen as a feed ingredient according to environmental performance? Feed production is named the most influential environmental factor for land and sea based meat production, and the initial question is important. This paper therefore investigates if the selection of LCI database or of LCIA method will influence ranking and hence the choice of protein source.

Methods

A study of protein sources for animal feed was used as a case study to explore the new Environmental Footprint (EF) database and impact assessment method, compared to databases and impact assessment methods that are widely applied today. The EF database is compared to AGRIBALYSE, Agri-Footprint and ecoinvent, while the EF method is compared to the CML method for climate change, acidification, and eutrophication and the AWARE method for water scarcity. The comparison is based on an LCA of four different protein sources used for animal feed, in particular fish feed: soy meal, rape seed meal, fishmeal and single cell protein. The protein sources are ranked according to environmental performance, and the rankings produced for each LCI database and for each LCIA method are compared.

Results and discussion

Results show a few differences in the ranking of a set of different protein sources depending on the choice of LCI database and LCIA methods. Modelling soybean meal from Brazil with the EF database gives much higher potential impacts in the climate change category than do modelling of the same products with other LCI databases. Modelling rapeseed meal and fishmeal give more consistent results across databases. There was only one difference in ranking between the protein sources when results from different LCIA methods were compared, although differences in variations between protein sources were large between methods. The ranking was also different in all the different impact categories advocating some weighting approach.

Conclusions (maximum: 75 words) (+ recommendations, optional, maximum 75 words)

The EF database and impact assessment method gives similar results to other LCI databases and other LCIA methods when comparing the ranking of different protein sources modelled with different approaches. This is comforting for the use of the EF database for decisions of feed ingredients. The results do, however, show that ranking varies greatly across environmental impact categories, advocating help to decision makers who shall use the PEF system in the future.

Keywords: LCA; LCIA methods; LCI databases; protein; environmental performance; climate change

Introduction

The European commission is currently working to establish product environmental footprint (PEF) as a standard for comparing the environmental performance of products. This paper uses protein for animal feed as case to compare results for both 1) the proposed life cycle impact assessment (LCIA) method for PEF with earlier LCIA methods, and 2) the proposed life cycle inventory (LCI) database for PEF with similar data from other databases.

The system for making PEF studies is quite rigid, and it is of interest to investigate whether results for environmental performance are comparable across impact methods and data sources. In this paper, the environmental performance of protein products based on soybeans, fishmeal, rape seed and single cell protein (SCP) are compared across life cycle impact assessment methods and across sources for life cycle inventory data. Results from the comparisons will both shed light on the validity of the PEF method and contribute to explain potential differences between the protein sources. Protein sources as animal feed have often been shown to be the most important upstream contributor to environmental impacts from meat production. The case is therefore of global relevance.

Material and methods

An LCA study of various protein sources was conducted in connection to the H2020 project SYLFEED. The SYLFEED project is concerned with protein sources in feed for aquaculture. Four main groups of proteins, with adjustments, are analyzed; soymeal, rapeseed meal, fishmeal, and single cell protein (SCP). In this paper, the LCA was performed with LCI data from the EF database (European Commission 2020) and compared to the use of LCI data from ecoinvent *cut-off by classification* v.3.6 (Wernet et al. 2016), AGRIBALYSE and Agri-footprint (Durlinger B, et al., 2017). Due to the nature of system processes in the EF database, results for the single cell protein SylPro® made from wood was impossible to reproduce, and this was only possible to include in the comparison of results from different impact assessment methods. The assessment was first performed with the LCIA methods (described by Fazio et al. 2018) as spelled out in the product environmental footprint category rules (PEFCR) for feed for food-producing animals (FEFAC 2018). Results were then compared with results from CML IA baseline v 3.05 (Guinee et al. 2001) for climate change, acidification, and eutrophication, and from AWARE for water scarcity. SimaPro Developer v.9.1 was used for modelling and calculation, and all methods and databases were applied as implemented in this software package.

The comparison of the LCI databases is based on the selection of processes from each database that were judged to be comparable to the extent of being similar enough to be substitutable when selecting proxy processes in a practical LCA modelling case. Results from modelling with feed data from LCI databases AGRIBALYSE v.1.3, Agri-Footprint v.3.0 (Durlinger et al. 2017), ecoinvent v.3.6 (Wernet et al. 2016) and Environmental Footprint (Fazio et al. 2018) were compared using the LCIA method EF Method 3.0 (JRC 2019). Relevant feed processes judged to be sufficiently similar to each other were selected for comparison. For the sake of simplicity only potential contribution to climate change is shown when comparing results from modelling with different LCI databases. For both comparisons between LCI databases and between LCIA methods, results are modelled cradle-to-gate, with the reference unit of 1 kg protein. The EF LCIA method v.3.0 as implemented in SimaPro Developer v.9.1 was applied for the impact assessment comparison.

Results

Comparisons of results from different databases

The comparison between LCI databases is illustrated by potential climate change results, as shown in Table 1. Intervals have been used where one feed process could not be singled out as more relevant for the comparison.

Table 1 Potential contribution to climate change (kg CO2-eq) per 1 kg of selected protein sources from different LCI databases.

Protein	AGRIBALYSE		Agri-Footprint		ecoinvent, cut-off		EF	
	kg CO2	Rank	kg CO2	Rank	kg CO2	Rank	kg CO2	Rank
Meal, rapeseed, Europe*	0.3	4	0.6	4	0.5	4	0.6	4
Meal, soybean, Min – Max	0.4-1.8	1	0.5-5.3	1	0.4-3.4	1	2.1-4.2	2
Meal, soybean, Brazil**	1.3	2	2.1	2	2.2	2	4.2	1
Meal, fish, Peru***	1.2	3	1.4	3	0.9-1.4	3	1.4	3

*Region France used for Agri-Footprint and AGRIBALYSE, Europe without Switzerland for ecoinvent and EF
** Average AGRIBALYSE data used; "deforestation" option gives higher emissions, non-deforestation lower emissions
***ecoinvent gives a choice of processes from different sources.

There are some discrepancies between the results from the different databases. For rapeseed and fishmeal, results are similar regardless of the database. Soybean, on the other hand, shows rather large differences, both for soybean from Brazil and for soybean meal produced in other locations. However, for the general soybean meal, the differences are also large within the same database.
In most instances, soybean meal shows a much higher impact in the climate change category when modelled with Environmental Footprint (EF) processes than any of the other databases. For all the analyzed databases, the ranking with regard to contribution to climate change is nevertheless the same when the min and max values of soybean meal is disregarded: European rapeseed meal is associated with lower greenhouse gas emissions than Peruvian fish meal, which in turn has lower emissions than Brazilian soybean meal.

Comparison of results from different LCIA methods
The comparison of results across impact assessment methods is given in relative numbers as the ranking of products between different LCIA methods is the important issue. Different LCIA methods often use different units and different reference compounds, but when they aspire to depict the same environmental issue, they should ideally produce the same ranking between an identical set of products. We compare four protein sources per kg protein. The protein source with the highest impact in each impact category and method is assigned a score of 100%. The protein sources are also ranked and the protein source with the highest impact is ranked as number 1, the second highest impact is ranked as number 2 and so forth. This is shown in Table 2. For water scarcity, AWARE is used because CML does not support impact assessment for this category.

Table 2 Comparison of LCIA methods. The relative impact per kg protein are shown for four impact categories and two (three) impact assessment methods. The protein sources with the highest impact is assigned a score of 100%. The protein sources are ranked according to their impact, the highest impact protein source is ranked as no. 1, the second highest impact is ranked as no. 2 and so forth.

	Climate change				**Acidification**				**Eutrophication**				**Water scarcity**			
	CML		**EF**		**CML**		**EF[1]**		**CML**		**EF[2]**		**AWARE v1.01**		**EF**	
Protein	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**	**%**	**Rank**
Rapeseed meal	20 %	4	21 %	4	49 %	3	50 %	3	73 %	3	19 %	3	24 %	2	23 %	2
Soyprotein	100 %	1	100 %	1	40 %	4	35 %	4	100 %	1	66 %	2	7 %	4	7 %	4
Fish meal	30 %	3	29 %	3	100 %	1	100 %	1	39 %	4	14 %	4	7 %	3	10 %	3
SCP	67 %	2	67 %	2	60 %	2	53 %	2	79 %	2	100 %	1	100 %	1	100 %	1

1 Terrestrial and freshwater
2 Freshwater

As we see in Table 2, the ranking of protein sources with respect to impact, vary for the two studied LCIA methods when looking at the impact category Eutrophication. Soy protein and SCP change places while the variation in results is much smaller for the CML method than for the EF method. For the other impact categories, the internal ranking remains the same. The results do show, however, that the ranking varies across the different environmental impact categories.

Discussion

Comparison of results across LCI databases

The comparison of feed data between different databases is contingent on the LCA modelling that was employed by the respective databases. Several issues can be thought to influence the figures, such as differences in system boundaries, allocation (e.g. physical vs. economic) and geographic and temporal relevance between the databases. In addition, the databases may have different sources for their data and reflect variations in the existing industry. Even though the comparison is based on a given amount of protein, the quality of the protein and the content of other nutrients might differ. Due to the lack of unambiguously phrased, consistent and complete documentation of several of the database processes, these issues are unfortunately difficult to compare across databases.

Results for modelling of soymeal shows large variations in all the compared databases, implying that it might be just as important to choose the right process (or production location) as the right database. Particularly for soymeal production from Brazil, the results show substantial variation between the databases. Results for climate change with soymeal modelled with data from the EF database are higher than when modelled with data from the other databases, in fact more than three times higher than for AGRIBALYSE. As Brazilian soy is an important source of feed, this indicates an inherent uncertainty in the carbon footprint of many existing land and sea based meat products. Due to the relative opaqueness of the databases, it is difficult to explore the causes. Even when employing the "associated to deforestation" option of the AGRIBALYSE database, which yields a higher GWP result (1.7 kg CO_2-eq/kg) this is still lower than for the other databases. For European rapeseed meal there are some differences in results between databases, but much smaller. For Peruvian fish meal the results are more similar between the databases. In general terms, it is plausible that discrepancies between the "industry standard" ecoinvent database and the new EF database as demonstrated above becomes an important issue in the LCA discourse. The transparency of each database needs to be improved in order for such challenges to be resolved.

Comparison of results across impact assessment methods

Despite differences between the impact assessment methods, one should expect that the ranking between the protein sources would be stable. This is the case for most of the investigated impact categories. For eutrophication, however, the internal ranking changes. In addition, the relative result for the protein sources also vary. For rape seed meal, CML gives an impact that is 73% of the impact for soymeal, while the same percentage in the EF-method is 19%. For rape seed, transport to the fish feed factory contributes to 14% of the eutrophication potential in the EF-method, while direct emissions to water and air are the largest contributor. With the CML-method, the transportation impact on eutrophication is less than 5%. A contribution analysis shows that for potential acidification impacts, even though the ranking between the protein sources is identical between the LCIA methods, there are great differences in what contributes to the result. For soymeal, the CML-method assigns almost all the contribution to the transport of soybeans, while according to the EF-method only ~33% of the impact is due to the same transport. Here the dominating process is direct emissions from the agricultural process, in addition to a small contribution from glyphosate and energy in agriculture.

One of the great advantages of LCA is that, by investigating several impact categories at the same time, one can avoid problem shifting. In this study the impact categories Land Use and Respiratory Inorganics have also been analyzed, but these were difficult to compare with impact categories from other LCIA methods. For Land Use, soymeal has the highest ranking (i.e. highest impact), followed by rapeseed, SCP and fishmeal. For Respiratory Inorganics, fish meal has the highest ranking, followed by SCP, rapeseed and soymeal. One of the things to notice is that the internal ranking of the protein sources varies within all the studied environmental impact categories. This calls for some sort of weighting for a decision maker to choose the environmentally appropriate protein feed ingredient to use.

In the same way as LCI databases yields different results, also the impact assessment yields different results and, thus, different ranking between feed ingredients and this must be considered when performing an LCA.

Conclusions

The analyses performed in this paper shows relatively small variations in the ranking of environmental performance of selected protein sources both when different LCI databases are used for the modelling of their life cycles and when different LCIA methods are used for the environmental assessment. This is comforting for the choice of different protein sources.

Whether the differences in results between the databases highlighted in this paper can be mitigated through harmonization, or whether they reflect uncertainty or actual industry variation, should be analyzed through future research. Environmental impacts connected to soybean meal production should perhaps be particularly carefully investigated to possibly resolve the big variations. Although the conclusion might be that there is rather a lack of variation for other protein source product life cycles because too few production routes have been investigated.

LCIA methods that purportedly assess the same indicator are not always directly comparable due to fundamental differences in goal, scope and methodology. Strong harmonization of LCIA methods such as the recommendations of Fazio et al. (2018) may be useful, but may also conceal the inherent variability of the fundamental assumptions of different methods. As a consequence, LCA modelling with the use of several impact assessment methods may be considered by practitioners. The example case showed this to be particularly relevant for the eutrophication category as both the ranking and the variation shifted from the CML to the EF method. The use of several LCIA methods may allow the attainment of more nuanced and cautious conclusions from the LCA study in question.

Results in this study showed different ranking between protein sources across different environmental impact categories. This means that a decision maker choosing the protein ingredients to make feed will have to make implicit or explicit weighting between different categories. When Product Environmental Footprints are starting to be applied, it will be interesting to follow how users are informed about, and how they handle, such issues.

There will always be uncertainty whether LCA studies are able to capture the right impacts within the most relevant categories. For instance, the Land Use category in the EF method should perhaps be a good proxy for biodiversity in future assessments, with its purpose to capture possible impacts to soil quality. As for now, the input data, and the method framework do not seem to allow sophisticated analyses and should be further researched.

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LCA as Decision Support Tool for Sustainable Protein Food: R&D Case Studies

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Abstract

Global food production is the largest pressure caused by humans on Earth, threatening local ecosystems and the stability of the overall system. This is demonstrated impressively by the planetary boundaries model. As such, providing a growing global population with healthy diets from sustainable food systems is an immediate challenge. Alternative protein sources and more resource-efficient production systems are urgently needed to meet the (growing) protein demand. This requires innovative, holistic approaches along the entire value chain as well as tools to evaluate and support the progress within research, development and production. The methodology of Life Cycle Assessment (LCA) offers a well-established and standardized approach to deal with the quantification of impacts through the entire life cycle of a product or service in various industrial domains. This study presents two LCA case studies on novel approaches in the food chain, which are targeted at implementing the valorization and upcycling of waste and side-streams, respectively.

Case study I deals with the development of insect-based fish feed for aquacultured systems as a sustainable alternative to conventional fish feed, whose production is associated with high resource use and negative environmental impacts. By reducing the share of fish protein in favor of insect proteins in combination with vegetable feed components, the environmental burden of fish feed could be significantly reduced. The presented LCA study focuses specifically on the production of fish feed from *Hermetia Illucens* larvae and *Lemna Minor*, for which an inline recirculating aquaponics model for urban sites was developed, optimized and scaled-up, which efficiently combines waste and environmental service concepts into one production system. At the same time, this value chain produces high-quality, market-accessible raw materials for the food industry.

Case study II looks at the sustainable development and production of plant-based protein food. The increasing demand for food proteins can be met by utilization of proteins from alternative and new sources which includes under-explored legumes and protein crops and fungi as well as side streams from food processing. In this context, Smart Protein, a new Horizon 2020 project funded by the European Commission, will develop protein products from plants (including fava beans, lentils, chickpeas and quinoa), but also strongly focus on the utilization of byproducts and residues, ingredients that are usually used for animal feed. Microbial biomass proteins will be created from edible fungi by up-cycling side streams from pasta (pasta residues), bread (bread crusts) and beer (spent yeast and malting rootlets).

Keywords: *insects; sustainability; fish feed; protein food; circular economy*

Introduction

Worldwide food production is the biggest burden brought by people on Earth, putting in danger the local biological system and the balance of overall system. This is shown amazingly on planetary boundaries model (Rockström et al., 2009). The agricultural and food sectors are globally responsible for the exceedance of approx. 50% of all boundary categories considered. Excessive nutrient inputs to terrestrial and aquatic ecosystems mean that the nitrogen and phosphorus cycles are of the greatest importance, followed by excessive land-use change and biodiversity loss caused by agriculture and food (Meier, 2017).

Herein, two projects on novel approaches in the food chain are introduced, which are targeted at implementing the valorization and upcycling of waste and side-streams, respectively. In both studies, LCA is used as decision support tool accompanying R&D activities in order to launch environmentally sustainable products.

Methodology

The general framework of International Standards Organization (ISO 14040 and 14044) are followed in this study. LCA as a methodology is aimed at analyzing the ecological aspects and potential impacts associated with a service or a product by compiling the input-output inventory of the process, calculating environmental burdens associated with those input-output and finally interpreting the results of impact assessment corresponding to the aim of the study. Life Cycle Assessment has been used extensively for several years in order to assess agricultural systems, food processing and manufacturing activities, and to compare alternatives (Smetana et al., 2020; Kralisch et al., 2018; Kralisch and Ott, 2017; Ott et al., 2014).

Case Study I

Fish and meat production and processing will grow drastically in the coming decades. The importance of the impacts of agricultural practices on water and land use, climate change and environmental degradation, such as eutrophication or terrestrial and marine acidification, is well acknowledged and has been exhibited by many studies. In this context, within the last years, insects are repeatedly discussed as a future-oriented, sustainable source of protein for food industry, as the ecological, economic, physiological and ethical advantages outweigh those of meat (Rodríguez-Miranda et al., 2019; Zielińska et al., 2018; Rumpold and Schlüter, 2015; Kim et al., 2019).

In aquacultured systems, insects are also gaining interest as feed to provide a sustainable alternative to the fishmeal paradox, whose production leads to a high consumption of resources and negative environmental impacts. Reducing the proportion of fish protein in favor of insect proteins in combination with vegetable feed components could significantly reduce environmental burdens. Within the scope of the project discussed herein, the production of fish feed from *Hermetia Illucens* larvae and *Lemna Minor* in an inline recirculating aquaponics model for urban sites was developed, optimized and scales up, which efficiently combines waste and environmental service concepts in one production system at the same time, the value chain produces high-quality, market-accessible raw materials for the food industry. Figure 1 shows the system boundary considered for the LCA study.

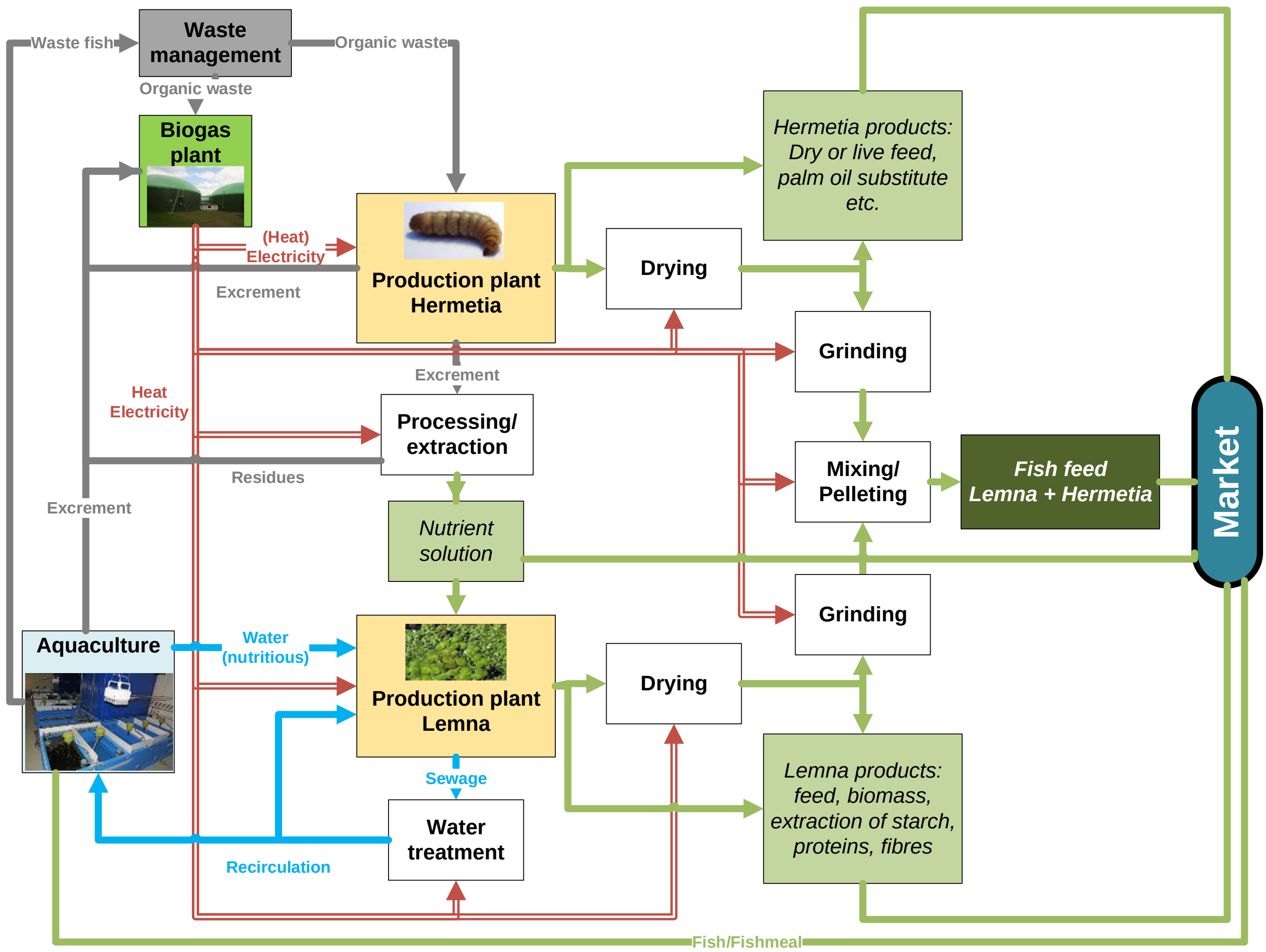

Figure 1: Production scheme of case study I

On the one hand, we could identify main ecological drivers of *Lemna* and *Hermetia* rearing. Various studies on the environmental assessment of insect breeding prove the high ecological influence of feed and energy consumption. If using vegetable peel residues approved as animal feed as well as excessive heat produced from the biogas plant which is coupled to the insect production plant, more than 70% of the environmental burdens (w.r.t. climate change, water footprint, land use and primary energy demand) can be saved. On the other hand, the production of *Lemna* resulted in significantly higher ecological impacts, which need to be overcome in future R&D and scale-up activities. Nonetheless, from an environmental point of view, the pellets produced from *Lemna* and *Hermetia* are already ecologically comparable to standard fish feed, see Figure 2, showing the comparison of environmental impacts between different pellet composition (Pellet 1-3) and a standard fish feed, i.e. tilapia feed as reference. So far, Pellet 2 shows the promising results in terms of nutritional content and pellet formation/stabilization. Currently, tilapia feeding trials are still running and the performance of this alternative fish feed, i.e., acceptance, health and growth of fish, muscle protein content etc. needs to be considered finally to come up with a holistic statement and roadmap for further research needs.

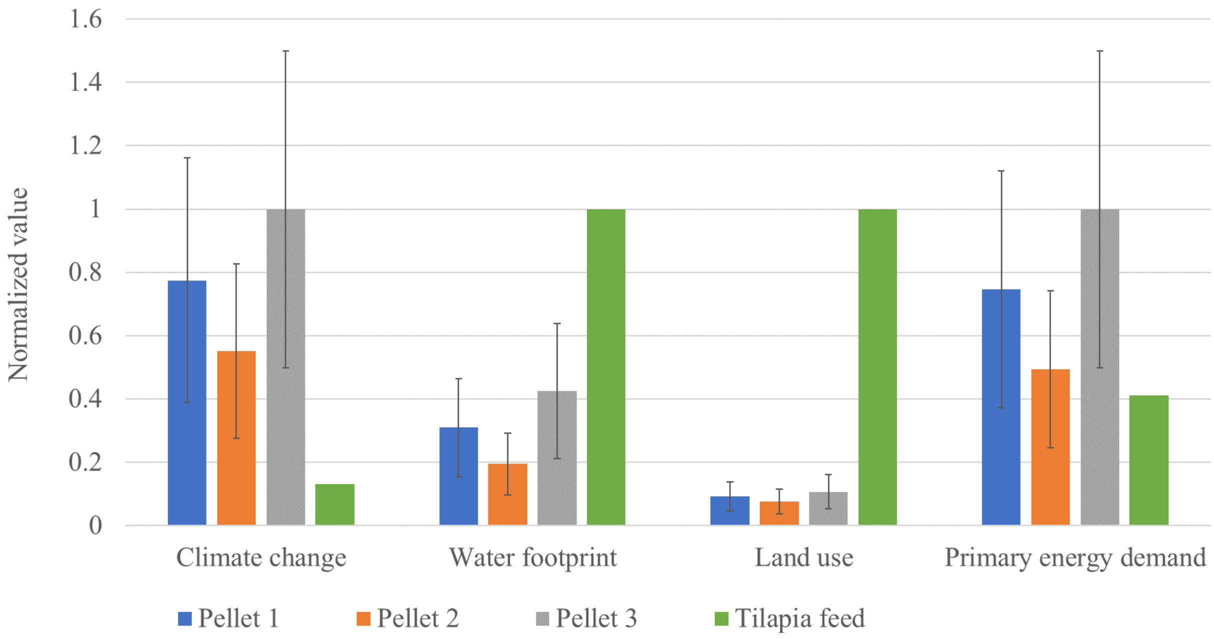

Figure 2: Relative comparison of environmental impacts to produce 1 kg pellets. Lemna/Hermetia composition (w/w): Pellet 1 – 50/50, Pellet 2 – 30/70, Pellet 3 – 70/30. Error bars indicate the impact of ± 50% performance compared to standard feed.

Case Study II

Animal-derived protein contributes significantly to the production of greenhouse gases, intensifies pressure on land use, and can have negative health consequences (Godfray et al., 2018; Song et al., 2016). In the EU, two-thirds of agricultural land is already in use to produce livestock, either for feed production or grazing, with increasing competitive pressure from feedstock demand for non-food applications such as biofuels. The increasing demand for food proteins can be met by utilization of proteins from alternative and new sources which includes under-explored legumes and protein crops and fungi as well as side streams from food processing.

Within the EU-funded project "Smart Protein", protein products will be developed from plants, including fava beans, lentils, chickpeas, and quinoa. The focus remains on improving their structure, taste, flavor, and also on the upcycling of by-products and residues – ingredients that are usually used for animal feed. The value chain study presented herein considers the use of brewer spent yeast for mushroom cultivation and microbial biomass protein production. More than 70% of the impacts in the brewery process (w.r.t. climate change, water footprint, land use and primary energy demand) are associated with the raw material supply. If using resulting side streams for mushroom cultivation, the environmental impacts of lignocellulosic biomass supply could be avoided. This biomass is used for solid state fermentation technology (SSF), on which the mushroom cultivation process is mainly based on.

Conclusions

LCA serves as an important decision support tool in R&D: it helps to identify main ecological drivers, to give recommendations for further development activities and to compare to benchmarks in order to reduce ecological burden and explore environmentally friendly products. The case studies herein highlight the importance of innovative and circular economy thinking and contribute to close loops to face our future challenges in food security and simultaneously to reduce ecological impacts.

As in case study 1and 2, the waste or side-stream from a process could be utilized as a resource for another process. This is an essential challenge of future food systems as more focus is given on valorization of waste or side-streams of food industry. The effective utilization of these not only helps to reduce the environmental burden of the product but also helps to achieve circular economy. An efficient food system or value chain is the need of the hour when more than one-third of the food generated gets wasted or lost.

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Topic 8:
Agri-Food,
Dietary and Nutritional LCA

Abstract code: 57

Multi-dimension evaluation of dietary sustainability with a case study for Switzerland

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Abstract

Problem and Aim
Dietary change works as a demand side intervention, and can greatly contribute towards the achievement of 2030 national Sustainable Development Goals (SDGs). However, most previous studies analysing the consequences of dietary change focus on a single dimension of sustainability (e.g., environment) using a limited number of indicators and dietary scenarios. A multi-dimension evaluation with various quantitative indicators can assess the potential trade-offs for transition to alternative diets.

Methods
Here we first designed nine alternative dietary scenarios (healthy Swiss diet, healthy global diet, vegetarian, vegan, pescatarian, flexitarian, protein-oriented and meat-oriented diets, and a food greenhouse gas tax diet) based on current (year 2011) food consumption data. Next we calculated five environmental (greenhouse gas emission, water, land, nitrogen and phosphorus use), three nutritional (nutrient balance score, disqualifying nutrient score, percent population with adequate nutrition), one economic (daily food expenditure) and one human health indicator (DALYs) for current and alternative diets.

Results
Transition towards a healthy diet following the guidelines of Swiss society of nutrition is estimated to be the most sustainable option and is projected to result in 36% lesser environmental footprint, 33% lesser expenditure and 2.67% lower adverse health outcome (DALYs) compared with the current diet of Switzerland. On the other extreme, transition towards a meat or protein oriented diet can lead to large increases in diet related adverse health outcomes, environmental footprint, daily food expenditure and a reduction in intakes of essential nutrients (for Vitamin C, Fibre, Potassium and Calcium). We found that shifting to the vegetarian and vegan diet scenarios might lead to a reduction in intakes of certain micronutrients currently supplied primarily by animal-sourced foods (Vitamin B12, Choline and Calcium). Our results show that achieving a sustainable diet would entail a high reduction in the intake of meat and vegetable oils and a moderate reduction in cereals, roots and fish products and at the same time increased intake of legumes, nuts, seeds, fruits and vegetables.

Interpretation
Our analysis underscores the need to consider multiple indicators while assessing the dietary sustainability and provides a template to conduct such studies in other countries and settings, and identifies several data and research gaps that need to be filled through future efforts in order to get more accurate results. Future efforts should focus on assessing the potential of different interventions and policies that can help transition the population from current to sustainable dietary patterns.

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Considering both nutritional content and environmental impact in food product development

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Abstract

Purpose Future-proof food products provide a high level of the right nutrients, in the context of the diet, while having a low impact on the environment. The Sustainable Nutrition Balance (SNB score), a metric which is calculated using an optimization algorithm, guides product development in the direction of future healthy and sustainable diets. We calculated the SNB-score for over 170 products, serving as a benchmark for innovative product design.
Methods We used quadratic optimization to define the SNB score. Data for food consumption, nutritional properties of food products and nutritional requirements of a healthy diet originate from the European Food Safety Authority (EFSA). We compiled an average EU diet (173 food products). Life Cycle Assessment (LCA) was used to determine the environmental impact of the products in the diet. The amount of each product in the diet is varied in steps and optimized for nutritional constraints. The SNB score is the linear relationship between the sustainability indicator (e.g. carbon footprint) of the diet and the product quantity. A future-proof product has a lower SNB score.
Results and discussion Meat products, especially lamb and beef, have a high SNB-score (0.8 and 0.4 respectively); providing little relevant nutrients relative to their environmental impact. Nuts and oil seeds, like walnuts and sunflower seeds, have a low SNB-score (-0.11 and -0.17 respectively); higher consumption, at the cost of other products, lowers the environmental impact of the diet. Liquid dairy products, like milk and yoghurt, have an SNB-score close to 0 (both +/- 0.005); substitution of the nutrients in dairy products with products that have a lower environmental impact is difficult. The SNB-score of composite foods vary greatly (0.20 to -0.05). The trendline, used to calculate the linear relationship between the sustainability indicator of the diet and the product quantity, tends not to be fully linear.
Conclusions The SNB-score is a useful tool to guide the development of food products and innovations to be more future-proof in terms of health and sustainability. The challenge is to lower the SNB-score. This can be done by reducing 'negative' nutrients (e.g. salt and saturated fat), improving beneficial nutrients (e.g. dietary fiber and vitamin D) or reducing environmental impact by altering the recipe or reducing use of resources in processing.

Keywords: Sustainable products; nutrition; sustainable nutrition balance, carbon footprint

Introduction

The world's food system faces a great balancing act (World Resources Institute (Searchinger & et al., 2013). By 2050 it must feed around 10 billion people (United Nations Department of Economic and Social Affairs Population Division, 2017) in a more sustainable way: without increasing the area of agricultural land, using less natural resources and, very importantly, emitting less greenhouse gases. In addition, diets should be healthier and meet human nutritional needs. They should prevent both malnutrition and non-communicable diseases, like obesity and cardiovascular disease.

A main challenge for all food and beverage producing companies is to become future-proof with respect to health, environmental and other sustainability concerns. The increasing pressure of our food system on the environment calls for innovative food product development (Broekema et al., 2020). Food product development needs to consider the health of people as well as the pressure on planetary boundaries (Willett et al., 2019).

Future-proof products provide a high level of the right nutrients, in the context of the diet, while having a lower impact on the environment than other products in the diet that could deliver these nutrients. The Sustainable Nutrition Balance (SNB score), a metric which is calculated using an optimization algorithm, guides product development in the direction of future healthy and sustainable diets. We calculated the SNB-score for over 170 food products, serving as a benchmark for innovative product design.

Material and methods

We used quadratic optimization to define the SNB score of over 170 products, in the context of the average European diet. Computations were implemented using Optimeal® 3.0, a software package developed by Blonk Consultants in cooperation with the Netherlands Nutrition Centre (Blonk Consultants, 2019). Optimeal was used before defining sustainable diets for UK (WWF, 2017) and the Netherlands (Kramer & Blonk, 2015).

The starting point of the analysis was a European reference diet. It is based on Food Consumption Surveys. The diet is constructed for doing environmental oriented optimizations with a synoptic and limited set of products. To derive the European reference diet the EFSA Comprehensive European Food Consumption Database (EFSA, 2018a) was used. This is a source of information on food consumption across Europe and contains detailed data for many European countries. The European reference diet is an average diet over all age categories, activity levels and genders and is composed of 173 products (out of 4000+ products). The construction of the European reference diet is explained in a separate report (Blonk Consultants, 2019).

The optimization is defined by nutritional constraints which determine if a diet can be considered healthy or "nutritionally sound". If the nutrition provided by the sum of the individual products which we call the diet falls outside of one of the boundaries, it will be corrected during the optimization to fit to the nutritional constraints. Two reports of EFSA substantiate the nutritional constraints for the EU: Dietary Reference Values for Nutrients (EFSA, 2017) and Tolerable Upper Intake Values for Vitamins and Minerals (EFSA, 2006). Dietary Reference Values (DRVs) is the umbrella term for the complete set of nutrient reference values which include population reference intakes (PRIs), the average requirements (ARs), adequate intakes (AIs) and reference intake (RIs) ranges for macronutrients. These values indicate the amount of a nutrient which must be consumed on a regular basis to maintain health in an otherwise healthy individual (or population) (EFSA, 2017). PRIs, ARs, AIs and RIs were not all available for all the nutritional properties. When a choice was to be made between PRIs, ARs and AIs; PRI was chosen over AR and AI, and AR was chosen over AIs. RIs were used for macronutrients like 'fat' and 'carbohydrate' which were given as energy% referenced to the total dietary energy.

Nutritional properties of the food products are based on the EFSA Food Composition Data (EFSA, 2018b). This database contains over 1340 unique products with multiple preparation methods (e.g. cooking in water, baking, cooking in oil, steaming) reported by 10 European countries. For each nutrient, an average was calculated based on the reporting countries. Missing nutrient data were completed with data from NEVO (Dutch Food composition database (RIVM, 2016)), the USDA Food Composition Database, or a similar product or preparation method from the EFSA database was used as a proxy. Over 60 nutritional properties were considered.

For each food item we used life cycle assessment (LCA) to calculate environmental impacts like greenhouse gas emissions (GHGE) and land occupation (LO). The LCAs took account of agricultural activities such as application of fertilizers; and emissions from activities due to transport, processing, packaging, distribution, retail (e.g. lighting and cooling), cooling at home, food preparation and waste treatment. Wastage was accounted for at all life-cycle stages. The methodological and data choices made and references used are explained in a separate document (Blonk Consultants, 2019).

The amount of each of the 173 products in the diet is varied in steps of 10 grams (from 0 to the point that there is no solution) and optimized for nutritional constraints, using quadratic programming. Solutions were found by minimizing the summation of the quadratic differences in the consumption amounts (in grams) of each food item, while satisfying specific constraints. At every step, the diet is adjusted to meet the nutritional constraints and the environmental impact of the diet is calculated. The SNB score is the linear relationship between the sustainability indicator (e.g. carbon footprint or land use) of the diet and the product quantity. The lower the SNB score, the more future-proof the product is. With an SNB score below zero, the environmental impact of the diet can decrease, when all suggested dietary changes are implemented. The product then has a more favorable balance between nutrients and environmental impact than the other food products with a higher SNB score.

Results

Meat products, especially lamb and beef, have a high SNB score (0.8 and 0.4 respectively). This means that they provide little relevant nutrients relative to their impact on the environment in the context of the European diet. Nuts and oil seeds, like walnuts and sunflower seeds, have a low SNB-score (-0.11 and -0.17 respectively). This means that higher consumption, at the cost of other products, lowers the environmental impact of the European diet. Liquid dairy products, like milk and yoghurt, have an SNB score which is very close to 0 (both +/- 0.005). This means it is difficult to substitute the nutrients that dairy products provide with products that have a lower environmental impact. Vegetables have an SNB score above 0 (0 to 0.1). High yielding, open field vegetables like beetroot, cabbage and onions tend to have a lower SNB score than green leafy vegetables and vegetables. The SNB scores within the food group of grains and grain products do not vary greatly (-0.055 to 0.045). The SNB-score of composite foods can vary greatly (-0.05 to 0.20, figure), depending on the composition.

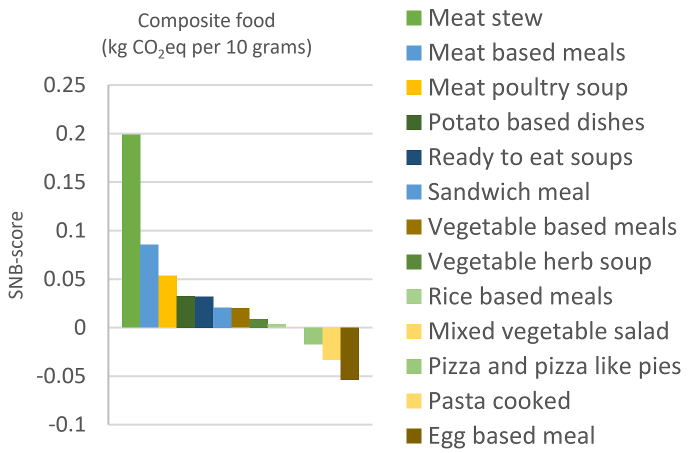

Figure 1: SNB-score for composite foods.

Discussion

The trendline, used to calculate the linear relationship between the sustainability indicator of the diet and the product quantity, tends not to be fully linear. In the final steps, the optimization will find a solution, but the dietary changes tend to be extreme; a shift in the trendlines will be noticed towards the final steps. For instance, the trendline for the stepwise optimization of a sandwich meal shows a sharp increase in impact of the diet on global warming and a sharp decrease in the impact on land use in the final steps (see figure). We recognized this break in the trendline, resulting in omission of the final steps in calculating the SNB score. This might give a more representative SNB score, as they will be used as benchmarks for product development.

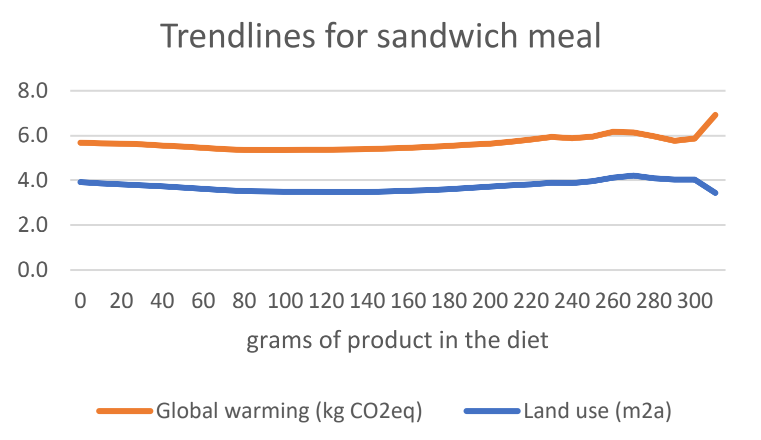

Figure 2: Trendline for the impact of the optimized diet on global warming and land use with varying amounts of sandwich meal.

The computation is done by minimizing the summation of the quadratic differences in the consumption amounts, in grams, of each food item. This means that water weight, which in fact does not contain nutrients (other than water), is considered in the computation. This limits the shift of products in the diet with a high water content, like vegetables. Optimization based on dry matter instead of 'as is' will make it easier to shift wet products like vegetables, possibly leading to a better SNB-score.

We recognize that a healthy diet is not solely based on the intake of the right amount of nutrients but should also be guided by food-based dietary guidelines (FBDGs). We have not considered FBDGs in the analysis. It is possible to include lower and upper constraints for intake of specific food groups according to FBDGs in the optimization. We recommend investigating the impact of doing so in future analyses.

The SNB score is calculated in the context of a regional diet, specific nutritional constraints and environmental properties calculated specifically for the region of the diet. This means that SNB scores will change when the context changes. SNB scores, calculated with a specific dataset, can not be used as a benchmark for product development outside of the region.

The challenge is to lower the SNB-score. This can be done by reducing 'negative' nutrients (e.g. salt and saturated fat), improving 'beneficial' nutrients (e.g. dietary fiber and vitamin D) or reducing environmental impact by altering the recipe or reducing use of resources in processing. The model does not predict actual consumer behavior and the SNB score should always be interpreted in the context of the diet.

Conclusions

For 173 food products, which are regularly consumed in Europe, the sustainable nutrition balance (SNB-score) was calculated. The SNB score gives insight as to whether a product fits well into a future-proof diet, meeting nutritional needs and limiting the impact on the environment with the aim to stick to planetary boundaries.

Meat and meat products tend to provide little relevant nutrients relative to their impact on the environment, in the context of the European diet. The nutrients provided by other food groups, like liquid dairy and grains and grain products tend to be difficult to substitute with products that have a lower environmental impact. There are also food groups with a good balance between nutrition provided and environmental impact, like nuts and seeds. For some food groups, the SNB score is highly dependent on the ingredients of products, production systems or computation algorithm.

The SNB scores of the 173 food products can serve as a benchmark in product development. The challenge for innovative food products is to achieve a lower SNB-score than the benchmark.

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Abstract code: 133

The relevance of integrating nutrition in the environmental comparison of legume-based products versus traditional foods

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Abstract

We compared the environmental efficiency of legume-based food and beverage products with traditional products, and determined trends across different impact categories. Case studies of available products were used: German pea protein balls versus beef meatballs, Bulgarian chickpea pasta versus wheat pasta, Scottish pea gin versus wheat gin, and pea-soy burger versus beef burger. We performed attributional LCAs from cradle to fork for the food products, and cradle to factory gate for the gin. The products were assessed across the sixteen impact categories recommended by the Product Environmental Footprint guidelines (European Commission 2018a) in OpenLCA v1.10 (GreenDelta 2019). One serving of product was defined as the functional unit. A second functional unit was used only for the food products to capture nutrition: one Nutrient Density Unit (NDU) – first proposed by Van Dooren (2016) –allowing to identify foods that offer the lowest environmental footprint per nutrition achieved. Per serving/bottle, legume-based products were associated with environmental burdens that were generally lower than their traditional counterparts, excepted for the land use categories for the pasta and gin. The nutrient densities of the food products were significantly higher for the legume-based food products. Consequently, the legume-based products had a significantly lower environmental footprint across most categories when the NDU was used as a functional unit. Our research shows that these innovative legume-based products hold potential to deliver nutrition at a lower environmental cost than the traditional products. The use of the NDU permitted the identification of foods that were both more nutritious and less environmentally harmful, addressing the two major challenges of the food sector in developed areas. This aspect is usually ignored in food LCAs, and is particularly relevant when comparing foods that substitute each other while having different ingredients. Land use remains higher for legume products that substitute cereals, highlighting the need for yield improvements. Running consequential LCAs is still needed to evaluate the effects of a diet change in Europe, in which the traditional products will be partially substituted with the legumes-based products.

Keywords: *legume; alternative; diet; nutrition; alcohol*

Introduction

According to the latest universal assessment of diet, health and the environment, unhealthy diets pose a greater risk to morbidity and mortality than does unsafe sex, alcohol, drug and tobacco use combined (Willett et al. 2019). By virtue of their numerous environmental and nutritional benefits, the use of legumes offers great potential in answering consumer demand for more healthy alternatives to popular foods that have a lower environmental footprint without compromising on taste (Bazzano et al. 2011; Foyer et al. 2016). Numerous companies have tapped into the potential of legumes as an effective ingredient in processed foods, leading to an increase in vegetarian products such as meat substitutes in the market (European Commission, 2018; Statista, 2019) that act as transition products towards more sustainable and healthy diets.

For many of these food substitutes, quantification of environmental and nutritional benefits is either limited or non-existent, making an informed consumer choice as to which product to choose difficult. The study presented in this talk combines novel case studies comparing environmental impacts of popular food and drink products with legume-based substitutes, using a serving as a functional unit, and one Nutrient Density Unit (NDU) for food products (Van Dooren 2016). These products are a) pea gin versus wheat gin b) chickpea pasta versus durum wheat pasta c) pea protein balls versus beef meatballs and d) soy and pea burger versus beef burger.

Material and methods

The gin and pasta data used in this paper are the baseline scenarios from Lienhardt et al (2019) and Saget et al. (2020), respectively. Similarly, primary LCA data for the meat substitutes were collected from food companies. The beef meatballs LCA data were adapted from Biswas and Naude (2016) to model meatballs production in Europe. Ecoinvent v3.6 (Wernet et al. 2016) and Agrifootprint v3.0 data (Blonk Consultants 2019) were used in OpenLCA v1.10 (GreenDelta 2019) to model the product systems. Legume and cereal agriculture data were modelled following IPCC guidelines (IPCC 2019). Due to the absence of primary data, two scenarios for cattle production systems were used: "market for cattle for slaughtering, live weight- BR" from Ecoinvent v3.6 (Steubing et al. 2016) and "Beef cattle for slaughter, at beef farm, PEF compliant Economic – IE" from Agrifootprint v3.0 (Durlinger et al. 2017). Economic factors were adopted for the slaughtering co-products (van Paassen et al. 2019).

The NDU was applied following Van Dooren's (2016) Eq. (1). Nutritional data were obtained with the identical methods by the same laboratory as described in Saget et al. (2020). NDU values are recorded in Table 1.

$$\mathrm{NDU} = \frac{\left(\frac{\text{g essential fatty acids}}{12.4\ \text{g}}\right)+\left(\frac{\text{g protein}}{50\ \text{g}}\right)+\left(\frac{\text{g fibre}}{25\ \text{g}}\right)}{3\times\left(\frac{\text{kcal energy}}{2000\ \text{kcal}}\right)} \qquad \text{(Eq. 1)}$$

Results

The NDU results were recorded in Table 1. The NDUs of the chickpea pasta, pea protein balls, and meatless burger were 1.6, 0.5, and 0.6 times higher, respectively, than those of their traditional alternatives. A summary showing the number of environmental impact categories across which the legumes alternatives had at least a 20% lower impact than the non-legume alternatives per serving and per NDU was recorded in Table 2. Overall, environmental burdens per serving were lower for the legume-based products, excepted for the land use impact of the products that substitute something other than meat, which was at least two times higher. The differences between the environmental burdens of the meat and meat analogues varied greatly. Depending on the impact category, the environmental burdens per serving of pea protein balls were between 24% and 100% smaller than those of beef meatballs. The environmental burdens of a meatless burger were greater than those of a beef burger across 2 to 5 categories out of 16, depending on whether the beef came from Ireland or Brazil. Climate change burdens were between 17% (pasta) and 88% (meat(less) balls) lower per serving of legume-based product than per serving of their respective alternative. Per serving, climate change, acidification, water scarcity, terrestrial and marine eutrophication remained lower for the legume products than their alternatives.

Apart from wheat pasta, the food products had a NDU that was superior to 1 (Table 1), and thus their environmental burdens per NDU were lower than the ones per serving. For the pasta, this widened the environmental burden differences across categories in which the burdens were already lower for the chickpea pasta, and decreased the differences in which they were higher. The climate change burden of chickpea pasta went from being 17% lower when using a serving functional unit, to 68% lower when using the NDU; the land use burden of chickpea pasta from 2 times higher when using a serving functional unit, to 17% higher when using the NDU.

The three product comparisons showed different effects of going from a serving FU to a NDU FU. In the case of the meat(less) balls, the overall results did not change when the NDU was used as a FU, due to the pea protein balls already having a lower environmental footprint across all categories when the serving FU was used. In the case of the burger patty with Brazilian beef, the use of the NDU increased by 50% the proportion of impact categories across which the meatless burger had at least a 20% lower burden than that beef burger. In the third case, the chickpea pasta went from having at least a 20% lower burden across less than half of the categories to 88% of them with a NDU FU.

Discussion

Per serving, the legumes alternatives were shown to have lower environmental burdens across most categories. Performing an analysis over several categories was key, highlighting trade-offs of land use. The higher land use burdens for the pasta were due to the lower agricultural yield of legumes than cereals, highlighting the fact that more research to improve wheat yield than legume yields was performed (van Loon et al. 2018). This reflects the need for research to significantly improve legume yields, as was done with cereals (Foyer et al. 2016).

The LCIA results with the NDU as a functional unit for the food products suggest that legume-based food products may deliver more nutrition at a lower environmental cost. Identifying such foods is key due to the current food system being characterized by high environmental impacts and the increased consumption of high-energy nutrient-poor foods. However, land use still remained higher for the chickpea pasta when the FU was the NDU. The meat substitutes were both more nutrient-dense and associated with significantly lower environmental burdens across most categories, producing significantly less GHG emissions and acidification, and using less land and water resources.

Therefore, these innovative legume-based foods hold potential to participate in a sustainable dietary transition in Europe to achieve better health, nutrition, and environmental sustainability. From an environmental perspective, running consequential LCAs is needed to evaluate the effects of a diet change in Europe, in which the traditional products will be partially substituted with the legumes-based products.

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Table 1: Nutrient Density Units of the products assessed, with essential fatty acid, protein, fiber, and energy contents per 100g of food product.

	Pasta		Meat(less) Balls		Burger	
	Chickpea	Wheat	Pea	Beef	Soy/pea	Beef
NDU	**2.3**	**0.9**	**2.0**	**1.3**	**2.3**	**1.4**

Table 2: Number of impact categories out of 16 across which the legume alternative has at least a 20% lower environmental burden than the traditional alternative.

Meatless burger patty		
	Per serving	Per NDU
Beef burger patty (Irish beef)	13	13
Beef burger patty (Brazilian beef)	10	15
Pea protein balls		
	Per serving	Per NDU
Beef meatballs (Irish beef)	16	16
Beef meatballs (Brazilian beef)	16	16
Chickpea pasta		
	Per serving	Per NDU
Wheat pasta	7	14

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Drivers of global warming potential and diet quality of Swiss food consumption

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Abstract

Purpose: Although diets are an important link between human health and the environment, knowledge on differences between dietary habits of population subgroups and how these link to differences in diet quality and environmental impacts is still limited. We therefore aim to investigate how different dietary habits in Switzerland perform with regard to human health and global warming potential, and which sociodemographic and lifestyle factors can be linked to different impact levels.
Methods: We calculated the global warming potential and a diet quality score, the Alternate Healthy Eating Index, of recent dietary recall data from Switzerland (menuCH). The dietary recall data contained foods consumed during the last 24 hours as well as sociodemographic and lifestyle factors of the participants. Using multiple linear regression, we then calculated associations between sociodemographic and lifestyle factors and food choices on the one hand, and associations between sociodemographic and lifestyle factors and impacts on the other hand. Results of these regressions were then combined to shed light on how sociodemographic and lifestyle factors can be linked with impact levels via food choices.
Results and discussion: Our results showed that performance of diet quality and global warming potential was particularly distinctive for age groups, language regions, nationalities, and smoking status, while education and income group seemed less relevant. Furthermore, some food groups offer synergies between diet quality and global warming potential when being reduced, such as different types of meat, dairy, and eggs. Thus, these food groups should be recommended and consumed with care, and their intake limited to the extent that they provide substantial added value in terms of nutrients provided. Other food groups, such as whole grains, pulses, nuts and seeds, vegetables, and fruits contribute to an improved diet quality, while having relatively low global warming impact intensities.
Conclusions: We can thus conclude that increases of these latter food groups are synergistic for diet quality and global warming potential. Sociodemographic and lifestyle factors that reveal levels with increased consumption values of these food groups are language region, age group, civil status, and education. These insights can help to target actions for improvements of the performance of diets with regard to diet quality and global warming potential more effectively.

Keywords: *Food consumption; Global warming potential; Diet quality; Sustainability*

Introduction

Current food consumption and the associated production practices cause adverse impacts on both human and planetary health (Tilman & Clark, 2014; Willett et al., 2019). On the one hand, food consumption is an important factor for our human wellbeing, and suboptimal dietary patterns can be linked to several non-communicable diseases (Afshin et al., 2019). On the other hand, current food

production practices contribute to approaching or transgressing several planetary boundaries (Campbell et al., 2017; Steffen et al., 2015).
In recent years, much scientific literature has investigated effects of different current dietary patterns and possible improvement options on a range of environmental impacts (Poore & Nemecek, 2018). In addition to environmental impacts, also diet quality and its implications for human health were increasingly considered (Mertens et al., 2017), leading to improved knowledge of potential synergies and trade-offs of environmental and human health impacts of different diets. However, since many analyses focus on average dietary patterns or hypothetical dietary scenarios, information on performance of population subgroups is still scarce. Moreover, these differ per country, due to e.g. cultural backgrounds. For Switzerland, detailed assessments of climate change impacts and diet quality of dietary intake data were not linked to population characteristics, although dietary habits in Switzerland prove an interesting case study. This is due to the multilanguage characteristics of Switzerland, which are well reported in a harmonized dietary recall called menuCH. In this study, we therefore investigated sociodemographic and lifestyle drivers that can be linked to certain food choices, which, in turn, define climate change impacts and diet quality of the associated dietary patterns.

Material and methods

Dietary recall data menuCH

menuCH, the first dietary recall of Switzerland, was conducted between January 2014 and February 2015 (Chatelan et al., 2017). In total, 2,057 participants completed two 24h dietary recalls, thus reporting all food items consumed within the last 24h. We transformed the dietary recall data to become consistent with the reference units of the environmental impact intensities employed (e.g. cooked to raw), and food waste factors applied to get to food supply levels (Beretta et al., 2013; Beretta et al., 2017). In menuCH, also sociodemographic and lifestyle factors of the participants were available: sex, nationality, age, highest completed education, civil status, gross household income, smoking status, and being currently on a weight-loss diet. In addition, measurements of weight and height were used to derive the Body Mass Index (BMI). Moreover, the language regions were defined based on the canton of residence. Finally, by applying a weighting scheme to account for differences in sex, age, nationality, marital status, household size, major area in Switzerland, weekdays, and seasonality, the employed data became representative for persons between 18 and 75 years old of most regions in Switzerland (Pasquier et al., 2017).

Impact assessment: global warming potential and diet quality

GHG emissions of each dietary recall were calculated based on life cycle assessments from cradle-to-farm-gate modelled with the biophysical mass-flow model SOLm (Muller et al., 2017; Schader et al., 2015), and from farm-gate-to-consumer (for the stages processing and transport) inventories from Ecoinvent 3 were added. SOLm covers all mass and nutrient flows in agricultural production relevant for the calculation of resource use and emissions. Inputs and outputs of each crop and livestock activity are defined and form the basis for the inventory analysis. Of the relevant inputs and outputs, the global warming potential (GWP) was then calculated, thus covering the following stages: feed production, enteric fermentation, manure management, processing, and transport.
As an index for diet quality, we employed the Alternate Healthy Eating Index (AHEI) (Chiuve et al., 2012; Pestoni et al., 2019). Based on predefined thresholds for food and nutrient intake, a maximum of 10 points are allocated for 11 food and nutrient categories, resulting in a score with a maximum of 110 points.

Statistical analysis and integration

The data analysis was performed in three steps. In the first step, we employed multiple linear regression to identify associations between different sociodemographic and lifestyle factors and food choices. In a second step, we used multiple linear regression to identify associations between different sociodemographic and lifestyle factors and impact levels. Then, in a third step, results from step one and two were integrated. This was done by first selecting levels of sociodemographic and lifestyle factors that show significant results for the impacts (p-value $\leq$ 0.05). Then, for each of these significant levels, we added information on food choices. This information constitutes not only the direction of the association between levels of sociodemographic and lifestyle factors and intake per food group, but also a broad indication of the strength of the impact intensity (above or below median).

Results

In Figure 1, mean impacts for AHEI and GWP of the weighted dietary recalls are presented. For the AHEI, the median value of all dietary recalls lies at 43.7 points, while for GWP, the median value lies at 1.6 kg CO_2eq per dietary recall. Results of the dichotomization into above or below median of the impact intensities are as follows: for the AHEI, mainly the food groups fish and seafood, cereals (whole grains), pulses, vegetables, nuts and seeds, and fruits contribute to an increase of the score (above median). For GWP, mainly the animal-source food categories reveal above median impact intensities, together with oils and fats.

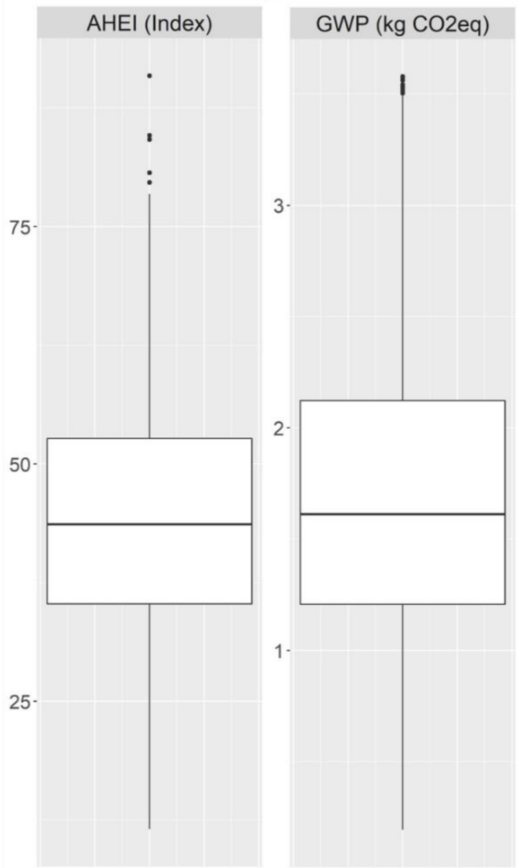

Figure 1: Weighted boxplots of the impacts of all foods consumed by a participant in the 24 hours of the recall. AHEI = Alternate Healthy Eating Index, GWP = global warming potential.

Table 1 displays the integrated results of the regression analyses on food choices (first step) and impacts (second step). For GWP, we see that eight levels of the sociodemographic and lifestyle factors had a significant association. Of these, all associations were positive compared to the respective reference groups (e.g. participants originating from the French-speaking language region revealed a higher GWP than participants originating from the German-speaking language region (+0.1 kg CO_2eq)). Then, information on food choices was added, from which we can see which food choices showed a positive association: for example, French-speaking participants consumed more cattle meat than the German-speaking reference. In addition, information on the strength of the impact intensity of cattle meat for GWP is indicated by the shade of the colour – as cattle meat falls into the above median impact intensity group for GWP, it is coloured in dark yellow. From these information, we can see that higher consumption of cattle meat can be linked to higher GWP (+0.6 kg CO_2eq) of participants from the African & Eastern Mediterranean region, compared to Swiss participants. Moreover, the higher GWP of French-speaking participants (+0.1 kg CO_2eq), compared to German-speaking participants, can be explained by their higher cattle meat and chicken intake – and to a lower extent also by their higher pulses and vegetables intake. Further, the higher GWP of older people than the reference (45-59 years: +0.2 kg CO_2eq, 60-75 years: +0.3 kg CO_2eq, compared to the reference group of 30-44 years) could be influenced by the higher fruits consumption. The higher GWP of married participants (+0.2 kg CO_2eq), compared to single participants, correlated with a higher cattle meat and milk products intake. Finally, for current smokers (+0.1 kg CO_2eq) compared to non-smokers and being currently on a weight-loss diet versus not (+0.3 kg CO_2eq), higher GWP values could be explained by their higher alcoholic beverages and higher vegetables intake, respectively.

For diet quality, represented by the AHEI, 12 levels of sociodemographic and lifestyle factors showed significant results (Table 1). In fact, the lower score of the AHEI for male participants (-1.3 points) was associated with a lower consumption of fruits. Further, participants from the European region, compared to the Swiss region, revealed a higher AHEI (+1.5 points), as did participants from the Western Pacific / South-East Asia region (+8.4 points). The former result can be explained by higher fish and seafood intake, while the latter result can be linked to higher vegetables consumption. Furthermore, the two language regions French-speaking and Italian-speaking showed a higher AHEI than the German-speaking reference (+1.7 points and +2.7 points), which can be explained by their increased pulses and vegetables consumption and their lower sugar consumption. Moreover, also older participants scored higher on the AHEI, which can be linked to increased fruits and vegetables consumption. The same pattern applied for people with tertiary education. Current smokers, on the contrary, revealed a lower AHEI score (-3.1 points), which correlated with lower fruits consumption. Furthermore, the lower AHEI of overweight participants (-3.0 points) can be linked to a lower consumption of cereals (whole grains), vegetables, and fruits. Lastly, participants that were currently on a weight-loss diet revealed a higher AHEI (+4.2 points), which can be explained by their higher vegetables consumption.

Table 1: Association of sociodemographic and lifestyle factors and different impact categories (GWP and AHEI) (coefficient estimate) (n=2,057). The colour legend for the squares indicates the direction of the association between the sociodemographic and lifestyle characteristics and the food groups (positive, negative, non-significant), and the strength of the impact intensity of the respective food group (strong indicates an impact intensity above median, weak indicates an impact intensity below median per impact category).

Covariates	Reference	Impact	Food groups														
		Coefficient estimate	Cattle meat	Pork	Chicken	Milk products	Eggs	Fish and seafood	Cereals	Potatoes	Pulses	Vegetables	Nuts and seeds	Oils and fats	Fruits	Sugar, other sweeteners	Alcoholic beverages
Global warming potential GWP (kg CO_2eq)																	
Nationality: African / Eastern Mediterranean	(Swiss)	0.6	positive, strong														
Language region: French-speaking	(German-speaking)	0.1	positive, strong		positive, strong	negative, strong					positive, weak	positive, weak				negative, weak	
Age group: 45-59 years	(30-44 years)	0.2			negative, strong										positive, weak	negative, weak	
Age group: 60-75 years	(30-44 years)	0.3			negative, strong										positive, weak	negative, weak	
Civil status: Married	(Single)	0.2	positive, strong			positive, strong						positive, weak					
Income group: <6000 CHF/month	(6000 – 13'000 CHF/month)	0.1										negative, weak	negative, weak				negative, weak
Smoking status: Current	(No smoker)	0.1													negative, weak		positive, weak
Currently on a weight-loss diet: Yes	(No)	0.3							negative, weak			positive, weak					
Alternate Healthy Eating Index AHEI (Index)																	
Sex: Male	(Female)	-1.3	positive, weak						positive, strong		positive, strong				negative, strong		
Nationality: European	(Swiss)	1.5						positive, strong						positive, weak			
Nationality: Western Pacific / South-East Asia	(Swiss)	8.4	positive, weak									positive, strong				positive, weak	
Language region: French-speaking	(German-speaking)	1.7	positive, weak								positive, strong	positive, strong				negative, weak	
Language region: Italian-speaking	(German-speaking)	2.7												positive, weak		negative, weak	
Age group: 45-59 years	(30-44 years)	3.6													positive, strong	negative, weak	
Age group: 60-75 years	(30-44 years)	6.4										positive, strong			positive, strong	negative, weak	
Education: Tertiary	(Secondary)	2.5	negative, weak									positive, strong			positive, strong	negative, weak	
Smoking status: Current	(No smoker)	-3.1	positive, weak												negative, strong		
BMI group: Overweight	(Normal)	-3.0							negative, strong			negative, strong			negative, strong		
BMI group: Obese	(Normal)	-5.0															
Currently on a weight-loss diet: Yes	(No)	4.2							negative, strong			positive, strong					

Legend: positive, strong; positive, weak; non-signifcant; negative, strong; negative, weak

Discussion and Conclusion

This paper provides new insight on how GWP and AHEI relate to different sociodemographic and lifestyle characteristics in Switzerland, with food choices being the essential binding part. The proposed analysis of occurrence and reasons for higher GWP and AHEI allows to identify crucial synergies and trade-offs between climate change impacts from food production on the one hand, and diet quality on the other hand. In fact, food groups that do not contribute to an increase of the AHEI – such as all types of meat, dairy, and eggs – but at the same time contribute to GWP with above median strength emit synergies for GWP and AHEI, if reduced. Thus, these food groups should be recommended and consumed with care, and their intake limited to the extent that they provide substantial added value in terms of nutrients provided. Sociodemographic and lifestyle factors that could be related to higher intakes of these food groups are nationality, language region, and civil status – and to some extent also age group. Further, a second group of food items, consisting of whole grains, legumes, nuts and seeds, vegetables, and fruits, contributes to an increase of the AHEI, while revealing below median impact intensities for GWP. We can thus conclude that increases of these food groups are synergistic for AHEI and GWP. Sociodemographic and lifestyle factors that reveal increased consumption values of these food groups are language region, age group, civil status, education, and currently on a weight-loss diet. Thus, the respective levels of these factors point at population subgroups that perform favorable with regard to the consumption of these food groups, and accordingly to the performance of AHEI and GWP related to this. However, although GWP is undoubtedly an important environmental indicator, it should be noted that GWP only represents one aspect of our food productions' environmental burden, and results could thus change if other environmental indicators were employed. The insights of this study provide entry points for actions to improve both the climate change impacts and diet quality aspects of current diets.

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Trade-offs and synergies between human health and sustainability of Swiss dietary scenarios

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Abstract

Purpose: Aspects of human health and sustainability of diets are often analysed separately. Food systems dynamics, such as the availability of permanent grasslands, are often not accounted for in the assessment of diets based on attributional LCAs. This paper aims at an integrated analysis of diets focusing on trade-offs and synergies between healthy nutrition and sustainable food systems.

Methods: We used an integrated modelling approach, linking three different models: a global mass flow model, a system dynamics model and an environmentally extended input-output model. The models were used to analyse human health, environmental, social and economic impacts and related trade-offs and synergies for a number of future scenarios of Swiss agricultural production and food consumption for three scenarios for the Swiss Food Sector in 2050. These scenarios were either developed in a participatory process during a series of interviews and group discussions with different groups of stakeholders or optimised environmental impacts while at the same time complying with different nutritional recommendations and agronomic restrictions.

Results and discussion: Our results illustrate two scenarios of how healthy diets and sustainable food systems could look like. Both the SwissFoodPyramid2050 and the FeedNoFood2050 scenarios require similar dietary changes, such as a reduction of meat consumption and an increase in consumption of pulses. However, there are also some fundamental differences between the diets in the two alternative scenarios, e.g. regarding the type of meat consumed. These differences can be interpreted as trade-offs that result from agronomic boundary conditions such as the coupled production of milk and meat, the availability of natural resources, such as grassland and co-products of food processing, and health aspects of Swiss diets.

Conclusions: Our results imply that there is a lack of a comprehensive food systems’ view in the current discussion on healthy and sustainable diets. Stronger coherence between human health, food and agricultural policy is needed to account for systemic boundary conditions and, thus, to allow for minimising trade-offs and maximise synergies. Current agricultural policies fail to address the health perspective. Financial support for meat and sugar producers, which lead to lower prices for those products and ultimately to a higher consumption than without these policies, are two obvious examples. Yet, comprehensive visions such as the SwissFoodPyramid scenario, the FeedNoFood Scenario or optimised scenarios would require an even more complex policy mix of incentives, regulations and information campaigns.

Keywords: *environmental impacts, food, agriculture, grassland, sufficiency. Food-feed competition*

Introduction

Aspects of human health and sustainability of diets are often analysed separately (Willett et al. 2019). Food sector dynamics, such as the availability of permanent grasslands, are not accounted for in the assessment of diets based on attributional LCAs (Frischknecht et al. 2017; van Zanten et al. 2018). This paper aims at analysing trade-offs and synergies between healthy nutrition and sustainable food systems. First, we identified nutritional patterns of the Swiss population based on representative consumption data. The health impacts of these nutritional patterns were then analysed based on a review of the scientific literature on health impacts of food commodities and diets and by calculating the Alternate Healthy Eating Index (AHEI) (Chiuve et al. 2012). Second, we comprehensively analysed health, environmental, social and economic impacts and related trade-offs and synergies for a number of future scenarios of Swiss agricultural production and food consumption.

Material and methods

For this, we used a modelling approach, linking three different models: a global mass flow model (Schader et al. 2015; Muller et al. 2017), a system dynamics model (Kopainsky et al. 2015) and an environmentally extended input-output model (Kopainsky et al. 2018). We modelled ten different scenarios for the Swiss Food Sector in 2050. These scenarios were either developed in a participatory process during a series of interviews and group discussions with different groups of stakeholders or optimised environmental impacts while at the same time complying with different nutritional and agronomic restrictions. Three scenarios were analysed with all three models in detail. Among these main scenarios was the SwissFoodPyramid2050 (SFP) Scenario, which assumes a widespread implementation of the dietary recommendations according to the Swiss Food Pyramid. The FeedNoFood2050 (FNF) Scenario assumes an improved use of agricultural land by feeding only grass and by-products to livestock, which was not competing with direct human nutrition, i.e. did not require arable land (neither in Switzerland nor abroad). The third scenario was a reference scenario, which assumes no changes in diets until 2050 and was used to compare the two alternative scenarios. The other scenarios were targeted at specific questions such as minimizing greenhouse gases.
Of these scenarios, we calculated a total of ten sustainability indicators, covering the environmental, economic, and social and health dimension. Four environmental indicators were calculated: greenhouse gas emissions, land occupation, biodiversity loss potential, and eutrophication. Further, the economic dimension was represented by household expenditure for food, gross value added, and an employment measure. The health and social dimension included two production-related indices: the Social Hotspots Index on the one hand, and production-related disability-adjusted life years on the other hand. Furthermore, a consumption-related index to include diet quality was employed: the AHEI.

Results

Our results illustrate two scenarios of how healthy diets and sustainable food systems could look like. Both the SwissFoodPyramid2050 and the FeedNoFood2005 scenarios require similar dietary changes, such as a reduction of meat consumption and an increase in consumption of pulses and nuts. However, there are also fundamental differences between the diets in the two alternative scenarios, e.g. regarding the type of meat consumed. These differences can be interpreted as trade-offs which result from agronomic boundary conditions such as the coupled production of milk and meat, the availability of natural resources, such as grassland and co-products of food processing, and health aspects of Swiss diets. Of primary importance in this respect was the use of permanent grasslands and the co-production of veal and beef with dairy production due to environmental reasons and reasons for optimally utilizing available resources. This means, if permanent grassland is maintained as an ecosystem, dairy production provides the basis for animal proteins. Thus, while in the FeedNoFood2050 Scenario veal and rather low-quality beef from dairy cows is consumed instead of meat from monogastrics, the SwissFoodPyramid2050 Scenario results in a higher amount of meat from monogastrics.

Figure 1 shows the performance of the SPF and FNF scenarios. For all indicators besides AHEI, scenario values below the reference indicate better performance, values beyond the reference indicate worse performance than the reference while for AHEI, the opposite applies. The SFP scenario performs well with respect to AHEI while no substantial environmental, economic and social disadvantages occur. The FNF scenario improves most environmental impact categories and also reduces the economic size of the food sector while the Social Hotspot Index is slightly higher. With respect to AHEI, the FNF scenario performs similar than the reference scenario.

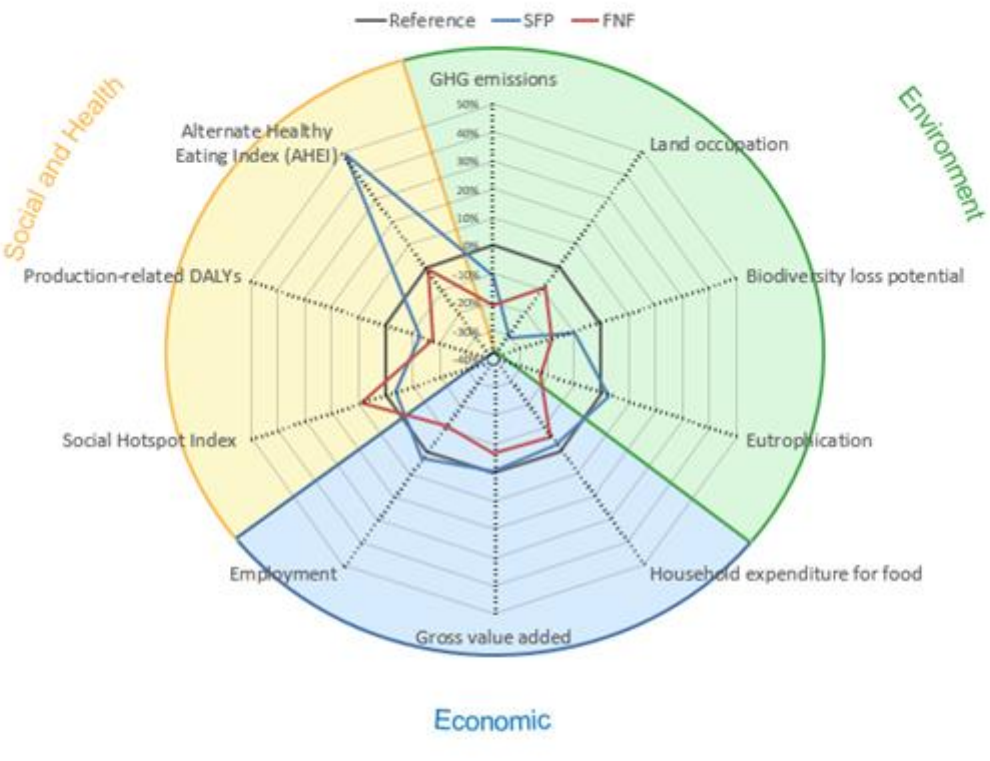

Figure 1 Comparison of the environmental, economic, and social and health performance of the SwissFoodPyramid2050 (SFP) and FeedNoFood2050 (FNF) scenarios against the reference scenario.

Discussion and Conclusions

Our results imply that there is a lack of a comprehensive food systems' view in the current discussion on healthy and sustainable diets. Stronger coherence between health, food and agricultural policy is needed to account for systemic boundary conditions and, thus, to allow for minimising trade-offs and maximise synergies. Current agricultural policies fail to address the health perspective. Financial support for meat and sugar producers, which lead to lower prices for those products and ultimately to a higher consumption than without these policies, are two obvious examples. Yet, comprehensive visions such as the SwissFoodPyramid scenario, the FeedNoFood Scenario or optimised scenarios require an even more complex policy mix of incentives, regulations and information campaigns. This would probably need an adaptation of the current institutional setting and division of competences between the Federal Offices for Agriculture (FOAG) and for the Environment (FOEN), the State Secretariat for Economic Affairs (SECO) and the Federal Food Safety and Veterinary Office (FSVO).

A commonly shared vision, including specific goals with respect to how the Swiss food system should look like, is urgently needed. Developing such a vision needs to involve all operators and stakeholders of the food system, as our results imply that more sustainable and healthy diets do not necessarily go along with financial benefits of both producers and consumers. These trade-offs and the knowledge of behavioural economics need to be considered for designing settings which create mutual benefits for operators in the food sector and consumers. For instance, neither the majority of consumers, food industry nor agricultural producers can be expected to respond altruistically as an entire sector in the long term. Therefore, policy needs to set financial incentives for internalising environmental and social externalities in order to push and pull the food system towards sustainability. Furthermore, it is crucial to account for agronomic boundary conditions and systemic aspects, such as the role of ruminants in utilizing grasslands and the unavoidable link of milk and meat production.

Acknowledgements

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Abstract code: 179

We are what we eat: socioeconomic profile and the environmental impact of our diet

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Abstract

The interactive public exhibition 'The Art of Living the Good Life' was developed with the goal of identifying potential relationships between socioeconomic profiles, environmental awareness, and the environmental impact of nutritional choices. Visitors are guided through the exhibition using a web app and are asked questions about their lifestyle and outlook on various topics, which allows categorisation into one of twelve socioeconomic profiles according to Stelzer & Heyse (2016). They are also asked about their dietary, housing, and mobility habits, and about their environmental awareness. Based on the frequency of meat, milk and yoghurt, cheese and quark, wine, and coffee consumption and how regularly visitors waste food, the nutrition-related environment impact is calculated using the ecological scarcity method (Frischknecht et al., 2013). After answering the questions, visitors receive detailed information on their environmental impact as well as personalised tips, customised for each profile, explaining how they can reduce their impact.

The median yearly environmental impact resulting from nutrition varied between socioeconomic profiles, ranging from 2.9-3.3 million eco-points per person. The difference between groups is not particularly large, but there is a considerable difference between individuals: there is an almost three-fold difference between the lowest and highest nutrition-related impact. Visitors with the lowest nutrition-related impacts tend to consume little to no meat, milk products, wine, and coffee and rarely waste food and those with high impacts consume these products more frequently and waste food more regularly. The nutrition-related impact is higher for omnivores than for vegetarians and vegans. The environmental impact resulting from nutrition tended to be slightly lower for environmentally aware participants and female visitors tended to have slightly lower nutrition-related environmental impacts than males.

There are only small differences in the nutrition-related environmental impact of the socioeconomic groups, but a large range within the groups, indicating that other factors play a larger role. The large range of impacts resulting from nutrition indicates that there is significant improvement potential in this area.

Keywords: *Environmental impact; socioeconomic profile; nutrition; vegan; vegetarian*

Introduction

In order to meet Switzerland's sustainability goals and reduce the country's resource consumption to an environmental footprint of "one world", mitigation measures are required both in terms of production and consumption (Kissling-Näf et al., 2013). The environmental impact generated by individuals' consumption is significant and the impact arising from food, housing, and transportation is especially relevant, accounting for a large proportion of the total environmental impact of private households in Switzerland (Jungbluth et al., 2011). This indicates that everyday decisions, especially in these areas, play an important role in achieving the goals of sustainable development.

Life Cycle Assessment (LCA) is used to quantify the direct and indirect environmental impacts associated with all life-cycle stages of products or services (ISO, 2006) and can be used to calculate the environmental reduction potential of behaviour-related actions. While the most environmentally beneficial lifestyle changes have been identified in previous LCA studies, i.e. Jungbluth et al., (2012), the everyday decision-making of most consumers does not seem to have been affected by these findings. It is difficult to draw general conclusions about lifestyle choices and consumption behaviour and FOEN (2016) describes the need for the identification of environmental types for Swiss households and age groups in order to develop specific recommendations regarding consumption.

The Life Cycle Assessment and the Sustainability Communication Research Groups of the Zurich University of Applied Sciences (ZHAW) designed and implemented the interactive public exhibition 'The Art of Living the Good Life' with the goal of identifying potential relationships between socioeconomic profiles, environmental awareness, and the environmental impact of nutritional choices. This novel combination introduces another perspective compared to tools only considering environmental impact like the WWF calculator. Additionally, we wanted to increase visitors' awareness of the environmental impact of their personal choices and habits. By providing individual tips based on their behaviour as well as their socioeconomic type, they become motivated to reduce their environmental footprint.

Material and methods

The interactive exhibition was installed in a pavilion in the ZHAW campus grounds in Wädenswil, Switzerland. The grounds are open to the public and attract around 12,000 visitors each year in addition to staff and students. Guided tours of the exhibition were offered and visitors could visit the exhibition independently. The exhibition looks like a small apartment with an entrance area, kitchen, living room, toilet, and office. Visitors ring the doorbell on arrival and hear a message from a reporter, who then interviews them: the questions are answered using a web app that guides them through the exhibition.

Visitors answer fourteen questions about their lifestyle and opinions, which allows categorisation into one of twelve socioeconomic profiles according to Stelzer & Heyse (2016). This model is based on Gunnar Otte's research: Otte described various lifestyles theoretical and empirically validated them using three large-scale population surveys in Germany (Otte, 2005).

In order to determine visitors' environmental awareness, they are asked to what extent they agree with four statements: two of these refer to the so-called "environmental self-identity" and have been adapted from those in Moser et al. (2016) and a further two questions were taken from the "material values scale" from Müller et al. (2013).

Visitors are also asked about their dietary, housing, and mobility habits, in order to determine their environmental impact. The food sector is the most impactful consumer sector in Switzerland, accounting for nearly 30% of the total environmental burden of Swiss consumers, followed by mobility (17%) and housing (16%) (Jungbluth et al., 2011). By focussing on these areas, we were able to estimate the environmental impact using a limited number of questions, ensure high participation rates, and keep the exhibition interesting. The answers to these questions were used to calculate the environmental impact of the visitors' individual lifestyle using the ecological scarcity method (Frischknecht et al., 2013).

In terms of nutrition, meat and fish, milk and eggs, and beverages are responsible for the lion's share of the environmental impact (Jungbluth et al., 2012). Visitors supply information on how frequently they consume meat, milk and yoghurt, cheese and quark, wine, and coffee. Portion sizes and average consumption data were obtained from a national nutrition survey (BLV, 2017b; BLV, 2017a). Fish consumption was calculated as a fixed percentage in addition to meat consumption (Jungbluth et al., 2015). Additionally, the environmental impact of other foods, such as grains, vegetables, oils etc., was calculated based on whether visitors are vegan, vegetarian or omnivorous (Jungbluth et al., 2015). Visitors are also asked how often they throw food away. Average food waste rates were taken from Beretta et al., (2017) and adjusted depending on how frequently visitors throw out food.

After answering the questions, visitors receive detailed information on their environmental impact as well as personalised tips, customised for each profile, explaining how they can reduce their impact.

Results and discussion

Between 30.8.2018 and 31.10.2019, 1262 visitors used the web app and 741 made their data available to the research department. Figure 1, (top) shows the 12 socioeconomic profiles according to the Stelzer & Heyse (2016) model. The dimension "social and economic capital" is based on individuals' wealth, cultural capital, such as level of education, and social capital, e.g. networks of relationships. The dimension "modernity" is a measure of how open individuals are to new experiences and how important tradition is to them. The median yearly environmental impact resulting from nutrition varied between socioeconomic profiles, ranging from 2.9 million eco-points for the group "status-conscious middle-class" to 3.3 million eco-points for the "consumption-orientated materialist" category (see Figure 1, bottom). The range is large overall and especially for the profile types "youth culture entertainment-orientated", "performance-orientated middle class", and "efficiently pragmatic".

There is almost a three-fold difference between the nutrition-related environmental impact of the visitor with the lowest impact (2.4 million eco-points) and the visitor with the highest (6.8 million eco-points). Both individuals are in the "performance-orientated middle class" category, both are less environmentally aware and omnivores. The individual with the lowest impacts, however, eats only small quantities of meat, consumes no milk products, coffee or wine. Additionally, they rarely waste food. The individual with the highest impact does not consume coffee or cheese. The high impact arises due to extremely high meat and wine consumption, as well as regular food waste.

Figure 2 shows the nutrition-related environmental impact by category for three example visitors at the 5th, 50th, and 95th percentiles. The category "other" including grains, fruits, vegetables, oils etc. contributes the largest proportion of the impact for all example visitors. Food waste also plays a significant role, but for the participant at the 95th percentile, meat and fish, and coffee are more relevant. The visitor at the 5th percentile is a vegetarian who consumes little cheese and no other milk products. They do not drink wine and waste little food: these habits lead to low nutrition-related impacts. In general, the visitors with the lowest nutrition-related impacts consume little to no meat, milk products, wine, and coffee and rarely waste food and in contrast, those with high impacts consume these products more frequently and waste food more regularly.

The environmental impact resulting from nutrition tended to be slightly lower for environmentally aware participants (median = 3.0 million eco-points, average = 3.1 million eco-points) compared to the less environmentally aware participants (median = 3.1 million eco-points, average = 3.2 million eco-points). Female visitors tended to have slightly lower nutrition-related environmental impacts (median = 2.9 million eco-points, average = 3.0 million eco-points) than male visitors (median= 3.1 million eco-points, average = 3.3 million eco-points).

In total, 82% of the participants were omnivorous, 13% vegetarian, and 5% vegan. The proportion of vegans and vegetarians is higher among the environmentally aware visitors (23% compared with 9%) and female visitors (24% compared with 11% of males), which partially explains the lower nutrition-related impacts of these groups. The proportion of vegans and vegetarians varies between the socioeconomic groups, ranging from zero (limited traditional and youth culture entertainment-orientated categories) to 35% (status-conscious middle class). The proportion of vegetarians and vegans is highest for the middle-income profiles (24%) and lowest for the high- (13%) and low-income (14%) profiles.

Social and economic capital				
High	Upscale conservative	Status-conscious success	Performance-conscious intellectual	Reflective avant-garde
Moderate	Soundly conventional	Status-conscious middle-class	Performance-orientated middle class	Efficiently pragmatic
Modest	Limited traditional	Defensively disadvantaged	Consumption-orientated materialist	Youth culture entertainment-orientated
Lifestyle typology	*Traditional*	*Semi-modern establishment*	*Semi-modern consolidation*	*Modern*
	Modernity			

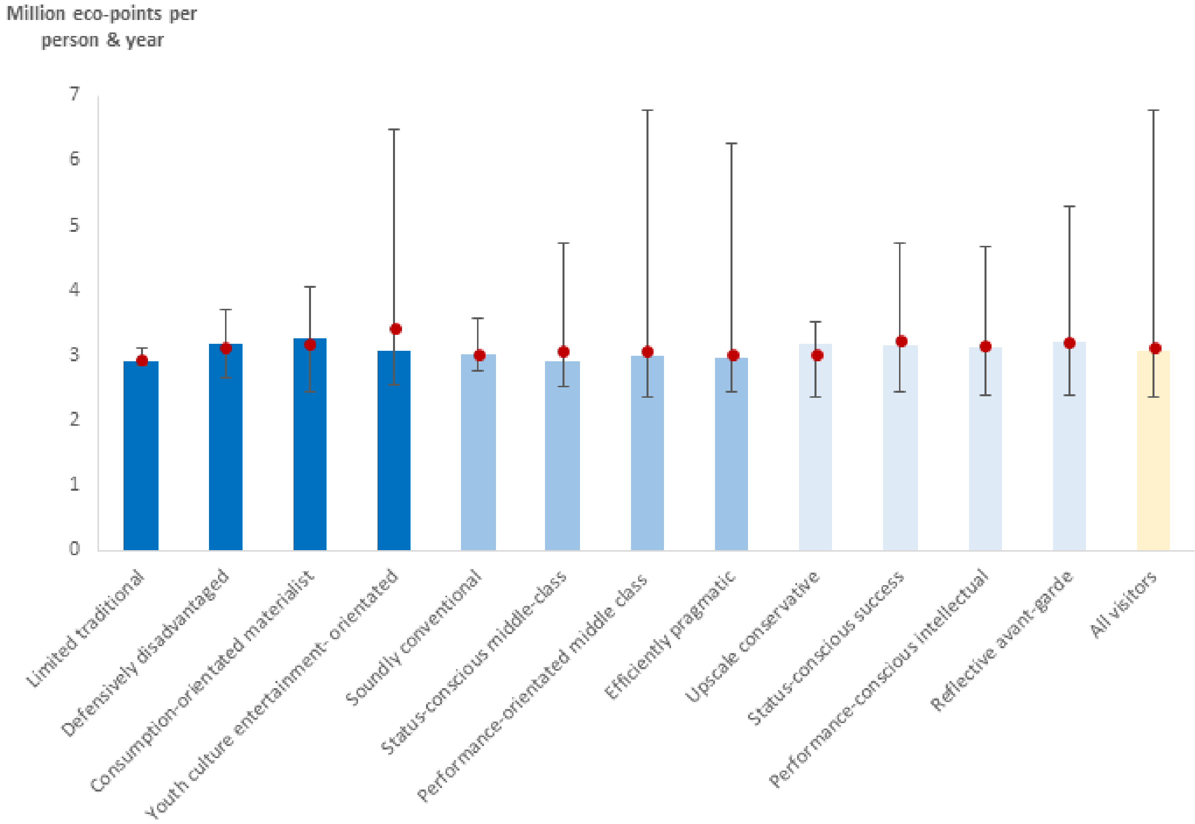

Figure 1: Top: model of the socioeconomic profiles determined by available social and economic capital combined with modernity (Stelzer & Heyse, 2016). Bottom: the environmental impact of nutrition according to socioeconomic profile and of all visitors (yellow) in million eco-points per person and year according to the ecological scarcity method (Frischknecht et al., 2013). The bars represent the median values, the red dots the average. The error bars show the range from the lowest to the highest value within each category.

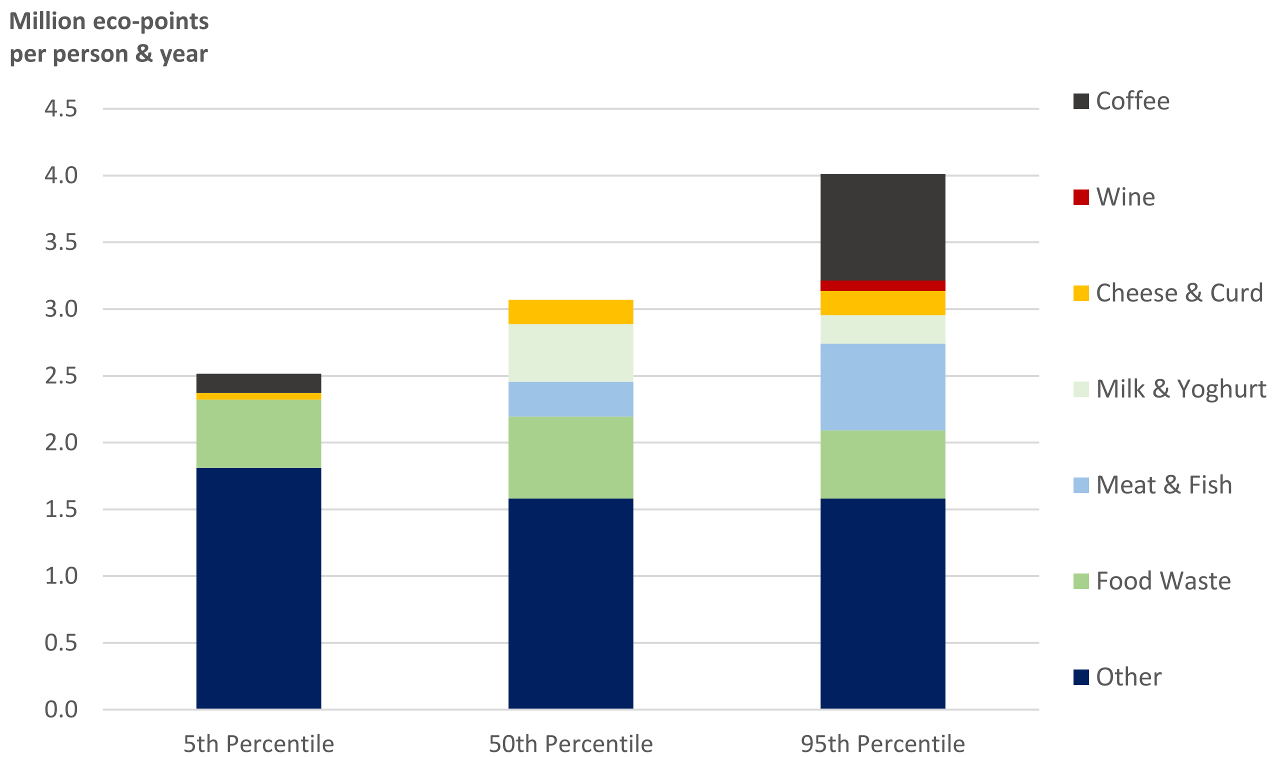

Figure 2: The environmental impact of nutrition by category of three participants at the 5th, 50th and 95th percentiles, in million eco-points per person and year according to the ecological scarcity method (Frischknecht et al., 2013).

The proportion of visitors who are vegetarian and vegan is considerably higher than the Swiss average: according to a survey by Swissveg (2020), 5.1% of respondents do not eat meat, compared with 18% of visitors. The exhibition has attracted many visitors, ranging from school students to retirees, which has allowed us to consider a broad spectrum of society. However, we expect that the majority of the visitors are at least somewhat interested in environmental issues and therefore do not necessarily represent the broader public.

The nutrition-related impact is highest for omnivores (3.2 million eco-points on average) and lower for vegetarians (2.8 million eco-points on average) and vegans (2.9 million eco-points on average). While some studies show lower impacts from vegans compared to vegetarians, i.e. Jungbluth et al., (2015), a study evaluating the impact of nutrition using individual recorded dietary intakes rather than average diets found no difference between vegetarians and vegans (Rosi et al., 2017), similar to our results.

The limitation of questions to the most relevant aspects ensured high participation but reduced the level of detail possible for the analysis. More detailed data could reveal larger differences between the socioeconomic profiles that were not revealed in our study.

Conclusions

While there are only small differences in the nutrition-related environmental impact of the socioeconomic groups, there is a large range within many of the groups, indicating that other factors, such as gender and environmental awareness, play a larger role. The large range of impacts resulting from nutrition indicates that there is significant improvement potential in this area. The exhibition has allowed us to collect valuable data and gain insights into trends and patterns.

Acknowledgements

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Abstract code: 185

Testing the use of nutritional-LCA for estimating nutritional and environmental sustainability dimensions of agri-food production

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Abstract

Purpose: Improving agricultural food production in a nutritionally and environmentally responsible manner can help address global challenges such as climate change and micronutrient deficiencies. However, enhanced methodological approaches, such as nutritional-LCA, are needed for such endeavors. Nutritional-LCA is a nascent but important method that integrates nutrition into LCA so that the environmental impacts of food systems can be better represented when accounting for the multi-functionality of food.
Methods: To this end, we test the application of n-LCA with a global case study at the national food supply and food group levels, by combining food production, trade, environmental LCA, and nutritional databases. For this analysis, we use a nutritionally-adjusted functional unit. We calculate metrics related to nutritional quantity at the individual food group and national food supply levels along with metrics that estimate the nutritional diversity of a food supply. Nutritional estimates of supply are calculated via a trade-weighted matrix by combining regionally-specific nutritional databases with food supply data from FAOSTAT. We estimate environmental impacts, accounting for imports, by attributing regional environmental impacts from a meta-analysis of national food supply. We further explore methodological challenges associated with integrating nutrition into environmental LCA. Examples of such challenges include scaling, weighting, normalization, and comparative vs. non-comparative measures.
Results and discussion: A clear assemblage of food groups emerge when measured on a nutritional and environmental basis. However, trends at the supply level are not as clearly defined. We further find that integrating nutrition into environmental LCA reveals new tradeoffs and affects results at both the food supply and food group levels. Finally, we find that methodological choice also influences final outcomes.
Conclusion: N-LCA study results dictate how actors can improve sustainable agri-food production systems; different results due to methodological choice or the use of a nutritional functional unit instead of one that is mass-based will change the consequent messages to society, which have repercussions in how we respond when optimizing our food system.

Keywords: *nutritional LCA; environmental sustainability; nutrient diversity; nutrition security; sustainable food production; life cycle assessment*

Introduction

Optimizing agri-food production on both a nutritional and environmental basis is needed to improve the overall sustainability of our food system, and recent papers have indicated that food system actors need more robust methods to accomplish this (Bogard et al., 2018; Green et al., 2020; Nelson et al., 2018). Food production can create significant environmental impacts such as biodiversity loss and freshwater scarcity (Campbell et al., 2017). Moreover, production can alter nutritional compositions (Green et al., 2020); for example, farmers can increase the nutrient content in meats by changing an animal's diet; alternatively, farmers can increase the vitamin content in fruits or vegetables via organic practices or biofortification.

We organize this work into three main parts. First, we estimate environmental impacts of agri-food production as well as components of nutrition security for national populations. Nutrition security encompasses all aspects of food security and places a strong emphasis on nutrient adequacy as opposed to only caloric adequacy (Ingram, 2020). Currently, over 2 billion people are micronutrient deficient and these deficiencies exist across all economic regions. In addition to food supply, we also calculate the nutrient-content of food groups and compare this against their environmental impacts. Second, we use nutritional-Life Cycle Assessment (n-LCA) to combine these indicators and assess agri-food production sustainability. The environmental impacts that we examine include greenhouse gas emissions, water use, eutrophication, land use, arable land use, and pasture land use. Nutrient measures include metrics that estimate nutrient quantity and nutrient diversity. Specifically, we use a more comprehensive variant of the Nutrient Rich Food Index 9.3 (i.e., NRF21.2) and Rao's quadratic entropy (Q). The NRF21.2 is a nutrient index that assesses the nutritional adequacy of food supply and includes both qualifying (e.g., protein, calcium) and disqualifying (e.g., sodium) nutrients that are measured against age-sex specific Daily Recommended Intakes. Q measures the diversity of food supply via a distance matrix based on nutrients and it is weighted by food quantity. Third, we examine methodological issues associated with integrating nutrition into environmental LCA. Key methodological questions that we answer include:

(i) Which metrics are more suitable for the functional unit and for what questions?

(ii) How should metrics be applied (e.g., capping, including/excluding disqualifying nutrients, weighting factors, nutrient selection)?

(iii) How should impact results be interpreted (e.g., comparative vs. non-comparative measures)?

(iv) How do environmental impacts of food groups or the food supply change when evaluated on a nutritional basis?

(v) How should we handle issues of scaling and normalization for different nutritional metrics, within LCA?

(vi) How should one handle challenges associated with data quality including system boundary discrepancies, harmonized datasets, and the appropriateness of proxies?

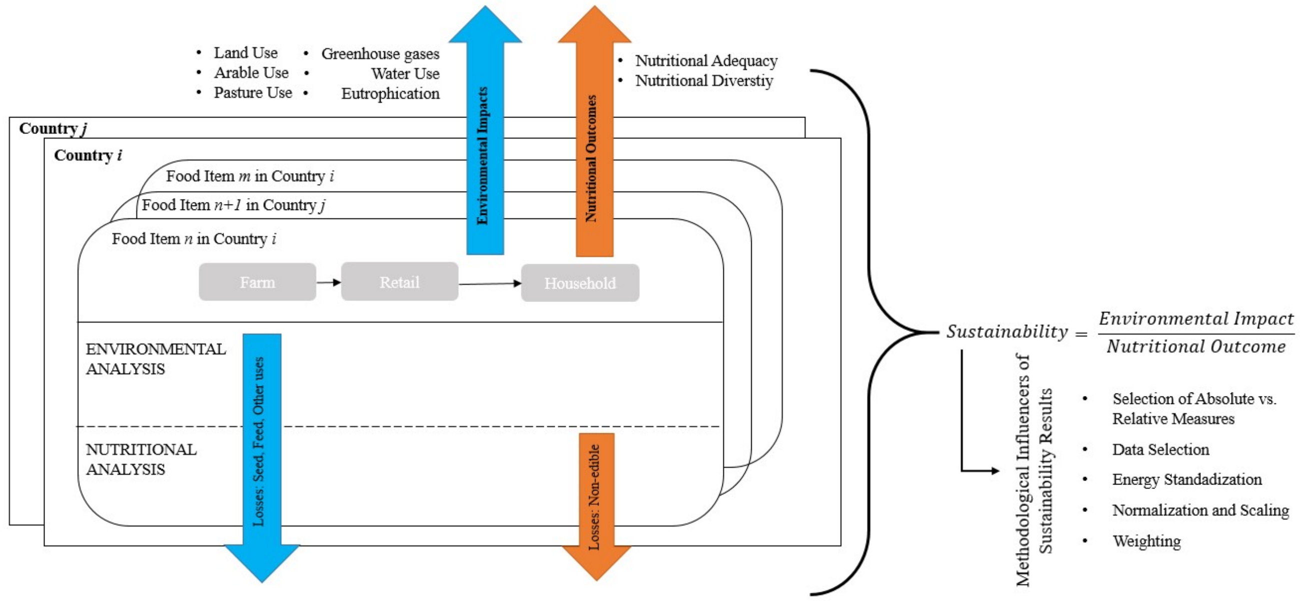

Figure 1. Overview of the paper's objectives and methods.

Material and methods

For this analysis, we integrate a nutritionally-adjusted functional unit into environmental LCA. For the nutritional analysis, we calculate metrics related to nutritional quantity at the individual food group and national food supply levels along with metrics that estimate the nutritional diversity of a food supply. Nutritional estimates of supply are calculated via a trade-weighted matrix by combining regionally-specific nutritional databases with 2014-2017 food supply data from FAOSTAT. We do this because FAO presents data in terms of aggregated Food Balance Sheet groups. However, groups such as 'other fruits' or 'other vegetables' are comprised of many diverse items (FAOSTAT, 2020). Nutrient data comes from regionally-specific databases (Smith et al., 2016). We estimate environmental impacts, accounting for imports, by attributing regional environmental impacts to national food supply calculated from FAO data. Environmental data at the regional level is adapted from a previous Science publication (Poore and Nemecek, 2018).

Results and discussion

In this contribution, we focus on selected, preliminary results that we summarize below:

- Spearman rank correlations show that many of our nutrient metrics are not correlated, which signifies that researchers can use a suite of indicators when assessing sustainable food systems.
- As expected, we find that including nutritional aspects of food does influence LCA results. At the food group level, we see that accounting for nutrition can reveal new tradeoffs in the system. For example, animal-based products, on average, have higher impacts than plant-based products; however, animal-derived items also provide specific nutrients that are not readily accessible in plant-based foods. Moreover, as shown in Figure 2, when accounting for nutrient diversity, the percentile rankings of countries change. Countries that changed rankings generally have a substantially higher nutrient diversity than other nations.
- Differences within food groups can be important levers to pull when trying to optimize food systems. For instance, we show how impacts of foods on a combined nutritional and environmental basis vary amongst different meat products (i.e., poultry, bovine, pig, and goat/sheep).

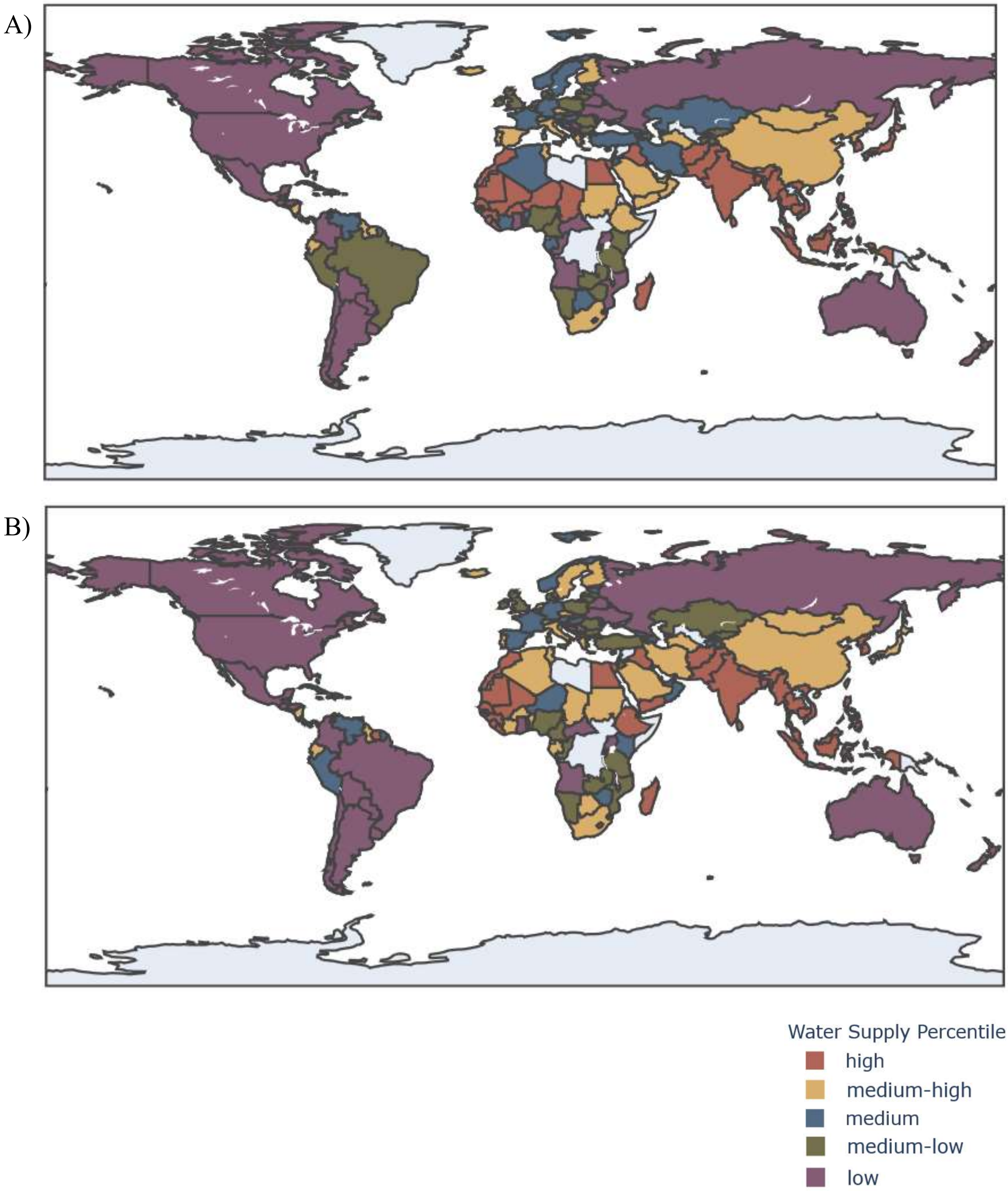

Figure 2: Water use (L) of food production for each country. Figure 2A is measured against a functional unit of 1 kg of food supply and figure 2B is measured against a nutrient diversity [i.e., functional dispersion (Fdis)] adjusted functional unit. Fdis is an alternative metric that is strongly correlated with Q. The colors represent percentile rankings of countries; 'low' shows the 20 percent of countries that are in the bottom quintile.

Methodological issues that we examine include the use of nutrition metrics as the functional unit so that assessments can represent the health-environmental benefit to society. This is needed because previous studies have been predominately mass or kcal based, which leads to incomplete assessments that do not consider the multi-functionality of food systems. As mentioned in Figure 1, we explore five key methodological challenges. One challenge that we explore is the inclusion or exclusion of disqualifying nutrients in the functional unit (FU), which can lead to negative impact values, depending on the type of nutrition metric used (i.e., quantity vs. diversity). We find that disqualifying nutrients pose a challenge with nutrient quantity metrics but not for diversity metrics.

Conclusion

Targeting the agri-food production of specific food items can greatly influence the sustainability of food supply and diets because actors can optimize foods across or within food groups on nutritional and environmental bases to meet specific nutrient requirements or environmental goals. We suggest that studies carefully consider and detail the assumptions behind the five methodological issues outlined in Figure 1. Methodological choice can greatly influence results and the resultant information communicated to food actors describing how to optimize their food system.

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Abstract code: ID 53

Proposal and application of a nutrient density-based functional unit for food LCA studies

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Abstract

Purpose: Nutrient density indexes are increasingly used as complementary functional units (FU) in food life cycle assessments (LCA), but the lack of standardized methods has led to unharmonized results difficult to compare. This work aims to systematically assess the role of methodological variables in nutrient density calculations, identify and apply a method best suited to be incorporated in comparative environmental studies.
Methods: The Nutrient Rich Food (NRF) index was used for assessing the nutrient density of 118 food products. Forty-five NRF variants were developed and the role of reference unit, number and choice of nutrients, the application of capping and/or weighting evaluated. The index variant ranking foods with highest coherence to the Swedish food-based dietary guidelines was identified and further used to compare a subset of protein-rich foods in relation to their nutrient density and climate impact.
Results and discussion: The index variant, NRF11.3, (NRF 9.3 + folate and vitamin D) expressed per portion size or 100 kcal with weighting was identified as the best-performing indicator. Other methodological choices, such as including a higher number of nutrients or the use of capping alone or in combination with weighting did not improve the results. When the climate impact of protein-rich foods was related to NRF11.3, legumes, some soy-based products, pelagic fish and low-fat dairy products were identified as relatively higher in nutrient density and relatively lower in climate impact.
Conclusions: The method development conducted in this study allowed to identify a nutrient density index suitable to be used as a complementary FU in food LCA. Its application to the analysis of the climate impact of protein sources indicates foods that optimize nutrition at the lowest climate cost, hence providing a base for future recommendations on sustainable and healthy foods for the human diet.

Keywords: nutrient dense food, functional unit, LCA, methodological choice

Introduction

Nutrition-based functional units (FU) have been evaluated in the last years as an alternative to the traditional weight-based FU in food life cycle assessments (LCA). Although some studies have analyzed the impact of using nutrient density as a complementary FU as compared to other FUs in ranking foods for their environmental performance, very little is known regarding how the method should be optimized for this purpose. No recommendation exists for which nutrient density score ranks foods more correctly, leaving it open for LCA researchers to choose among many different indexes, with the consequence of results being difficult to compare and interpret.

Building on a recent literature review conducted by this group (Hallström et al., 2018), the Nutrient

Rich Food (NRF) index (Fulgoni et al., 2009) was identified among many nutrient density indexes as a robust, versatile and validated method, suitable for incorporation in environmental assessments, and therefore selected for use in this study. Here, we conducted a systematic assessment of the methodological variables related to the NRF index, with the aim to identify the variant able to rank foods with highest coherence to food-based dietary guidelines. We additionally assessed the suitability of the index to be used in climate impact analyzes of protein-rich foods. The outcome of this analysis constitutes a basis for future recommendations on how nutrient density indexes can be used in combination with environmental metrics by different stakeholders in the food system to drive a global shift towards more sustainable and healthy food consumption patterns.

Material and methods

Nutrient density calculation

Nutrient density was calculated for 118 food products, from different food categories, representative of the Swedish diet, according to different variants of the base indicator NRF9.3 index (Eq 1) (Fulgoni et al., 2009):

$$NRF = \sum_{i=1}^{x} \frac{Nutrient\ i}{DRI\ i} - \sum_{j=1}^{y} \frac{Nutrient\ j}{MRI\ j} \qquad \text{(Eq 1)}$$

Where x is 9, the number of desirable nutrients (protein, fiber, vitamins A, C, E, Ca, Fe, Mg, K), y is 3, the number of non-desirable nutrients (saturated fat, added sugar, Na), nutrient i/j is the content of nutrient i or j per reference unit of the food product, DRI is the Dietary Reference Intake of desirable nutrient i and MRI is the Maximum Recommended Intake of non-desirable nutrient j. DRIs and MRIs were obtained from the Nordic Nutrition Recommendations 2012 (NCM, 2014). Nutrient composition was derived from the Swedish Food Agency (SFA) Food Composition Database (version 20171215). For products containing added sugars, the content was obtained from personal communication from the SFA. Portion sizes were retrieved from the same database, or, if not available, from the Food Composition Databases of the U.S. Department of Agriculture (USDA).

Selection of a nutrient density index

Forty-five different NRF variants were assessed regarding their ability to rank foods clustered in 53 subgroups. The index variants differed in reference unit (100 g, 100 kcal, portion size), number and choice of desirable nutrients (9, 11 and 21) and the application of capping and/or weighting. Capping of nutrients exceeding 100% of DRI was used to avoid crediting overconsumption of nutrients in the NRF calculation. Weighting was applied to correct the weight of the individual nutrients in the NRF formula based on the nutritional status of the studied population (Amcoff et al., 2012).
For each variant, the level of coherence with the Swedish food-based dietary guidelines (SFA, 2017), was assessed in the highest quintile (Q1) of nutrient density. Specifically, the percentage of healthy foods ("green foods", i.e. foods which should be eaten more, or "yellow foods", i.e. foods considered healthier alternatives) and the representation of healthy food groups emphasized by the guidelines ("green food groups": vegetables and legumes, nuts and seeds, fruit and berries, seafood) were calculated for Q1.

Combined climate impact and nutrient density of foods

The best performing NRF variant was used to combine nutrient density and climate impact of protein-rich foods (≥ 20% energy from protein) in a two-axis graph. The climate impact of the analyzed foods was based on data from Research Institutes of Sweden (RISE) Food Climate Database (2019; 2018).

Climate impact was expressed as kg of CO_2 equivalents per kg food, including greenhouse gas emissions produced between primary production and industry gate, excluding emissions from packaging and land use change.

Results

When the NRF variants were assessed for the percentage of healthy foods in Q1, the indexes NRF9.3 and NRF11.3 reported similar results. It is apparent that the inclusion of more nutrients in the NRF algorithm (NRF21.3) instead led to ranking food subgroups with the weakest level of coherence to the food-based guidelines (Figure 1). When the representation of the four groups emphasized by the dietary guidelines was analyzed in Q1, NRF11.3 calculated per portion size or per 100 kcal with the application of weighting were the index variants based on the simplest calculation algorithm that gave best results (Figure 1). NRF11.3 as compared to the base NRF9.3 algorithm, includes two additional nutrients, vitamin D and folate, which are at risk for deficiency in the Swedish population. The application of capping, alone or in combination with weighting, did not lead to a higher coherence to the guidelines for any of the NRF variants analyzed in this study.

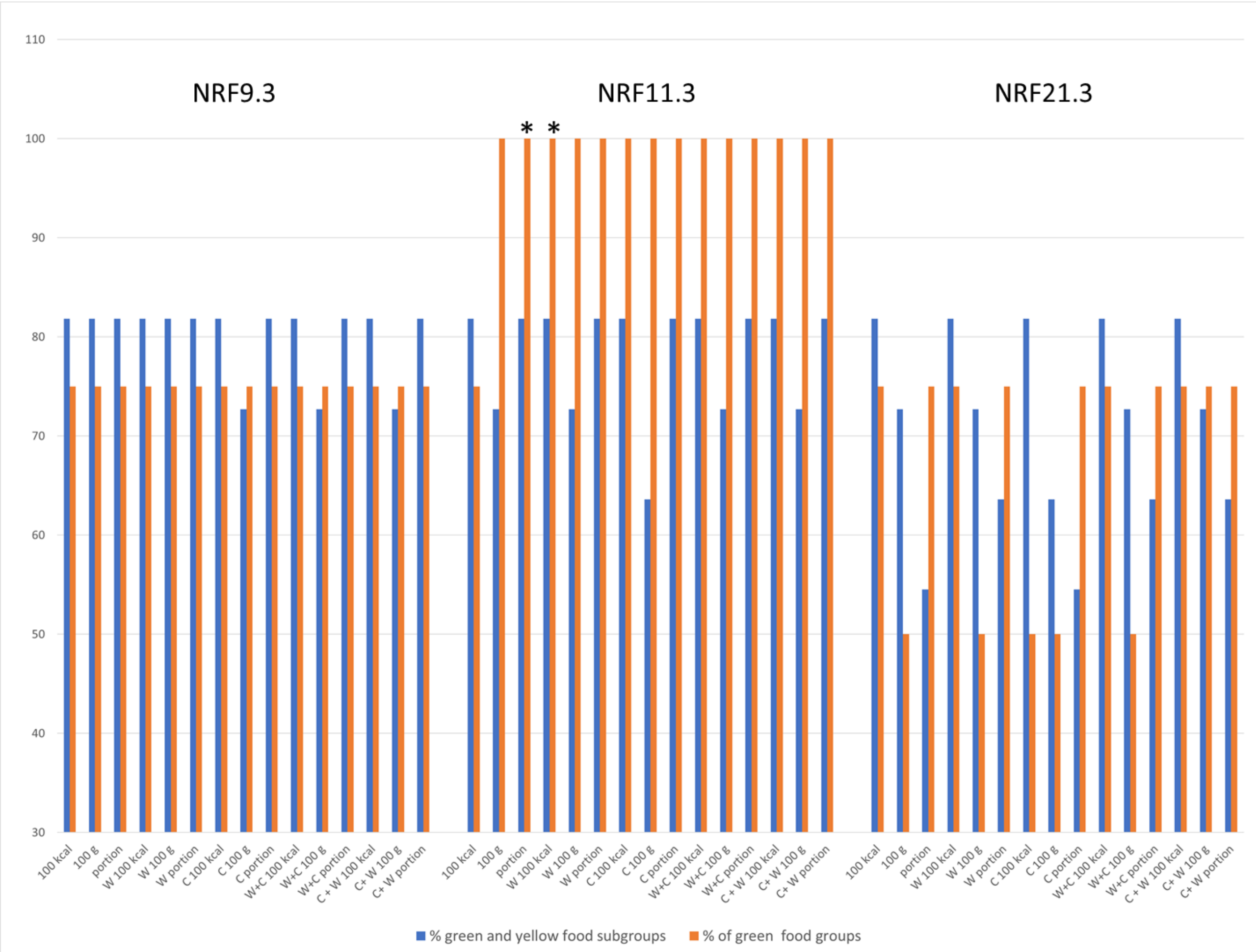

Figure 1: Level of coherence to the dietary guidelines in the highest quintile for nutrient density of food subgroups ranked according to 45 variants of NRF index. Variants are calculated per different reference unit (100 kcal, 100 g, and portion size), choice of nutrients (9.3, 11.3, 21.3) and the application of weighting (W) and/or capping (C). * indicates the index variants based on the simplest calculation algorithm that gave the best results.

When NRF11.3 calculated per 100 kcal with weighting was integrated with climate impact calculated per kg food product in the analysis of the 34 high-protein products, major differences in the performance of animal vs. plant-based foods could be appreciated (Figure 2). Mainly, meat products showed relatively lower nutrient density and relatively higher climate impact, with ruminant meats having the highest climate impact and pork ham the lowest nutrient density. Vegetables, legumes, enriched soy drink and low-fat dairy products showed relatively higher nutrient density and relatively lower climate impact. Low energy-dense vegetables such as spinach (outlier, not shown in the figure) and kale had the highest nutrient density, whilst red lentils showed the lowest climate impact.

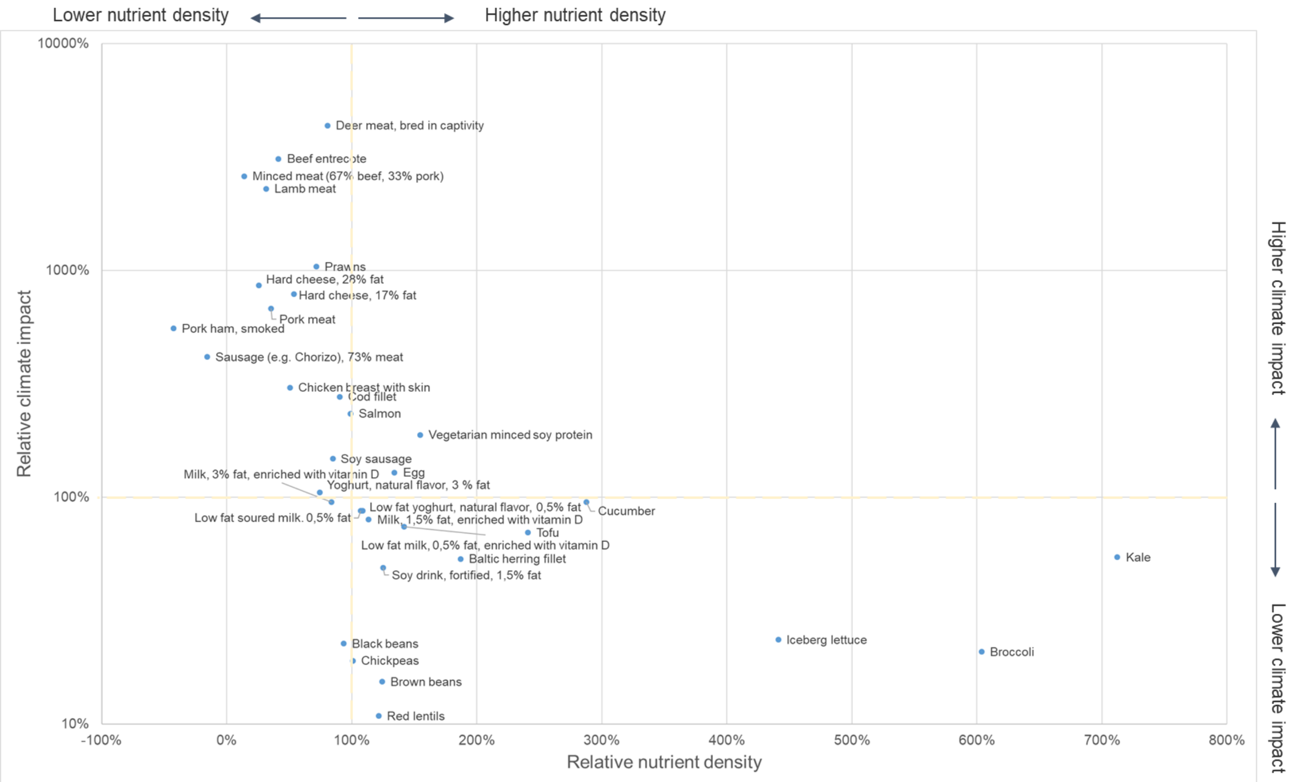

Figure 2: Relative nutrient density and Relative climate impact of protein-rich foods, expressed as percentage of median value. The relative climate impact is logarithmized. Nutrient density is calculated based on NRF11.3 per 100 kcal with weighting. Dotted lines represent median values. Spinach is not represented due to its high nutrient density (1374% of the median).

Discussion

In order to identify a nutrient density index best suited for use within food LCA, we developed a new method to validate nutrient density indexes based on the level of coherence to the dietary guidelines. Although the validation method was developed with reference to the Swedish dietary guidelines, its principles can be applied more broadly. Most of NRF variants assessed ranked foods coherently with the dietary guidelines, confirming that nutrient density is indeed an index of food quality that can be used to guide consumers and product developers towards healthier options. However, differences in methodological choices of reference unit, included nutrients and application of capping and/or weighting, had an impact on the performance of individual foods and food subgroups.

The identified method with highest performance (NRF11.3) is proposed as the most suitable index for use in a Swedish context as it includes two nutrients of special relevance for the Swedish population, folate and vitamin D. Further, our results indicate that NRF11.3 calculated both per 100 kcal with the application of weighting or per portion size equally well promotes healthier foods as the most nutrient dense, allowing for flexibility of use for different purposes.

Assessing the sustainability of dietary protein sources is today a central theme in the effort to drive shifts towards a more sustainable food consumption. Using a nutrient density index to include the nutrient quality in the evaluation of the climate impact of foods, provides the advantage of describing both the nutrition and environmental dimensions, and enables the identification of foods optimizing both aspects. When this approach was applied to food products potentially contributing to the protein intake of the diet, legumes, some soy-based products, pelagic fish and low-fat dairy products were highlighted as relatively higher in nutrient density and lower in climate impact compared to other animal-based protein sources.

The method highlighted in this study constitutes a basis for future recommendations on how nutrient density indexes can be used in combination with environmental metrics by different stakeholders in the food system to drive a global shift towards more sustainable and healthy food consumption patterns.

Acknowledgements

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Topic 9:

LCA Challenges in Americas

Abstract code: 311

Aquaponics in Canada: Environmental Burden or Food Security Solution?

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Abstract

Problem and Aim

Current agricultural production places enormous burdens on the earth. Thus, food production systems will be challenged in the future to meet food security goals given growing populations and mounting pressure to limit resource use and environmental impact. In Canada especially, the short growing season and cold climate limit vegetable production and create reliance on indoor food production, which is energy-intensive, both in terms of cultivation and transport[1]. One proposed solution is to employ aquaponics, which simultaneously produces fish and vegetables, to diversify production and increase resilience in the food system; however, it is important to ensure this innovation does not cause further environmental harm. While aquaponics systems are generally accepted as a solution due to reduced waste and efficient nutrient cycling[2], there is a large amount of uncertainty surrounding sustainability, especially in cold regions.
The gap between theoretical knowledge and practical application of aquaponics systems exacerbates the uncertainty surrounding their sustainability assessment and ideal operating conditions. Even more challenging is assessing emerging technologies with no clear definitions of structure and practice. Thus, this project aims to identify environmental and economic implications of a small-scale commercial aquaponics facility in Canada using a life cycle approach.

Methods

A life cycle assessment (LCA) and life cycle costing (LCC) model will be developed and tested with data collected from a small-scale facility in Nova Scotia, Canada. This system, located in a refurbished warehouse, produced trout and lettuce throughout the period of 1 year. Inputs, including feed, water, and energy, and outputs, including plants and fish, were boundaries for this cradle-to-gate study. As well, wastes produced on-site up to harvest, i.e. unusable fish and plant parts, are considered. Functional unit selection reflects mass allocation done in similar studies, where 1 kg of combined product consists of 90% plant and 10% fish. Then, life cycle inventory data is a culmination of published and operational data from literature and the facility. Based on this scope, impact assessment includes the categories of: ozone depletion, global warming potential, and eutrophication. Improvement scenarios are explored.

Results and Discussion

Preliminary findings from this study indicate that regardless of system type, large energy requirements in cold regions contribute to reduced profitability and increased environment degradation due to Nova Scotia's reliance on fossil-based energy. It is expected that other system inputs, including fish feed and water, will also impact environmental and economic sustainability. This is comparable to other studies that found that lighting and heating requirements were large and unsustainably costly in cold regions[3]. Overall, it is apparent that optimization of inputs and operational parameters, especially fish feed, lighting and heating, requires additional research, especially in cold regions. Results from this study will provide much needed clarity on the sustainability of aquaponics applications in Canada and in cold climates in general. In optimizing

aquaponics, potential for responsibly increasing fish and vegetable production can be developed in the future.

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Abstract code: 159

Net Zero Energy Barns for Industrial Egg Production Facilities: An Effective Sustainable Intensification Strategy?

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Abstract

Purpose Net zero energy (NZE) poultry housing has been proposed as a sustainable intensification strategy for the egg industry, but it's efficacy in improving sustainability outcomes compared to conventional layer barns is not well understood. The purpose of the research was to use environmental life cycle assessment to evaluate and compare environmental outcomes for NZE and conventional housing systems in the egg industry.
Methods To support sustainability management and the development of policy recommendations regarding using net zero energy (NZE) building technologies in Canadian poultry production, an ISO 14044-compliant attributional life cycle assessment (LCA) was performed. The LCA quantified and compared the environmental profile of an NZE free run egg barn located in Alberta, Canada to a parallel, hypothetical non-NZE barn. Results were evaluated and compared for 1) the barn infrastructure; 2) infrastructure plus direct energy use; and 3) all inputs and emissions associated with the cradle-to-farm gate production of one tonne of eggs in each barn. Environmental impact payback times (eIPBTs) (Xie et al. 2018) were calculated for use of the NZE barn in Alberta, as well as for a scenario assuming the barn operates in each Canadian province.
Results and discussion The NZE barn infrastructure has higher impacts, principally due to the solar PV array that is used to supply renewable energy. However, the combined impacts of infrastructure and operational energy inputs are much higher in the non-NZE barn. Overall, the life cycle impacts of egg production in the NZE barn are, depending on impact category, 0.89-64.82% lower. The eIPBT of the NZE barn in Alberta, which has a largely fossil fuel-based electricity grid, ranges from 1.38 to 20.66 years, depending on the impact category considered. All eIPBTs fall within the assumed 30 year life span of the barn, indicating that NZE poultry housing will generate net life cycle environmental benefits.
Conclusions Implementation of net zero energy poultry housing appears to present a promising sustainable intensification strategy for the egg industry. However, eIPBTs will be higher in regions with green electricity grids. Implementation of alternative, context appropriate renewable energy generations systems (for example, wind turbines, where sufficient wind resource exist), may reduce eIPBTs. Future research should incorporate analyses of economic feasibility and other social considerations.

Keywords: *net zero energy; poultry; eggs; sustainable intensification; agriculture*

Introduction

Eggs make a significant and growing contribution to global diets (Windhorst 2014). LCA studies generally agree that the production of feed inputs accounts for the largest share of life cycle impacts attributable to egg products (Pelletier et al. 2018). However, some studies have also suggested that direct energy inputs to housing operations may account for up to 50% of total non-renewable energy use along egg supply chains (Bengtsson and Seddon 2013). In addition, none of the LCA studies reported to date considers the life cycle burdens associated with construction, maintenance, and eventual decommissioning of the buildings in which intensively reared poultry are housed.

Net zero energy buildings (NZEBs) are energy efficient buildings that incorporate renewable energy generation systems so as to produce sufficient renewable energy to at least offset the total amount of non-renewable energy used by the building on an annual basis (Wells, Rismanchi, and Aye 2018). While ample research has considered commercial and residential applications, little attention has been paid to date to the feasibility and mitigation potential of net zero energy building technologies in the intensive animal agriculture sector.

A net zero energy (NZE) egg barn pilot project is currently underway in Alberta, Canada, with the aim of trialing technologies for reducing energy consumption and GHG emissions in this sector. The facility comprises a single-story free-run barn with a high efficiency building envelop. A 25-kW solar PV array has been installed to offset electricity use in the layer barn, and a heat recovery ventilator (HRV) is used to recover heat from exhaust air during winter months. The barn houses roughly 13,540 hens and produces approximately 370,685 dozen eggs per year. The aim of the current study was to utilize ISO 14044 compliant life cycle inventory modelling and assessment to characterize and evaluate the environmental profile (life cycle resource use and emissions) of this NZE poultry housing system compared to a reference (non NZE facility) scenario. Specifically, the study aims to: (1) understand the comparative life cycle impacts of the NZE compared to non-NZE building infrastructure; (2) compare the direct energy requirements for housing laying hens in NZE compared to non-NZE buildings; and (3) assess the extent to which utilizing NZE housing may influence the overall life cycle resource and environmental impacts of egg production. The study also (4) calculates environmental impact payback time (eIPBT) for the NZE facility in Alberta compared to a hypothetical situation where the facility is located in other Canadian provinces so as to assess the relevance of regional electricity grid mix in determining the mitigation potential of such facilities.

Material and methods

The primary objective of this study was to use ISO 14044-compliant attributional life cycle assessment to quantify and compare the environmental profile of a pilot NZE egg production facility located in Alberta, Canada to that of a parallel conventional, non-NZE egg production facility. The cradle-to-farm gate Canadian egg supply chain LCI model that was used as the baseline model for this research is reported in (Pelletier 2017). This model includes all major stages of the Canadian egg supply chain (i.e. breeder flock, hatchery, pullet, and layer facility) and associated material and energy inputs and emissions but does not include housing system infrastructure. The current study expands the system boundary of (Pelletier 2017) to include the cradle-to-grave life cycles of the pilot net zero energy free run egg barn located at Brant Colony (Alberta, Canada) and an otherwise equivalent, hypothetical conventional, non-NZE free run egg barn constructed to current industry standards. Direct energy input and generation data for the NZE barn are based on 12 months of operational data for the year 2017, whereas direct energy inputs, including natural gas and electricity, for the non-NZE barn are based on an average of direct energy use in two conventional free run facilities in Alberta (3D Energy and Prism Engineering 2018). All upstream, core and downstream processes of a building's life cycle were taken into account. The openLCA 1.7 software platform was used to complete the LCIA phase. The impact categories considered were abiotic resources, land use, climate change, ecotoxicity, acidification, eutrophication, photo-oxidant formation, and cumulative energy use. All categories were assessed at mid-point level. eIPBT is the time required for a NZEB to offset the resource/environmental impacts (EI) associated with its life cycle relative to a non-NZE scenario. In this study, eIPBT was used (following Xie et al. 2018) to estimate the time needed for the NZE free run egg barn to offset its environmental impacts compared to a reference conventional non-NZEB barn. This was first calculated for the Brant Colony NZE barn, then subsequently for a scenario in which the NZE barn was assumed to be located in the different provinces and territories in Canada (each of which has its own independent electricity grid) in which egg farms are currently located.

Results and Discussion

Infrastructure-related life cycle impacts of the NZE layer barn were higher than those of the non-NZE barn, largely due to the solar PV system (Figure 1). Producing solar PV panels is widely recognized as an energy-intensive process (Xie et al. 2018). The embodied energy share of the total cumulative energy use hence increased from 29.07% to 66.79% between the non-NZE and NZE barn infrastructure. Despite having significantly more, the additional insulation used in the NZE barn added only a small increment to total infrastructure-related impacts. However, the additional insulation contributed to substantially reducing the use of natural gas for heating the NZE barn, hence making a critical contribution to achieving NZE status, as did use of the heat recovery ventilator.

The majority of cradle-to-farm gate resource use and associated emissions in the Canadian egg industry are attributable to feed production (35-81%), manure management (17-46%), and pullets (19-23%) (Figure 2). Based on the LCI models of the layer barns developed in the current study, housing infrastructure adds a small amount to total life cycle impacts. Average infrastructure-related impacts across all considered impact categories are around 4.34% and 2.40% for the NZE and non-NZE barns, respectively.

Despite increasing infrastructure-related impacts, the results of this study indicate that NZE housing for intensive, confined poultry production can nonetheless generate non-trivial benefits due to the overall reduction in direct energy use in poultry housing. Direct energy inputs account for 6.47% of the life cycle cumulative energy use of egg production when employing NZE housing, and 31.64% for egg production in the non-NZE housing (Figure 2).

Nonetheless, a cautionary note regarding the importance of considering context in place of accepting generalizations with respect to the potential environmental benefits of NZE poultry housing is clearly warranted. The scenario analysis undertaken in the current study indicated that the environmental impact payback time of NZE poultry housing with solar PV systems will generally be shorter than the anticipated life span of the barn in regions where fossil fuels dominate the electricity grid mix. This implies that the installation of the NZE infrastructure will provide net environmental benefits over time. Notably, eIPBT with respect to GHG emissions and cumulative energy use is well within the anticipated lifespan of the barn in all provinces. However, this may not be the case for all impact categories in regions with "greener" electricity grids (Table 1).

It should also be noted that the scenario considered in this study assumes *ceteris parabis*, and is hence overly simplistic. In reality, direct energy input levels will be influenced by climatic factors, which will vary province by province, as well as housing system-specific conditions. In addition, while solar PV may present the best renewable energy system for an NZE barn in Alberta, availability of solar and other renewable energy resources varies within and between provinces. In some cases, other renewable energy systems (for example, wind turbines) may be more suitable for integration into NZE housing systems. The optimal selection of a renewable energy generation system should consider barn locations (such as mountains or lowland) and local climates (such as wind speeds).

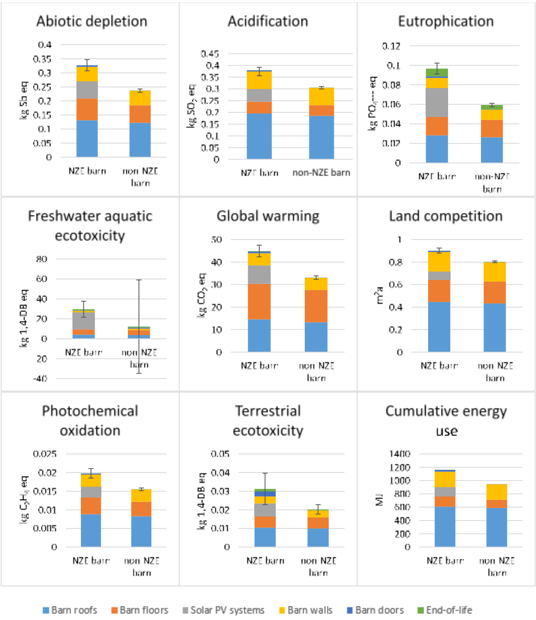

Figure 1 Comparison of the life cycle environmental impacts attributable to housing infrastructure only per tonne of eggs produced in the NZE compared to non-NZE free run egg barns (standard error indicated).

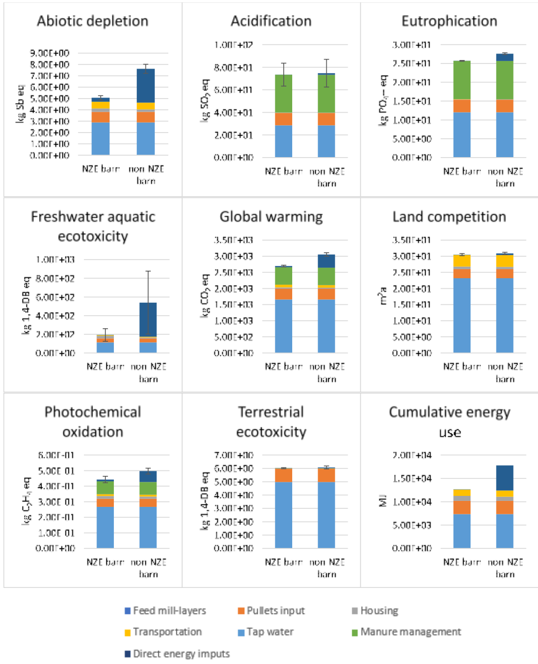

Figure 2 Comparative cradle-to-farm gate LCIA results of egg production in the NZE and conventional non-NZE free run egg barns (per tonne of eggs) (standard error indicated).

Province/ territory	Electricity sources	AD	Acid	Eutr	FAE	GWP	LC	PO	TE	CEU
AB	Nat. gas, coal	5.4	6.7	1.4	2.3	5.1	20.7	8.7	10.6	7.9
BC	Hydro	14.6	23.1	13.7	9.6	14.7	26.9	22.1	19.5	11.9
NT	Petroleum	10.0	8.4	16.7	11.1	9.4	27.4	10.4	8.0	9.5
SK	Coal, natural gas	6.3	8.2	1.8	2.8	6.0	23.0	10.1	12.5	8.6
MB	Hydro	17.9	27.1	22.9	11.2	17.7	29.1	24.4	25.4	12.8
ON	Uranium, hydro	15.1	24.3	23.9	11.00	15.3	28.9	21.4	22.3	7.2
QC	Hydro	18.8	30.1	35.7	44.9	18.9	31.19	26.4	34.7	13.0
NB	Uranium, Coal, hydro	7.9	8.0	8.3	7.1	8.1	13.9	9.9	14.7	7.5
NF	Hydro	16.9	21.9	26.3	11.7	16.5	29.6	21.4	20.3	12.5
NS	Coal, natural gas	4.7	3.9	3.6	4.2	4.8	7.1	5.6	11.0	7.0
PE	Wind	10.2	10.9	11.2	7.8	10.3	16.1	12.8	16.5	8.9

Table 1. Environmental impact payback time for the NZE barn with solar PV system in different provinces in Canada (yellow indicates instances where eIPBT) would not be achieved within the anticipated lifespan of the barn). AD = Abiotic depletion; Acid = Acidification; Eutr = Eutrophication; FAE = Freshwater aquatic ecotoxicity; GWP = Global warming potential; LC = Land competition; PO = Photochemical oxidation; TE = Terrestrial ecotoxicity; CEU = Cumulative energy use. AB = Alberta; BC = British Columbia; NT = Northwest Territories; SK = Saskatchewan; MB = Manitoba; ON = Ontario; QC = Quebec; NB = New Brunswick; NF = Newfoundland; NS = Nova Scotia; PE = Prince Edward Island.

Conclusions

Implementation of net zero energy poultry housing appears to present a promising sustainable intensification strategy for the egg industry. However, eIPBTs will be in higher in regions with green electricity grids. Implementation of alternative, context appropriate renewable energy generations systems (for example, wind turbines, where sufficient wind resource exist), may reduce eIPBTs. Future research should incorporate analyses of economic feasibility and other social considerations.

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Environmental life cycle impact of processed potato and tomato products - now and in the future

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Abstract

Purpose
The impact of climate change (CC) on future food systems is uncertain but is generally expected to reduce productivity, depending on the crops and the agro-climatic settings. The current study presents environmental footprints of Fruit and Vegetable (F&V) supply chains, now and through 2050, considering the impacts of CC on these systems. A life cycle assessment method (LCA) was used to evaluate three types of processed potato products (chips, frozen fries and dehydrated) and one tomato product (pasta sauce).

Methods
The overall method for this study is governed by an LCA Protocol, designed for evaluating the target products. The functional unit (FU) for the life cycle impact assessment (LCIA) is 1 kg of processed products, eaten by a consumer. Data for on-farm activities were partly based on crop modeling results and further enhanced by regional enterprise crop budgets. Biowaste generated across the supply chain was handled through waste treatment models, including composting, landfill, combustion and use as animal feed.

Results
It was found that decisions on the method of processing and food preparation have larger consequences for both carbon & water footprints than any farmers' decisions. For instance, the use of vegetable oil (e.g. in fries) was found to contribute significantly to the selected environmental footprints. Major parameters influencing the environmental profiles for each product were (i) conversion ratio of raw crop to the final products (ii) types of packaging materials used and their end-of-life treatments, (iii) crop yields and agro-management practices, (iv) processing inputs, (v) consumption behavior, and (vi) biowaste treatment models. In the future climate scenarios, impacts varied depending on the increase or decline in the productivity of the crops across the selected crop reporting districts (CRDs). A lower water footprint in the future scenarios was obtained, due to improved crop water-use efficiency, mainly due to the fertilization effect from elevated CO_2 on crop growth, as well as improved farm efficiency due to projected technological advancements in irrigation.

Conclusions: Environmental sustainability metrics, e.g. land use and water footprints may improve in the future, due to anticipated increase of yields, and GHG emissions can be mitigated by waste reduction and process modifications.

Keywords: Fruits & vegetables, climate change, LCA

Introduction

The agriculture sector is a major human activity contributing to climate change and is also a highly affected sector due to climatic stresses (Thornton and Lipper 2014). Potential negative effects of climate change (CC) on F&V production systems include the possible loss of field-productivity and reduced product quality. In addition, there are increased risks of failure of the current crop protection strategies, due to pest infestations and different crop-water and nutrient stresses (Parajuli, Thoma, and Matlock 2018). In this context a multidisciplinary project was initiated in the U.S. and is focused on evaluating the productivity, resilience, and sustainability of domestic F&V products (AFSI 2020). The project aims to evaluate strategies that can be applied to adapt to expected climatic effects across F&V supply chains, thereby helping maintain a nutritious, reliable, affordable, and environmentally-sound food supply. The overall purpose of the project is to integrate crop modeling, economic modeling, and environmental modeling to determine current and future climate and water availability impacts on yield, quality, price, and the environmental profile of selected F&V crops. This study is an integral part of that project and involved performing environmental life cycle impact assessments (LCIA) of potato and tomato products, accounting for the impact of climate change on the farm productivity of potatoes and tomatoes across the US.

Material and methods

The overall materials and methods for this study are supported by an LCA Protocol (Parajuli et al., n.d.). The protocol presents the detailed life cycle inventories (LCIs) and the underlying assumptions made for calculating product reference flows and the raw materials consumed at different stages of the supply chain, through consumption and handling of consumer waste. An overview of the materials and methods is given below:

Scope, functional unit, and impact assessment method

The main objective of this study is to evaluate the environmental life cycle impacts of consuming processed potato products (chips, frozen fries and dehydrated) and tomato pasta sauce. The potential environmental impact categories selected for the assessment, with their units are: global warming potential-100 (GWP_{100}) (in kg CO_2-eq), land use (LU) (in m^2a crop-eq), fossil resource scarcity (FRS) (in kg oil-eq) and water consumption (WC) (in m^3). These impact potentials were calculated using the ReCiPe 2016 Midpoint (E) method (Huijbregts et al. 2017); we chose the egalitarian cultural perspective as it is more appropriate for long-term assessment. We simulated using SimaPRO-9 with Ecoinvent v3.6 consequential system model for the background processes. The functional unit (FU) for the life cycle impact assessment (LCIA) is 1 kg product(s) eaten by a consumer.

Life Cycle inventory evaluation

A "cradle to grave" perspective was considered for the LCI evaluation. At the farm level, this study utilized the average LCI calculated for the major F&V crops producing crop reporting districts (CRDs) of the United States (US, capturing 80% of total production). Crop modeling of CC impacts on plant productivity was integrated into the LCA model. Future crop yields were estimated through a novel approach that involved combining effect of technology-trend on yield increment with the modeled effects of CC and higher levels of CO_2 (Gustafson, et al., in prep). Data for on-farm activities were partly based on crop models results (Zhao et al. 2019), and further enhanced by regional crop budget reports (University of Florida 2007; University of California 2017) and national statistics (USDA 2018). LCIs for the post-harvest stages were developed from related studies and engineering estimates (Parajuli et al., n.d.). LCIA was carried out for 8 scenarios: (i) baseline, as the current scenario, and (ii) two future climate scenarios representing the years 2030 and 2050, and (ii) three waste handling scenarios. Climate scenarios include the effects of elevated CO_2 and adaptation measures (earlier planting). Biowaste handling scenarios included composting (on-farm waste), animal feed (processor and retail waste); and for consumer waste undergoing composting, combustion and landfill (EPA 2018). In addition, anaerobic digestion (with further conversion of biogas to energy in a combined heat and power plant) was also considered as an alternative scenario.

Results and discussion

Overall environmental impact potentials

Environmental impact potentials and the relative contributions from the supply chain vary with the type of product. For example, in the baseline situation, the global warming potentials (or carbon footprint) (GWP_{100}) for potato-chips, frozen fries and dehydrated were 0.85, 1.21 and 0.65 kg CO_2eq per FU, respectively. Tomato pasta sauce had 1.5 kg CO_2eq per FU. Major parameters influencing the environmental profiles for each product were (i) conversion ratio of raw crop to the final products (ii) types of packaging materials used and their end-of-life treatments, (iii) crop yields and agro-management practices, (iv) processing inputs, (v) consumption behavior, and (vi) waste and loss generated and their treatment models. For other impact categories, in the order of potato-chips, fries and dehydrated products, the results were: FRS (0.22, 0.31 and 0.22), LU (0.57, 0.49 and 0.45 m^2-a-crop/FU) and WC (0.09, 0.1 and 0.088 m^3/FU). Regarding tomatoes, FRS was 0.5 kg oil-eq/FU, LU (0.75 m^2-a-crop/FU) and WC was 0.18 m^3/FU.

Environmental hotspots

Of the total greenhouse gas (GHG) emissions calculated for potato-chips, frozen fries and dehydrated products, the contribution due to potato farming was 23%, 18% and 30%, respectively. In the case of tomatoes, the GHG contribution from agriculture was 40% of the total impact. GHG emissions for potatoes was mostly due to the consumption of agro-chemicals, contributing 10-17% of the total impact, and followed by energy consumed for farm operations (farm implements and for irrigation) contributing about 4-7%, potato seeds (3%). For tomato sauce, it was mainly due to fuel consumption (for farm implements and irrigating water), contributing 22% of the total GHG emissions, agro-chemical production (9%), and production of tomato seedlings (7%). Processing of potato chips contributed 46%, while for potato-fries and dehydrated products, it was 33% and 37% of the respective impact. For tomato sauce, the contribution due to processing was 39% of the total impact. Retail (supermarket) contributed in the range of 11 to 25% for the processed products. At retail, potato fries had the highest impact compared to the other products, which was mainly due to the need of handling the frozen product in a refrigerated environment and during transportation. Contribution from the consumer stage for potato-chips, fries and dehydrated was 18%, 38% and 24% respectively. A higher contribution from the consumption phase in the case of fries was due to use of vegetable oil for deep frying.

Environmental benefits can be realized by utilizing unused crop product streams as substitutes for other materials, such as animal feed (through the utilization of biowaste generated from processing and retail), starch (recovered from the processing of potatoes) and composting of biowaste (handling on-farm and consumer waste). Environmental gains due to avoided products was thus in the form of crediting about 9-14% of GHG emissions for the processed potato products. Credits gained in the tomato pasta sauce supply chain were much lower (3%), because of the relatively higher moisture content and the equivalent functions/services of the marginal products they can displace. GHG emissions can be mitigated by waste reduction and modifications in the supply chain and consumer behavior.

Future environmental impacts

In the climate scenarios, impacts varied (Fig 1) depending on the variation in the productivity of the crops across the CRDs. In most of the CRDs, both crops showed increment in the yields, which was due to both effects of elevated CO_2 and technological advancement. We found that a resilient supply chain of potato-fries and tomato-pasta sauce can be anticipated through the adoption of planting adaptation strategies, mainly to avoid higher temperatures in later summer months. Expected yield increase and advancement in irrigation technologies showed prospects of reducing the land use and water footprints.

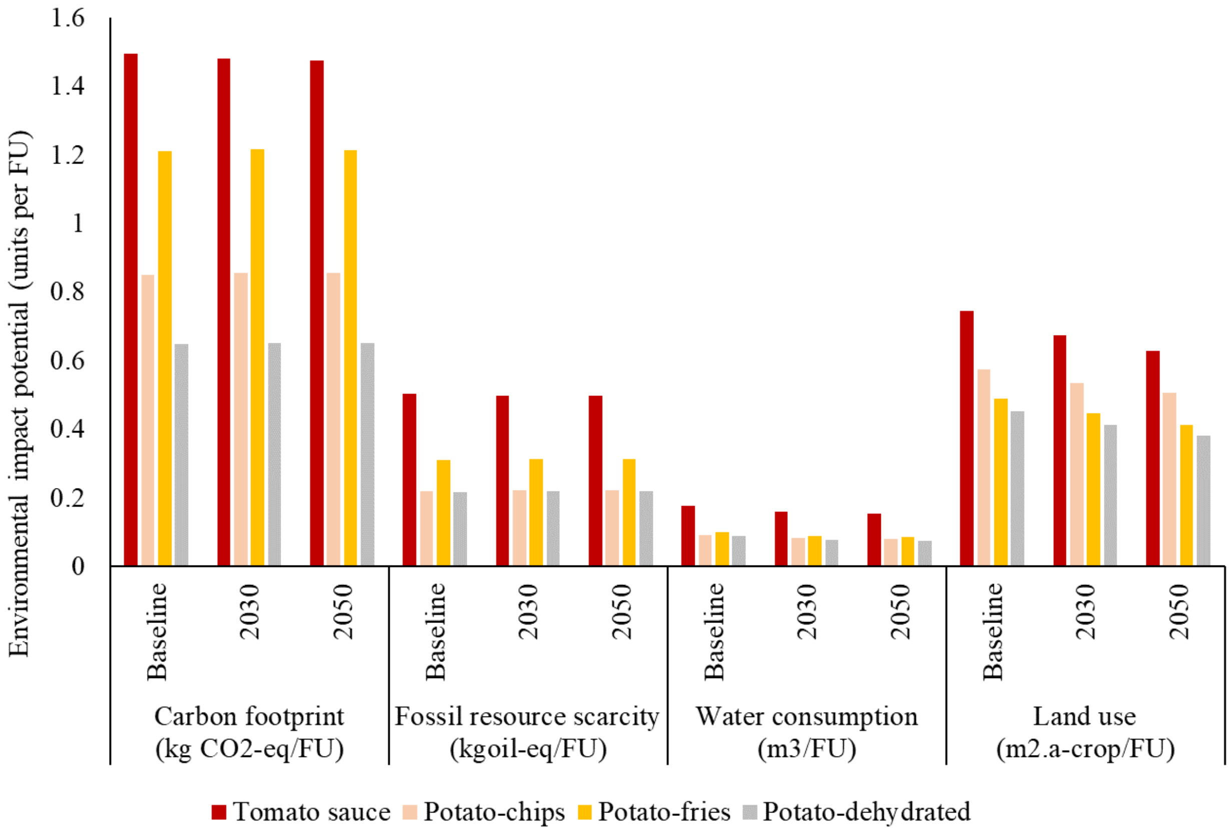

Fig. 1. Environmental impact potentials for consuming 1 kg product(s) in the baseline (2017) and in the future scenarios (2030 and 2050).

Conclusions

It was found that processing and food preparation activities have significant influence on both carbon & water footprints, overshadowing farmers' management decisions. The use of vegetable oil, e.g. in fries was found to contribute significantly to the environmental footprint. Environmental impact patterns for the selected products were largely dependent on the type of the product, which differed in terms of raw to final product conversion ratios, raw materials used and preparation at the consumer stage. Transportation and packaging materials were also the important contributing sources for the overall impact categories.

Due to effects of CC, maintaining resiliency in the F&V supply chain is increasingly challenging. We used a novel method to integrate climate, crop growth, economics and LCA models to the evaluate US potato and tomato supply chains. We aimed at characterizing the effectiveness of changing management strategies to adapt to CC. The results revealed that the supply chain of the two popular processed products in the US (French fries and pasta sauce) will be resilient through planting adaptation strategies to avoid higher temperature. Land use and water footprint are projected to decline over time due to anticipated increased yields. GHG emissions can be mitigated by waste reduction and process modifications.

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Environmental performance of controlled-environment agriculture: A case study on aquaponics and hydroponics in Indiana

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Abstract
Purpose
With high productivity and low land and water use, controlled-environment agriculture (CEA) has become a promising solution to feed the rapidly growing global population. However, CEA operations require high energy input, leading to potential environmental burdens.

Methods
This is the first study to evaluate and compare the cradle-to-gate environmental performance of two CEA systems, hydroponics and aquaponics, operated with identical system infrastructure in Indiana, US via an economic-based life cycle assessment (LCA).

Results and discussion
For a one-month cultivation period, tilapia and six vegetables produced in the aquaponics had almost twice the total value of the vegetables from the hydroponics. Aquaponics produced 45% lower endpoint environmental impact than hydroponics. Electricity use for greenhouse heating and lighting, and water pumping and heating contributed to the majority of the environmental impacts of both systems, which was followed by the production of fish feed and fertilizers. However, changing the energy source from coal to wind power could make the hydroponics more environment-friendly than the aquaponics.

Conclusions
The LCA model developed in this study is expected to provide CEA farmers in the Midwestern US with a decision-making tool to adapt farming practices with a lower environmental footprint, including energy source and feed formula.

Keywords: *Aquaponics; Hydroponics; Life cycle assessment; Economic functional unit; Controlled-environment agriculture; Sustainable aquaculture*

Introduction
Controlled-environment agriculture (CEA) produces food in an enclosed structure under optimized conditions for maximizing the yield of plant crops and/or aquatic animals using soilless systems such as hydroponics, aquaponics, and recirculating aquaculture system (RAS). Hydroponics grows plants using nutrient solutions without soil and needs less water and chemical fertilizer inputs than

open-field agriculture as the spent nutrient solution can be recirculated for an extended period. Aquaponics incorporates RAS into hydroponics to produce plants and aquatic species in a system linked by water and nutrients. In aquaponics, rather than being discharged and causing eutrophication and hypoxia in nearby water bodies, nutrient-rich wastewater derived from RAS, containing ammonia and feces excreted by fish, is directed to the hydroponic component, allowing nutrients to be recycled for plant growth. Additionally, aquaponics can eliminate fertilizer use, and thus reduce the associated environmental burdens. However, both aquaponics and hydroponics require high electricity input for heating, lighting, and water pumping for environment control, potentially leading to high global warming impact. Although there have been comparative studies between aquaponics and hydroponics on crop production (Yang and Kim 2019), their environmental performance was rarely compared in a systematic way.

While life cycle assessment (LCA) has been used for evaluating the resource use and emissions of aquaponics, most studies on aquaponics were conducted on lettuce considering it as the main product and fish as co-product (Forchino et al. 2017). This may result in an underestimation of the environmental impacts of fish, especially when they are allocated based on product mass. In this study, the environmental performance of hydroponics and aquaponics was, for the first time, explicitly compared using an identical infrastructure. We performed a cradle-to-gate LCA on these two independent systems mainly based on our primary experimental data collected over a one-month period. Both systems produced six plant species in addition to tilapia in aquaponics. This LCA study aimed to provide farmers with the groundwork to design and operate CEA production at reduced environmental cost.

Methods

Goal and scope of LCA

The main goal of this LCA study was to identify the environmental impact hotspots of the aquaponics and hydroponics, thus more sustainable practices can be recommended to CEA producers. The intended audience included aquaponic and hydroponic farmers who want to improve the environmental performance of their production. It is important to note that in addition to plants, aquaponics produces fish which generally has a higher market price. Therefore, instead of physical functional unit (FU), we considered the difference in product price by applying a monetary FU here for an economic-based comparison, which was defined as 1 US dollar (market price) of the products produced by each system. The system boundaries of both production were from cradle to farm gate, mainly including the production of fertilizers, chemicals and fish feed, feed milling, and farming operation. Fish hatchery was not considered here due to its small impact on intensive aquaculture system (Ayer and Tyedmers 2009). The material inputs for constructing the aquaponic and hydroponic systems were either measured onsite or estimated.

Life cycle inventory

Unless specified otherwise, the life cycle inventory data on all the stages in the system boundaries were primary, collected from the experiment conducted between February 25 and March 25, 2019. Due to the period of cold weather, the greenhouse air was heated, and the associated electricity consumed by the aquaponic and hydroponic units was allocated using the area occupied by each unit in the greenhouse. The electricity for heating, with coal being the main energy source in Indiana, US, was modeled and estimated via Virtual Grower software v3.1 (USDA). Since the fish feed used in this study is a commercial product (Purina® AquaMax® Sport Fish 500) and its precise composition is not disclosed, we referred to the composition of another commercial trout feed used by Avadí et al. (2015) for the inventory, which had highly similar ingredients and nutrient contents. Furthermore, the emissions from each system, including NO_x through air and NH_3, NO_3^-, and PO_4^{3-} through wastewater were considered. The environmental profiles of both systems were analyzed based on the monetary functional unit. The unit prices (per kg) of fish and vegetables were collected from the Aquatic Research Lab at Purdue University and the USDA database (USDA, 2019), respectively, in April 2019.

Impact assessment
The environmental performance, in terms of midpoint and endpoint impacts, of the developed aquaponics and hydroponics was determined and compared. The midpoint and endpoint impacts were calculated using the CML-IA baseline method v3.05 and Eco-indicator 99 (H) v2.10, respectively, both methods have been used in many LCA studies on aquaculture (Ellingsen and Aanondsen, 2006; Forchino, et al., 2018; Maucieri at al., 2018). Eleven midpoint environmental impacts were characterized, with a particular focus on the four which are related most closely to fossil energy use: fossil fuel abiotic resource depletion (AD), global warming potential (GWP, for 100-year time horizon), acidification potential (AP), and eutrophication potential (EP), because CEA operation is generally recognized with high energy demand (Maucieri et al., 2018). The endpoint impacts, in terms of damages to human health, ecosystem quality, and resources, were characterized and aggregated into a single score. All the data were analyzed using SimaPro v8.3 software.

Results and discussion
Inventory analysis
The total yields of vegetables in the aquaponics and hydroponics were similar (4128 vs. 3872 g/1.5 m^2/month), with economic values of \$16.21 and \$15.37, respectively. The fertilizer use efficiency (per unit of product, kg/kg) of the hydroponics was 0.0022 (N), 0.0018 (P), and 0.0067 (K). The feed conversion ratio (FCR) of tilapia raised in the aquaponics was 1.2, indicating a healthy and fast-growing state of fish (Avadí et al., 2015). Because of the higher total product value, the aquaponics used less water per FU than the hydroponics although it had a 1.67-fold higher total water consumption. Greenhouse heating and lighting for plant growth were the most electricity-consuming components, accounting for 43% and 40% of the total usage, while energy for fish feed production only contributed negligibly. The two systems also exhibited different profiles of the nutrients/chemicals added. Commercial fertilizers and $Ca(NO_3)_2$ were used only for the hydroponics to ensure the required nutrient concentration for plant growth. However, an almost 9 times higher volume of KOH/$Ca(OH)_2$ was needed for the aquaponics to maintain the pH of water because pH decreases rapidly in aquaponics compared to hydroponics due to nitrification and CO_2 excretion by fish (Yang and Kim, 2019). The emissions of NO_x, NO_3^-, and PO_4^{3-} from the aquaponics were almost 7-, 21-, and 3-folds, respectively, higher than those from the hydroponics, probably due to high fish feed input, active denitrification, and high fish-to-plant ratio.

Environmental impacts of aquaponics and hydroponics
The environmental impacts of the hydroponics (AD: 393.82 MJ; GWP: 38.22 kg CO_2 eq; AP: 0.24 kg SO_2 eq; EP: 0.07 kg PO_4^{3-} eq) were generally almost twice as high as those generated by the aquaponics (AD: 212.56 MJ; GWP: 20.77 kg CO_2 eq; AP: 0.13 kg SO_2 eq; EP: 0.04 kg PO_4^{3-} eq). With the identical configuration and energy consumption, the higher environmental impacts associated with the hydroponics can be mainly attributed to the lower total value of its products, which was only half of that of the aquaponics. For the single-score of the endpoint impact (Fig. 1), the hydroponics caused 2 damage points which was approximately 1.8 times higher than that produced by the aquaponics. The results indicated that the integration of fish cultivation into a CEA system can increase production value, and consequently improve its environmental performance on an economic basis. The environmental profile of the aquaponic system showed that electricity use was the dominant contributor to all the impact categories: AD (99.5%), GWP (98.8%), AP (99.0%), and EP (90.8%). Fish feed production was the second major contributor to the AD (0.5%), GWP

(1.2%), and AP (0.9%), while emissions from aquaponics operation accounted for the second-highest EP (7.8%). These results indicated that the impacts associated with nutrient solution discharge should not be neglected in LCA on aquaponics. Electricity use contributed even more significantly (> 99.9%) to all the environmental impacts of the hydroponics, greenhouse heating was responsible for more than 42.7%, followed by greenhouse lighting (40.4%) then water pump and heater operations (16.7%). The high contribution of electricity use to the environmental impacts of both aquaponics and hydroponics can be attributed to the energy source used, which consists of 88% of coal in Indiana, US. Coal-fired power plants produce numerous pollutants, including SO_2, NO_x, particulate matter and heavy metals, making coal-powered electricity a significant contributor to global warming (Freese, 2008).

Sensitivity analysis

Fig. 2 compares the primary energy source in Indiana (88% coal) with the US (30% coal, 34% gas) and California (44% natural gas) scenarios (Freese, 2008). The results showed that if the source of the electricity used for supplemental lighting and greenhouse heating was changed from coal to natural gas, the EP of the hydroponics would be lower than that of the aquaponics, while the trends of the other impacts remained unchanged. Moreover, if the primary energy source was replaced by renewable energy (wind power), hydroponics would become more sustainable than aquaponics in terms of GWP, AP, and EP. In this scenario, the mass-based GWP of the aquaponics (18.5 kg CO_2 eq/kg of products) could be as low as that of commercial aquaponics in tropical regions (US Virgin Islands, 8.64 kg CO_2 eq/kg of products (Boxman et al., 2017)).

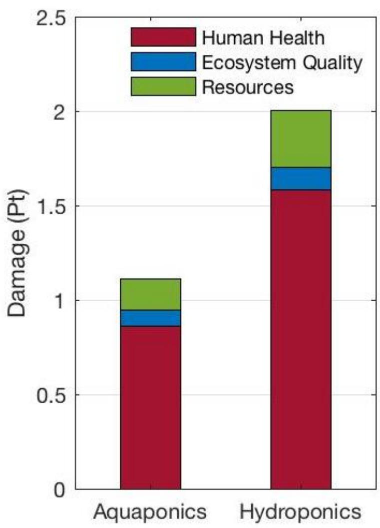

Fig. 1. Comparison between the endpoint environmental impacts (single score) of aquaponics and hydroponics.

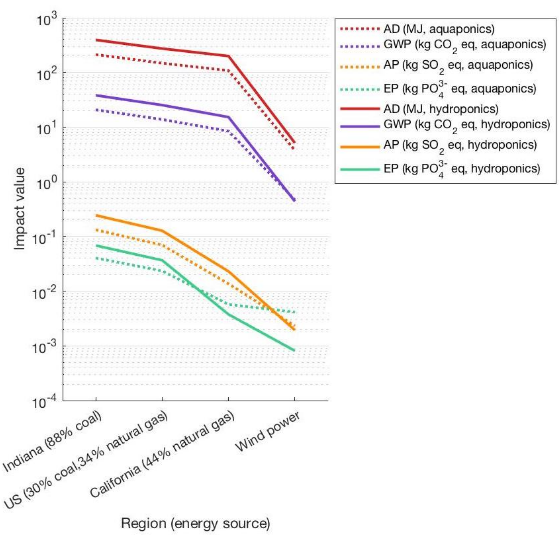

Fig. 2. Effect of energy source on the environmental impacts of aquaponics and hydroponics.

Conclusions

CEA is a surging technology to meet the rapidly growing global food demand because of its high productivity, and water and nutrient use efficiency. This cradle-to-gate LCA, for the first time, compared the environmental performance, on an economic basis, of aquaponics and hydroponics with identical system design. Compared to hydroponics, aquaponics produced nearly half the environmental impacts. While electricity use for operations of greenhouse and both systems was the environmental hotspot, changing the source of energy from fossil fuel to renewable energy could make hydroponics a more sustainable system. This LCA study can provide CEA farmers with the groundwork to reduce the environmental cost of their production.

Acknowledgements
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ELECTRODIALYSIS VS CONVENTIONAL PROCESSING APPLIED TO CASEIN PRODUCTION AND CRANBERRY JUICE DEACIDIFICATION: COMPARATIVE LIFE CYCLE ASSESSMENT

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Abstract

The modern food industries face high food demand to satisfy the needs of rapidly growing population. However, the inevitable increase of food production should be realized in the harmony with environment to ensure the human needs without undermining the integrity and stability of the natural systems. Thus, the present work focuses on the estimation of the environmental impacts of innovative electrodialysis approaches vs conventional ones used for the production of caseinates and deacidification of cranberry juice. The proposed way of caseinates production includes bipolar membrane electrodialysis coupled with ultrafiltration (EDBM-UF). The life cycle assessment was carried out to evaluate the potential environmental impacts associated with the production of caseinate powder from skim milk of two different scenarios: 1) EDBM-UF treatment and 2) chemical treatment (HCl-NaOH). Regarding the cranberry juice, its deacidification is an important processing step allowing to improve the juice organoleptic properties and to reduce possible side effects (e.g. diarrhea, vomiting and bloating). Two approaches for cranberry juice deacidification were tested: calcium carbonate and electrodialysis with bipolar membrane (EDBM) treatments. The results of these studies demonstrated that the proposed electromembrane processes had lesser environmental impacts compared to conventional technologies for both caseinate production and cranberry juice deacidification. Moreover, for the both food products the application of electromembrane technologies is more advantageous from the value point of view since they generate several by-products, which could be used in food industry. Hence, the innovative EDBM treatments could be an eco-efficient alternative to the conventional processes.

Keywords: *Life Cycle Assessment, Electrodialysis, Milk proteins, Cranberry juice, Eco-efficiency*

Introduction

To satisfy the demands of a growing population, the food industry should significantly increase its productivity taking into account environmental impacts. Thus, in the modern food processing chains, eco-efficient technologies should be developed and introduced, that is, technologies that allow obtaining high value products without significant environmental impact. Electrodialysis (ED) seems to be a good alternative to conventional food processing technologies since it does not involve any harmful chemicals and uses electricity, which can be derived from renewable sources (e.g. hydroelectricity). Therefore, the goal of this study is to verify the environmental performance of ED compared to the traditional technologies using chemical agents. Two processes will be considered, notably the production of caseinates from milk and deacidification of cranberry juice. Caseinates are an abundant food ingredient, since they allow improving functional properties of different food products and delivering essential amino acids playing important role in the normal growth and functionality of human organism. The conventional way to produce caseinates is precipitation of caseins from skim milk using mineral acid and dissolution of precipitated caseins using alkali. The innovative way to produce caseinates is to use the hybrid technology comprising electrodialysis with bipolar membranes (EDBM) and ultrafiltration (UF) (Mikhaylin *et al.*, 2018). Cranberry juice in its turn contains highly valuable compounds such as polyphenols having different biological activities and along with this, it has a high titratable acidity causing some side effects (e.g. diarrhea, bleeding, etc.). Thus, cranberry juice should be deacidified prior to its consumption. Conventional way of juice deacidification consists of using calcium salts, which interact with organic acids removing them from juice. The innovative way to act is to use EDBM to deacidify the juice and recover the valuable organic acids (Faucher *et al.*, 2020).

Material and methods

The life cycle assessment (LCA) was carried out according to ISO 14044 to evaluate the potential environmental impacts associated with the production of caseinate and deacidified cranberry juice. For caseinate powder, the functional unit was defined as being the production of 1000 kg eq. of sodium caseinate powder from skim milk at the dairy factory gate, ready to be delivered. Two different scenarios of caseinate production were evaluated: 1) EDBM-UF treatment and 2) chemical treatment (HCl-NaOH) (Fig.1).

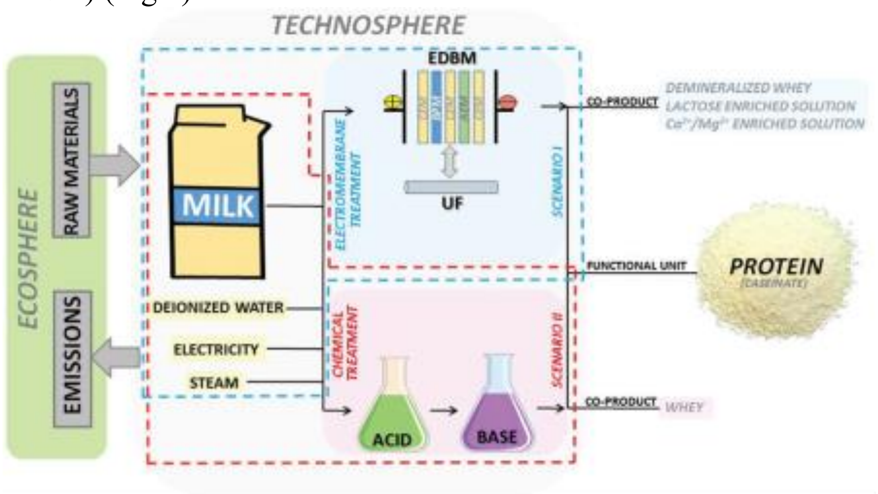

Figure 1. System boundaries of life cycle assessment of two processes for caseinate manufacturing.

Moreover, the sensitivity test of electricity mix supply at different regions of the world was carried out. The cut-off approach was applied to deal with the multifunctional character of caseinate powder production. Therefore, no environmental burdens are associated with the co-products generated by the respective product systems described in Fig. 3; they are all attributed to the caseinate powder. This approach is justified by the impossibility, at this stage of development, to define the market values of the different co-products.

For the cranberry juice deacidification, three scenarios of LCA were compared (Fig. 2): 1) EDBM without reuse of the recovery solution 2) EDBM with reuse of the recovery solution and 3) salt precipitation. The functional unit chosen to compare all scenarios was defined as the production of 1000 kg of deacidified organic cranberry juice in Quebec with 40% of organic acids removed (i.e. 40% deacidification rate). During production of raw cranberry juice, cranberries are pressed to extract the juice. The solid part remaining from this operation is called pomace and it is a co-product, since it can be used for animal feeding. To consider this co-product, system expansion with alfalfa production was used as allocation method based on calorific value. For electrodialysis with bipolar membranes, the organic acids recovered from the juice were purified in a separated compartment during the process and were available for their reuse in other industrial applications or as food preservatives. In this case, they represent a co-product and assessments were considered using physical allocation based on the mass of deacidified cranberry juice and organic acids. For deacidification by salt precipitation, the calcium salts recovered from the filtration are hardly useable and constitute a waste. Their disposal was considered in the LCA.

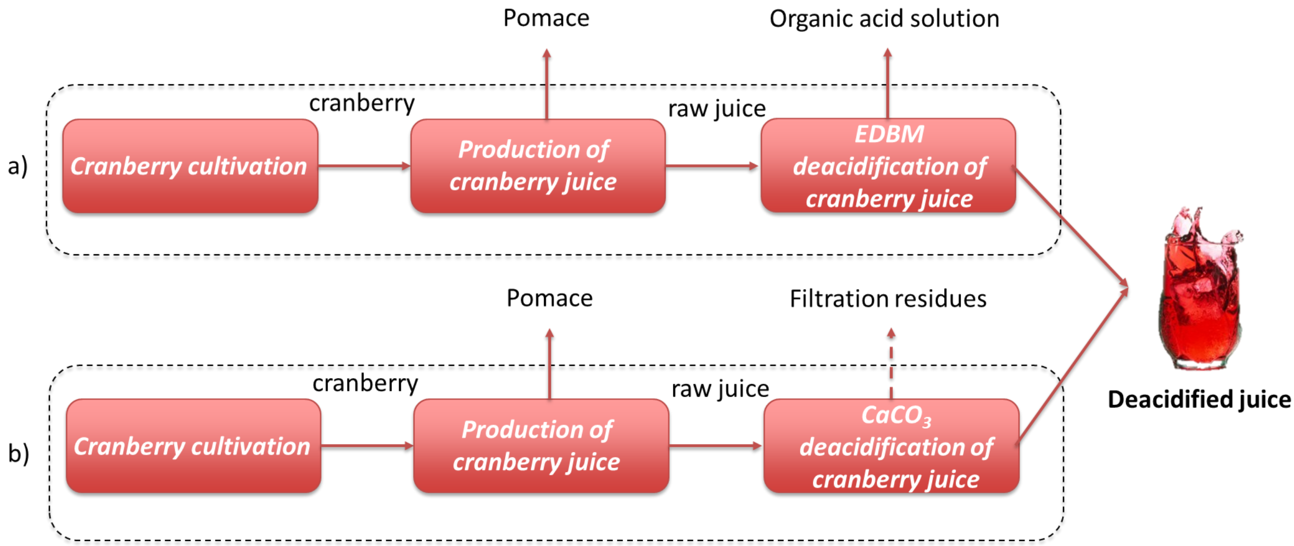

Figure 2. System boundaries of life cycle assessment for cranberry juice deacidification by a) EDBM (without and with reuse of the recovery solution) and b) salt precipitation.

Results and discussion

The LCA revealed that EDBM-UF for caseinate manufacturing has lesser impacts on climate change, human health, ecosystem quality and resources compared to the conventional process using chemicals (*Fig. 3*). The main reason of the lesser environmental impacts of EDBM-UF process is the use of lesser quantities of skim milk to produce caseinate. Indeed, the on-farm operations taking place during skim milk production significantly affect non-renewable energy use (i.e. animal feed production, drying fodder, milking, ventilation, etc.), water consumption and acidification (mainly due to the use of ammonia fertilizers). The other hot spot of the caseinate powder manufacturing process is the steam flux for the drying of sodium caseinate solution due to the use of non-renewable energy sources during steam generation. Concerning the eco-efficiency, EDBM-UF process has several important advantages compared to conventional chemical process. Indeed, chemical production derives caseinate and whey solution enriched with minerals, lactose and water, which should be removed prior to valorization. However, EDBM-UF process generates several byproducts such as a partially demineralized and concentrated whey, a solution enriched in lactose, a solution enriched in Ca^{2+} and Mg^{2+} ions, which could be valorized as supplements in the food, pharmaceutical and nutraceutical sectors. Moreover, NaOH, a byproduct generated in the basification compartment of the EDBM module, could be used as a solubilizing agent for casein and in the cleaning operations of dairy equipment. Hence, it could be concluded that EDBM-UF generates more valuable products with lesser environmental impacts compared to the conventional chemical process.

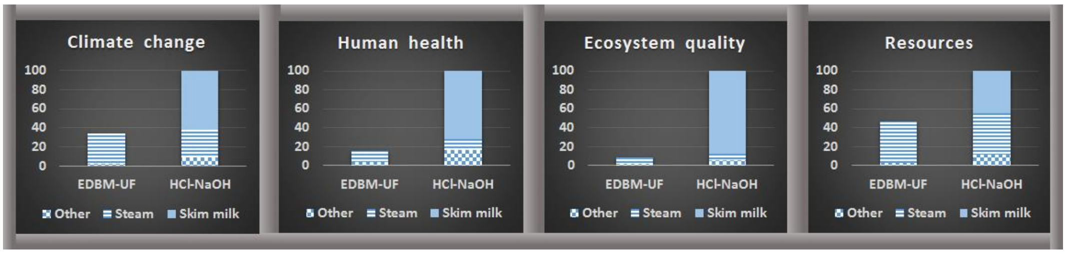

Figure 3. Relative contributions (in %) of caseinate powder manufacturing by EDBM-UF and acid/base technologies to the impact categories.

Regarding the cranberry juice (Fig. 4), EDBM has lesser impacts compared to calcium carbonate treatment for the climate change, human health, ecosystem quality and resources categories. Moreover, the less damaging scenario for all the damage categories was EDBM with reuse of recovery solution. It is worth noting that most of the overall environmental impacts were linked to the culture of cranberry whatever the scenario considered and that salt precipitation had the highest impact on the culture since this scenario required more raw juice. Furthermore, the results demonstrate that EDBM treatment allows cranberry juice deacidification without affecting its nutritional and organoleptic quality. Additionally, the organic acids which constitute the EDBM recovery solution can be used as preservatives increasing the process eco-efficiency while calcium carbonate juice deacidification leads to the loss of certain polyphenols and enriches the juice with excessive amount of calcium affecting its taste.

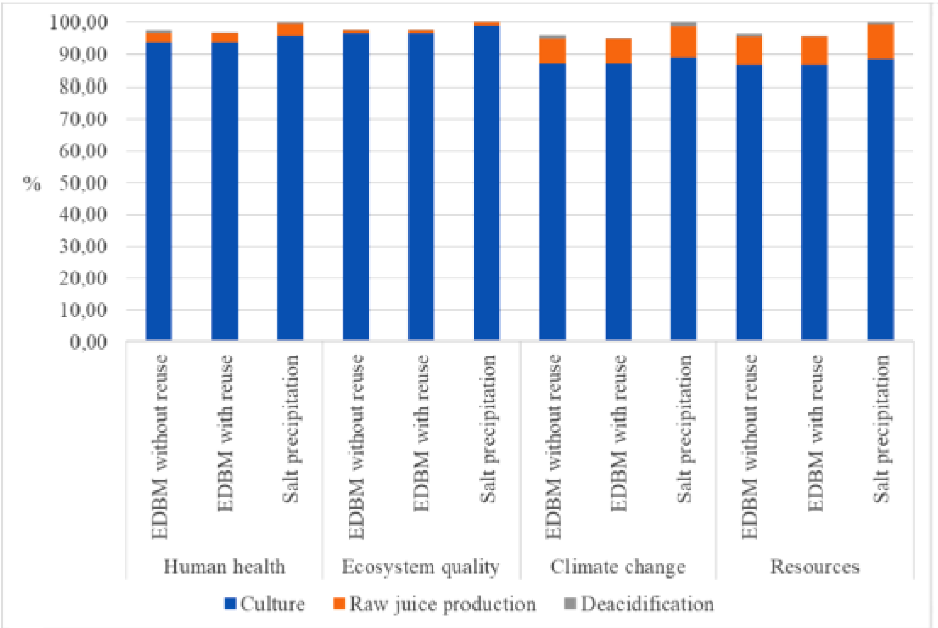

Figure 4. Relative contributions (in %) of cranberry juice deacidification by EDBM and $CaCO_3$ precipitation to the impact categories.

Conclusions

Considering the above results, it is clear that ED could become a perspective industrial process taking into account environmental concerns and providing better value products. Hence, the presented eco-efficiency assessment approach can be used for the other electromembrane processes as a reference tool for their implantation in industries targeting the UN Sustainable Development Goals and promoting the development of healthy human society.

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Upgrading the Peruvian waste treatment sector to reduce GHG emissions from food loss and waste

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Abstract

Purpose: Peru struggles to upgrade its waste treatment sector, with landfilling only just overtaking open dumpsters as the main disposal route. In parallel, an average Peruvian household spends 40-55% of its income on food, and approximately 58% of generated MSW is of organic nature. Therefore, it is apparent that a relevant portion of greenhouse gas (GHG) emissions can be linked directly to food loss and waste (FLW) management. Accordingly, the objective of this study is to determine the GHG emissions mitigation potential existing in FLW as compared to the current baseline scenario in selected Peruvian cities, by modelling alternative technologies to treat organic municipal solid waste.
Methods: Life cycle modelling was carried out using the waste-LCA software EASETECH. Five different treatment scenarios were modelled: i) open dumping; ii) landfilling with no landfill gas treatment; iii) landfilling with landfill gas treatment; iv) landfilling with energy recovery; and, v) anaerobic digestion. Data for household food purchase released by local institutions were used to obtain the amount of food purchased in the different cities. Considering the heterogeneous origin of food consumed in cities, only FLW occurring in the distribution, retail and consumption stages were considered, whereas agricultural loss was excluded.
Results and discussion: Results show substantial reductions in GHG emissions when hi-tech waste management systems are implemented, although they vary depending on dietary patterns and climatic conditions. If landfill gas treatment with energy recovery substitutes open dumping, a reduction of 55% in emissions would be attained, representing an annual mitigation of 0.72 Mt CO_2eq. When correct management systems are implemented, such as energy recovery or, especially, anaerobic digestion, a greater part of the carbon losses to the atmosphere would be avoided.
Conclusions: Efficient and resourceful management of FLW can help mitigate global warming, as well as end hunger, achieving food security and improved nutrition, while promoting sustainable food production and consumption in accordance with the UN Sustainable Development Goals.

***Keywords:** anaerobic digestion, diet, EASETECH, Life Cycle Assessment, waste treatment.*

Introduction

Peru struggles to upgrade its waste treatment sector, with landfilling only just overtaking open dumpsters as the main disposal route. Despite the benefits of this transition, including reductions in environmental impacts to the water and soil compartments, a recent study for three landfills in distinct climatic areas of Peru showed that greenhouse gas (GHG) emissions and other air emissions may increase as compared to dumpsters if adequate levels of technological sophistication are not implemented (Ziegler-Rodriguez et al., 2019). Considering an average Peruvian household spends 40-55% of its income on food, and ca. 58% of generated MSW is of organic nature, it seems plausible that a relevant portion of GHG emissions can be linked directly to food loss and waste (FLW) management. Hence, the main objective of the study is to determine the GHG emissions mitigation potential existing in FLW as compared to the current baseline scenario in 24 different Peruvian cities, by modelling alternative technologies to treat organic MSW.

Material and methods

Life cycle modelling was carried out using the waste-LCA software EASETECH (Clavreul et al., 2014). Five different treatment scenarios were modelled: i) open dumping (OD); ii) landfilling with no landfill gas treatment (LF); iii) landfilling with landfill gas treatment (LFG); iv) landfilling with energy recovery (LER); and, v) three alternative anaerobic digestion (AD) systems (see Figure 1). For certain cities only the final three scenarios were considered since open dumping has been essentially eradicated and landfilling without LFG treatment upgraded. Data for household food purchase released by the Peruvian Statistics Institute (INEI) were used to obtain the amount of food purchased per capita in the different cities. FLW ratios were obtained from the FAO report elaborated by Gustavsson et al. (2011) for South America. Considering the heterogeneous origin of food consumed in cities, only FLW occurring in the distribution, retail and consumption stages were considered, whereas agricultural loss, which is mainly disposed of in a decentralized, urban context, was excluded.

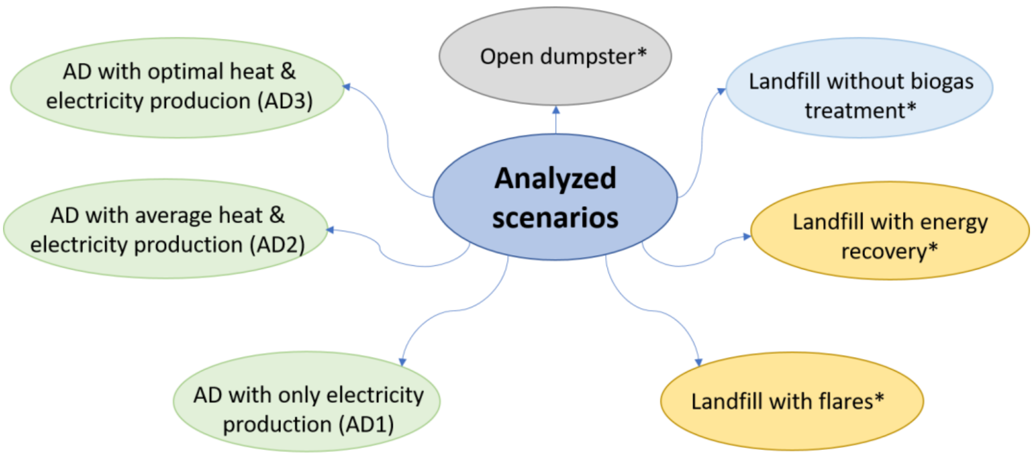

Figure 1. Methodological framework in which the waste treatment technologies included in the study are represented. The asterisk represents technologies previously

Results

GHG emissions linked to the disposal of FLW generated in the distribution and consumption stages ranged from 32 kg CO_2eq per capita and year in the case of Ayacucho (LFG) to 136 kg CO_2eq per capita and year in the city of Cusco (LF). This range is explained due to the fact that Ayacucho, together with Lima, Puno and Tarapoto, is the only city assessed that currently flares landfill gas, whereas the remaining urban areas analyzed either dump their waste or dispose of it at LF sites. If LFG management systems are implemented in all cities assuming ceteris paribus conditions, the city with lowest environmental impact per capita and year is Arequipa (31 kg CO_2eq), whereas the highest is Tarapoto (71 kg CO_2eq). Upgrading the entire system analyzed to LFG technology in landfills would imply a reduction of 0.37 Mt CO_2eq per year to 0.94 Mt CO_2eq. While this reduction is substantial (-29%), it still presents two important limitations from an environmental perspective: i) the management system would not be upgraded for the city of Lima and 3 other cities; and, ii) LFG technology, while an important step towards reducing the carbon profile of waste treatment, does not foster the circularity of resources embedded in organic waste (e.g., energy or nutrients).
The implementation of waste-to-energy technologies which aim at improving the circularity of the Peruvian urban waste treatment system show important net reductions in GHG emissions. On the

other hand, the implementation of landfill with energy recovery (LER) technologies throughout the cities assessed would imply a reduction of 0.72 Mt CO_2eq (-55%) as compared to the BAU scenario. Assuming that this scenario would be achievable by 2030, it would translate into a higher reduction in GHG emissions in the solid waste sector than the average reduction proposed for Peru (i.e., -30%). In this case, the highest emissions per capita would be achieved in Huaraz (43 kg CO_2eq/year). On the other hand, the implementation of AD technology would increase the net GHG emission mitigation to up to 1.56 Mt CO_2eq in the case of AD3 (-119%). For AD treatment negative GHG emission impacts would be attained in all the cities evaluated. No major differences in GHG emission reduction were identified between the three AD technologies modelled, which would suggest that other environmental indicators (e.g., ozone depletion or eutrophication), as well as economic and social criteria, would have to be applied to understand the convenience of a specific technology.

Table 1. Food loss and waste treatment GHG emissions reported in kg CO_2eq per capita and year in selected Peruvian cities.

	OD	LF	LFG	LER	AD1	AD2	AD3
Lima	NA	NA	56.13	33.02	-12.03	-12.80	-13.68
Arequipa	101.81	119.09	30.54	23.02	-12.01	-12.78	-13.67
Cajamarca	NA	129.00	50.27	40.74	-12.11	-12.94	-13.89
Cusco	NA	136.08	35.08	26.50	-13.85	-14.74	-15.75
Piura	98.44	113.61	56.18	35.34	-12.18	-12.55	-13.79
Pucallpa	112.85	124.73	63.65	58.23	-13.35	-12.55	-15.19
Puerto Maldonado	104.13	110.15	46.12	40.26	-12.54	-13.34	-14.25
Puno	NA	NA	33.62	25.42	-12.80	-13.65	-14.61
Trujillo	103.38	117.71	57.75	34.04	-12.00	-12.78	-13.69

NA= not applicable, a more sophisticated technology is already being applied; OD= open dumpster; LF= landfill; LFG= landfill with landfill gas flaring; LER= landfill with energy recovery; AD= anaerobic digestion.

Discussion

Despite the benefits in other environmental impacts, such as eutrophication or acidification (Ziegler-Rodriguez et al., 2019), transitioning from open dumping to conventional landfilling with no LFG treatment, and with only timid advancements in more sophisticated technologies would inhibit mitigation hopes by at least a decade (Vázquez-Rowe et al., 2019). In this sense, a direct leap from open dumpsters to landfills with LFG treatment is needed in a vast majority of cities throughout the country to start to visualize certain mitigation targets. It is obvious, considering the results of the study, that landfills with energy recovery and especially AD technologies would provide noticeable improvements in GHG emission reductions. However, it should be noted that although energy recovery (i.e., LER) in landfills had been planned by the Peruvian government as part of its nationally-determined contributions (NDCs), it was later discarded in the final report (MINAM, 2019), leaving landfill gas treatment and semi-aerobic landfills as the most sophisticated technologies Peruvian authorities are willing to finance. Moreover, slow policy-making and legislation procedures, with projects taking several years to be approved, as well as difficulty to obtain funding in international markets for these, are an important setback for short-term implementation of LER and AD in the country. In fact, it is highly unlikely that these types of plants will be functioning in Peru prior to the Paris Agreement deadline in 2030.

The challenges of implementing AD solutions in Peru are multiple and not limited only to governance. For instance, capacity building is highly necessary in a country that still lacks skilled labor in this sector. In fact, from a technical perspective, issues such as lack of constant substrate, the need of constant control and monitoring to avoid, e.g., harmful intermediate compounds (Banks et al., 2012), instability in the reactor (Zhang et al., 2013) or foaming (Grimberg et al., 2015), are important aspects that must require skilled personnel.

Conclusions

Results demonstrate that site-dependent conditions are fundamental when evaluating technological solutions to address waste management systems in Peruvian cities. While some cities are already implementing timid GHG mitigation actions through the available technologies, in most cases the situation is either open dumping or basic sanitary landfilling with no landfill gas treatment or energy recovery (Kahhat et al., 2018). Therefore, it is important to note that efficient and resourceful management of FLW can help mitigate global warming, as well as end hunger, achieving food security and improved nutrition, while promoting sustainable food production and consumption in accordance with the UN Sustainable Development Goals.

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Assessing the forced labor risk of US fruit and vegetable commodities

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Abstract

Studies on sustainable food consumption to date have largely focused on promoting human health within ecological limits. Much less attention has been paid to social sustainability, in part because of limited data and models. The aim of this research is to assess the forced labor risk of fruits and vegetables consumed in the US by compiling new datasets and developing a new forced labor risk scoring method. Several steps were needed to compute forced labor risk per serving, including compilation of trade, labor intensity, and price data; qualitative coding of risk associated with food production for each commodity-country combination, and quantitative risk characterization (i.e., S-LCA impact assessment). Because commodities had multiple origin countries, weighted means and ranges of risk were calculated. Our analysis of 292 country-commodity combination enabled us to identify the varying level of forced labor risk associated with each using the metric of medium risk hours equivalent. Our method and results represent the first attempt, to our knowledge, to estimate the risk of forced labor across a diverse set of foods. Our findings point to the importance of using and further developing granular data for social risk assessment of foods.

Keywords: forced labor; social life cycle assessment; LCA; fruit and vegetable consumption

Introduction

An estimated 1.7 million workers globally in agriculture and fishing are subjected to forced labor, defined as "situations in which persons are coerced to work through the use of violence or intimidation, or by more subtle means such as accumulated debt, retention of identity papers, or threats of denunciation to immigration authorities" (ILO 2017). While eliminating forced labor in food production is of clear policy importance, there is a paucity of research on this topic. This can be attributed in part to limitations in metrics, models, and data available to estimate social risks in a similar framework to environmental impacts of foods. Social life cycle assessment (S-LCA) has emerged to fill this gap (Benoît and Mazijn 2009; Benoît Norris et al. 2018) but its systematic application to foods has been limited to date.

Lacking data on social risks means that interventions to improve health outcomes or reduce environmental burdens of diets may result in unintended consequences. The objective of this research is to assess the forced labor risk of fruits and vegetables consumed in the US by compiling new datasets and developing a new forced labor risk scoring method, which is synergistic with those used by the Social Hotspots Database (SHDB). The Social Hotspots Database was the first comprehensive database for Social LCA. It pioneered many of the methods used for integration of social data in the LCA framework. It is widely used in the LCA community and is one of two existing options (the other is PSILCA).

Material and methods

To compute forced labor risk, we first compiled supply and origin data for US fruit and vegetable consumption. Second, we assessed the labor intensity per serving by multiplying worker hours from the SHDB and average US retail food prices. Third, we qualitatively coded the forced labor risk of fruit and vegetable production for each country-commodity combination using a tiered approach, with the most granular data available used in the final assessment. Finally, we applied the SHDB impact assessment method to convert to medium risk hours equivalent (mrh eq) and compute risk per serving. Detailed steps, variables, and data sources are described in the remainder of this section. The overall calculation for forced labor risk per serving of fruit or vegetable is described by Eq. (1-2):

$$CF_{i,k} \times WrkHrs_i \times Price_k = FL_{i,k} \quad (1)$$

$$\sum_{i=1}^{n} FL_{i,k} \times Prop_{i,k} = MeanFL_k \quad (2)$$

where each fruit and vegetable commodity is denoted by k and each country of origin is denoted by i; CF is the risk characterization factor assigned to commodity k from country i; WrkHrs is the labor intensity for the vegetable and fruit sector in country i (hours per dollar); Price is the retail price of commodity k (dollars per serving); FL is the forced labor risk per serving for each commodity k from origin country i (medium risk hours equivalent; mrh eq); Prop is the proportion of supply of commodity k accounted for by country i; and MeanFL is the weighted average forced labor risk per serving for each commodity k (mrh eq).

Trade data were from Kim et al. (2019), the UN Food and Agriculture Organization's (FAO) Food Balance Sheets (FAO 2020), and FAO Trade Matrix (FAO 2020b) . Countries that accounted for < 5% of each commodity's import volume to the US were excluded from the analysis. FAO commodities were mapped to the fruits and vegetables in the U.S. Department of Agriculture's Loss-Adjusted Food Supply data series (n=84; the unit of analysis).

We used labor intensity data (worker hours per $1 of country-specific sector output) from the SHDB (Benoît-Norris et al. 2019). We used average US retail prices per cup equivalent (i.e., per serving) (USDA 2018). Prices include preparation yield loss or gain.

We qualitatively coded the forced labor risk of fruit and vegetable production for each country-commodity combination using a tiered approach, with the most granular data available used in the final assessment. Risk was only assessed at the farming stage. The three levels were 1) commodity-country specific risk (e.g., fresh strawberries from the US), 2) sector-country specific risk (e.g., agriculture in the US), and 3) country-level risk (e.g. US). Two researchers independently coded each data source by applying qualitative codes that corresponded to a numeric risk score to specific and standardized language, with inter-rater reliability set at .90.

For level one, forced labor risk was qualitatively coded using known occurrences data from two sources (Verité 2017; DoL 2019). To assess risk for levels two and three, we integrated government response data (DoS 2019) to act as a counterweight when known occurrences are cited in a country with strong governance protections. When both data types were available, a weighted average risk code was calculated (85% known occurrences, 15% government response), otherwise risk from one type was used (Benoît Norris et al. 2019). Level two codes were developed for known occurrences data (DoS 2018). Level three risk data were sourced directly from the SHDB. To convert risk levels to medium risk hours equivalent (mrh eq) per serving, we applied characterization factors from the SHDB, where Very High Risk = 10, High Risk = 5, Medium Risk = 1, Low Risk = 0.01 mrh eq.

Results

37% of the 292 country-commodity combinations for the 84 commodities had commodity-country specific risk data available. Only 0.3% (n=1) required using country-level data. Therefore, the majority of combinations were assessed using level two, or country-sector level data sources.

Fruits with the highest risk of forced labor included various forms of pineapple, as well as mangoes and avocados (Figure 1). Pineapple products were sourced from five countries: three were very high risk (Thailand, US, Costa Rica) and two were high risk (Philippines and Indonesia). Mangoes were sourced from five countries, whose risk varied from low (US) to high (Mexico and Peru). 82% of the US mango supply was high risk. For avocados, 62% of supply was high risk (Mexico and Chile), with the remainder being low risk from the US. The US was low risk for mangoes and avocados but very high risk for pineapples because the latter had commodity-country specific data, while the former relied on level two data (government response only).

Fruits with the lowest risk of forced labor included various forms of apples, peaches, and watermelon. The supplies of each of these foods were assessed as medium risk, with the US the primary country of origin. Overall, the combination of medium risk coding and relatively low labor intensities per serving contributed to the low risk assessment for these foods.

For vegetables, asparagus, okra, and bell peppers had the highest risks of forced labor in their supplies (Figure 2). 77% of the asparagus supply was assessed as high risk (Peru and Mexico), while 95% of the okra supply was high risk (Mexico). For bell peppers, 38% of the supply was coded as very high risk (Mexico). The remainder of the supply was coded as low (57%, US) or medium (5%, Canada) risk. The combination of high labor intensity per serving and high or very high levels of coded risk resulted in high relative risk for these foods.

Vegetables with the lowest risk of forced labor included potatoes, and cauliflower. 85% of the potato supply was coded as low risk (US), with the remainder medium risk from Canada. For cauliflower, 99% of supply was coded as low risk (US). Low risk coding, in combination with low labor intensity, contributed to low risk for these foods relative to other vegetables.

Discussion

Our results illustrate significant variation in forced labor risk across fruits and vegetables, with implications for policy, industry, and consumers. For US policy, the Trafficking Victims Protection Reauthorization Act (2005) aims to preclude the import of any goods produced by forced or child labor into the United States; identifying high risk commodities may help target goods for action or further investigation. Our results are an invitation to food companies working within these supply chains to collect primary data and make their labor and human rights commitments and indicators transparent for stakeholders. They are also an invitation for consumers to demand further transparency about the labor conditions in the supply of the produce they purchase.

Due to the novelty and scope of our research, it is difficult to compare our findings against the literature. At the same time, recent media corroborates findings about some of our highest risk commodities, including pineapple (Shah 2020), mango (Poulden 2012), avocado (Dehghan 2019), asparagus (International Labor Rights Forum 2009), and bell peppers (Coalition of Immokalee Workers 2017). Developing methods to include evidence from investigative journalism in forced labor risk assessment is a promising area of future research to fill commodity-specific data gaps.

One key limitation of this research is that we assessed risk only at the level of farming, not yet for the full life cycle of the product. Additionally, results were only provided per serving. Future analyses will include estimates at the level of the entire US fruit and vegetable supplies, including waste and loss. Finally, we will pursue mixed methods approaches that pair our quantitative approach with qualitative analysis of worker narratives to center their experiences and contextualize our findings. Our findings point to the importance of using and further developing granular data for social risk assessment.

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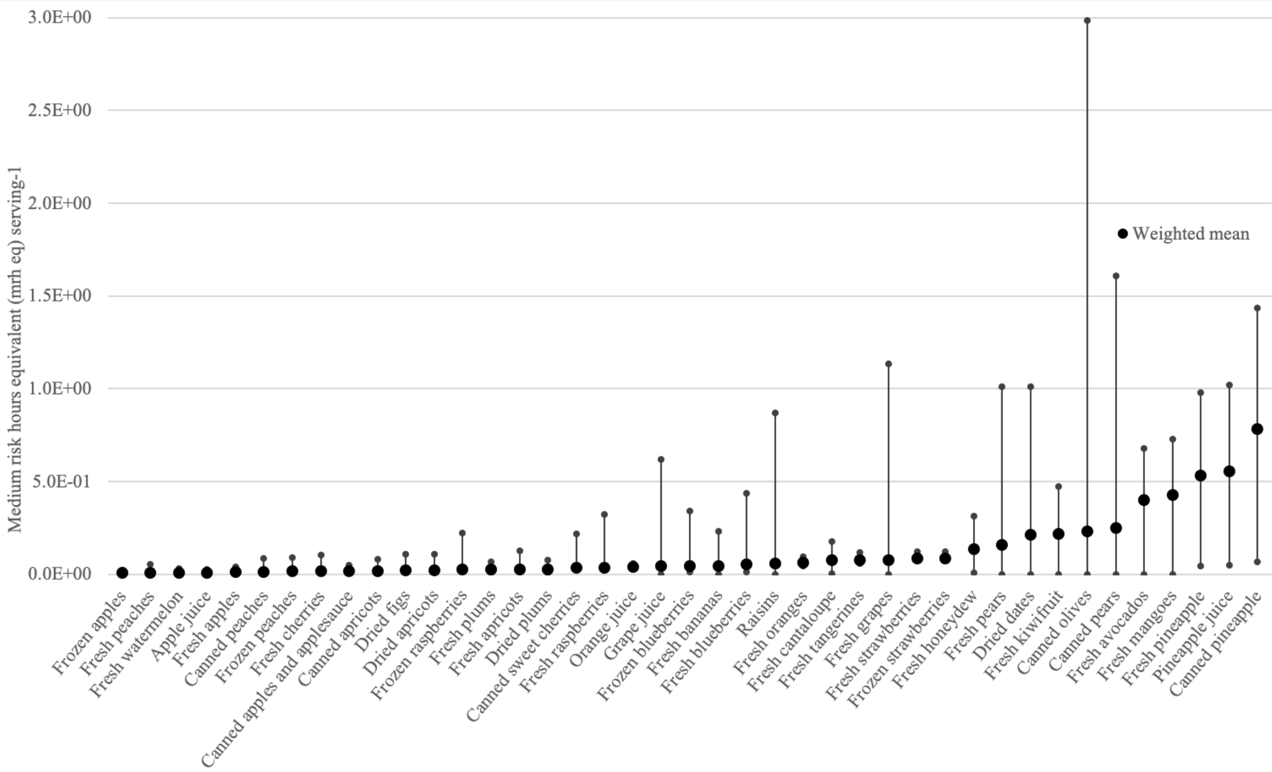

Figure 1: Weighted mean, maximum, and minimum estimated risk of forced labor per serving of fruits consumed in the US

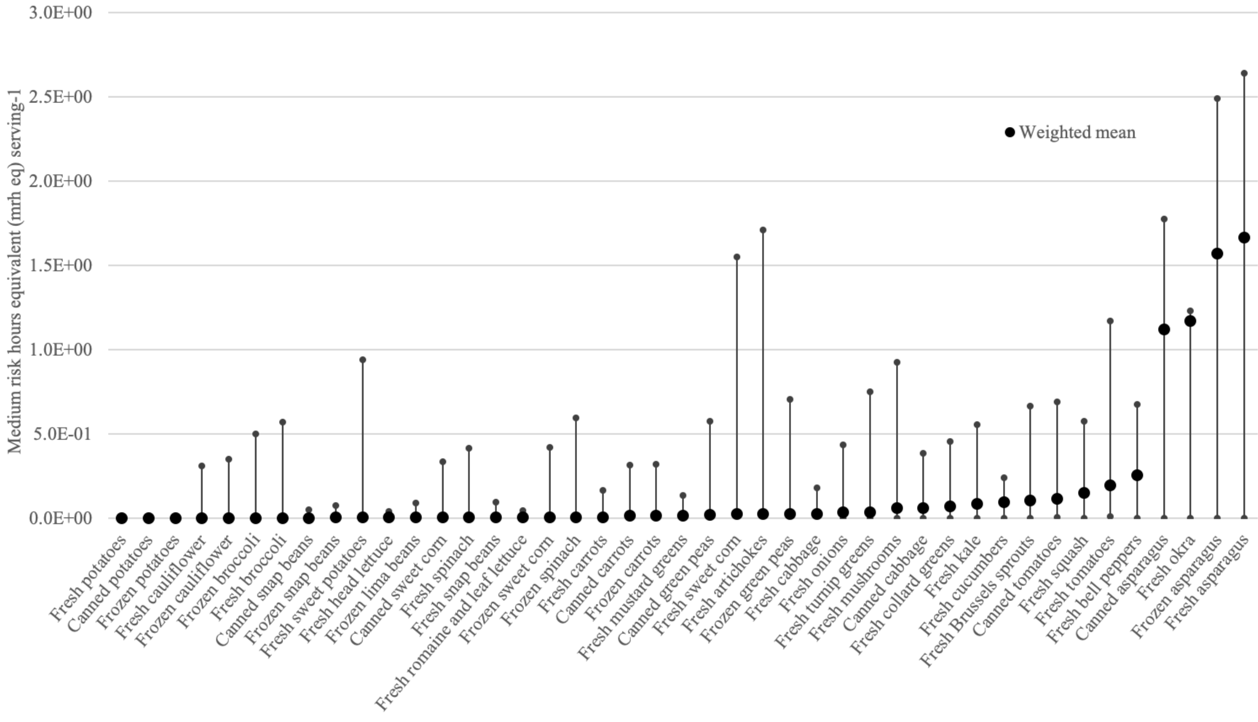

Figure 2: Weighted mean, maximum, and minimum estimated risk of forced labor per serving of vegetables consumed in the US

Abstract code: 186

Carbon footprint of cow-calf and fattening cattle systems in Colombia using a life cycle assessment approach

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Abstract

The beef production chain in Colombia accounts for approximately 15.5 million cattle heads. Cow-calf and cattle-fattening represent 40.4 and 45.2% of the Colombian beef herd respectively, and the remaining 14.4% corresponds to full-cycle systems. The present study aimed to estimate, based on a farm gate LCA approach, the carbon footprint (CF) of 251 cow-calf and 275 fattening farms in Colombia as well as to identify the hotspots of total environmental impacts, and the ways of production with better environmental performance. The functional units used were 1 kg live weight gain (LWG) and 1 kg fat and protein corrected milk (FPCM) leaving the farm gate. For cow-calf farms, economic, energy, and mass methods of allocating total greenhouse gas emissions into meat and milk were applied. Data were collected by using surveys developed in a total of 526 farms located in 13 Departments in Colombia. CF was estimated using the greenhouse gases (GHG) emission factors reported in the 2019 Refinement to 2006 IPCC, databases, and locally estimated emission factors. A principal component multivariate analysis (PCA) and a Hierarchical Clustering on Principal Components (HCPC) were performed. The proportion of GHG emissions allocated to meat differed, with the economic method assigning the greater burden, followed by energy content, and mass production. Either in cow-calf, and fattening systems the largest sources of GHG come directly from enteric fermentation and manure deposited on pasture. For each stage of production, three farms clusters were identified. Both stages of production had a cluster of better farms that provided low CF. Our results suggest that it is possible to reduce the CF by adopting improved pastures, better agricultural management practices, efficient fertilizer usage and using the optimal stocking rate.

Keywords: Colombian cattle systems; global warming potential; greenhouse gases (GHG); IPCC guidelines; livestock production systems.

Introduction

The beef production chain in Colombia accounts for approximately 15.5 million cattle heads (59% of the national cattle population) and is composed of cow-calf systems, fattening systems, and full-cycle systems, which annually produce 933 million kg carcass beef (DANE 2017). Cow-calf, and cattle-fattening account for 40.4 and 45.2% of the Colombian beef herd respectively, and the remaining 14.4% corresponds to full-cycle (DANE 2017). These farms used traditional-extensive and improved-extensive grazing systems, where animals graze on large plots, the stocking rate is low, and their diets usually include native forage species, which has led to low productivity rates (González-Quintero et al. 2020b; González-Quintero et al. 2020a).
Life cycle assessment (LCA) allows for the compilation and appraisal of inputs, outputs and potential environmental impacts of a product throughout its life from cradle to farm gate or to grave (Guinée 2002). To accomplish the national GHG emissions reduction target of 20% that the Colombian government is committed towards 2030 (Gobierno de Colombia 2015), the identification of the best beef sustainable production ways by using the LCA approach, in terms of higher productivity and better environmental performance, that effectively reduce emissions from cattle sector is required. The present study aims to (1) estimate the carbon footprint (CF) of cow-calf and fattening farms in Colombia using a farm gate LCA approach, based on data gathered directly from the farms; and (2) to identify the hotspots of total environmental impacts, and the ways of production with better environmental performance.

Material and methods

Life Cycle Assessment approach: An LCA approach was used to assess the carbon footprint for cow-calf and fattening cattle systems in Colombia. The publicly available specification (PAS, 2050: 2011) (BSI and Carbon Trust 2011) was used, which is based on LCA and allows the quantification of possible environmental impacts in the life cycle of products. The global warming potentials for a time-frame of 100 years were used: 25 for methane; 265 for nitrous oxide; and 1 for carbon dioxide (IPCC 2014).
Goal and scope definition: The system boundary was defined by the environmental impacts related to the cow-calf and fattening farms in a "cradle to farm-gate" perspective (Figure 1). The primary emissions are those generated within the farm system (on-farm) and the secondary off-farm emissions are those upstream emissions related to the production and transport of imported resources. The functional units were 1 kg fat and protein corrected milk (FPCM) and 1 kg live weight gain (LWG) leaving the farm gate. Due to the dual-purpose of cows in cow-calf systems (González-Quintero et al. 2020b), the environmental burden must be assigned between milk and meat based on an allocation method. Three allocation methods were used: (1) Economic allocation that was based on the price per kg and the total amount of meat (LWG) and milk (FPCM) produced per year; (2) Energy allocation that was based on the energy content (MJ) and the total amount of meat (LWG) and milk (FPCM) produced per year; and (3) Mass allocation was based on the quantity of meat (LWG) and milk (FPCM) and produced per year.
Life cycle inventory and impact assessment: data were collected by using surveys developed in 251 cow-calf and 275 fattening farms located in 13 Departments in Colombia. The data collection process, and the description of farms were well described by González-Quintero et al. (2020a).
For cow-calf farms, milk production was standardized to fat (3.7%) and protein (3.3%) corrected milk (FPCM). Live weight gain (LWG) was quantified as kg of animals produced from the farm, assuming no change in the size of stock on-farm and no animals bought into the farm.
A nitrogen balance at farm level was made to check for possible N surplus and thus risk of N leaching. Estimations of primary and secondary emissions were performed on an annual basis using the 2019 Refinement to 2006 IPCC guidelines (Gavrilova et al. 2019), databases, and locally estimated emission factors.
Statistical analyses: To perform a numerical classification of farms, a principal component multivariate analysis (PCA) and a Hierarchical Clustering on Principal Components (HCPC) were done by using the FactoMineR package (Husson et al. 2015). A nonparametric approach of Kruskal-Wallis was used to determine differences among clusters in each system of production, followed by a post hoc test using the Kruskal-Nemenyi test (Pohlert 2016).

Results and discussion

The N surplus per ha at farm level was low (8.7 and 6.6 kg N ha^{-1} $year^{-1}$ on average for cow-calf and fattening systems) in most farms assessed when compared with specialized dairy systems with high fertilization rates

(186 kg N ha^{-1} $year^{-1}$) (Penati et al. 2011). The difference between the N surplus at farm level and the N lost by gaseous emissions was too low for most of farms, therefore, N loss from manure and N fertilizers through leaching of the N was assumed to be negligible.

Allocation of environmental burdens between meat (LWG) and milk (FPCM) in Cow-Calf farms: The percentages of environmental burdens allocated to meat varied according to the allocation method used, with the economic approach assigned higher percentages to meat – 83% –, while energy and mass allocation methods allocated 80 and 73%, respectively.

Contribution of on-farm and off-farm processes to total greenhouse gas emissions (GHG) by productive orientation: Most of the GHG emissions arose from on-farm animal activities. Enteric fermentation and manure deposited on pastures were the main hotspots contributing with 98% and 95% of total emissions for cow-calf and fattening systems, respectively. A similar emission pattern was reported for extensive beef cattle systems in Brazil, where emissions from cattle herd represented approximately 99% of the total GHG emissions on average for 22 farms (Cerri et al. 2016).

Variation among farms for cow-calf and fattening operations: The PCA showed that milk yield (kg FPCM cow^{-1} $year^{-1}$) and meat production (kg LWG AU^{-1}) were negatively correlated to carbon footprint (per kg FPCM and per kg LWG), which suggests that by increasing milk yield per cow and the LWG per animal unit, reductions on CF can be achieved. This analysis also showed a positive correlation among stocking rate and meat production (kg LWG ha^{-1}). Increasing the forage production through the adoption of improved pastures and better agricultural practices allow the increasing of stoking rate and thereafter the meat and milk production. After the cluster analysis three groups of farms for each stage of production were identified (Table 1). Both cow-calf and fattening systems had a cluster of farms with a low carbon footprint characterized by a higher percentage of the area of improved pastures, forage production, and better grazing management practices.

Carbon footprint and comparison with other studies: for cow-calf farms, considering the results from the 3 clusters the CF ranged between 10.3 to 14.5 CO_2eq $kgLWG^{-1}$. It has been reported that carbon footprint for cow-calf operations in Canada, USA, and Ireland ranged between 10 and 11 kg CO_2 $kgLWG^{-1}$, and these systems were characterized by high quality seeded pastures, high reproductive rates, and high use of inputs. In addition, In Latin America CF for cow-calf operations grazing over natural and improved pastures ranged between 11.4 and 32.2 kg CO_2 $kgLWG^{-1}$ (Becoña et al. 2014; Faverin et al. 2019), therefore, our results were at the lower end of this range. The above was due to the allocation of emissions between milk and meat performed, which is unusual for cow-calf farms, assigning a share of total emissions to milk that conducted to a reduction in CF for meat. However, when we allocate all the GHG emissions to meat, CF increases between 17 and 27%, reaching similar values than CF reported for cow-calf systems in Uruguay (Becoña et al. 2014). For fattening farms, in the three clusters identified the CFs ranged between 9.9 to 18.7 CO_2eq kg LWG^{-1}. In fattening operations, reported CF ranged from 9 to 43 kg CO_2-eq per kg LWG (Casey and Holden 2006; Pelletier et al. 2010; Dick et al. 2015; Ruviaro et al. 2015). The lower values of this reported range corresponded to farms with high quality of diets which conducted to higher animal productivity. Our results coincided with the lower end of this range but were mainly due to the low use of inputs by farms not by the high quality of pastures and animal productivity.

Conclusions

Our findings suggest that as a general behavior the hotspots of GHG emissions in cow-calf and fattening farms in Colombia arise from the animals, being enteric fermentation and excreta deposited on pastures the main sources. We identified three farm clusters for the cow-calf and fattening systems. Both production systems had a cluster of farms with low carbon footprint characterized by a higher percentage of the area of improved pastures, forage production, and better grazing management practices. The adoption of improved pastures, the adjusting of fertilization rate, and the implementation of better grazing management practices led to reduce the carbon footprint.

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Figures and tables

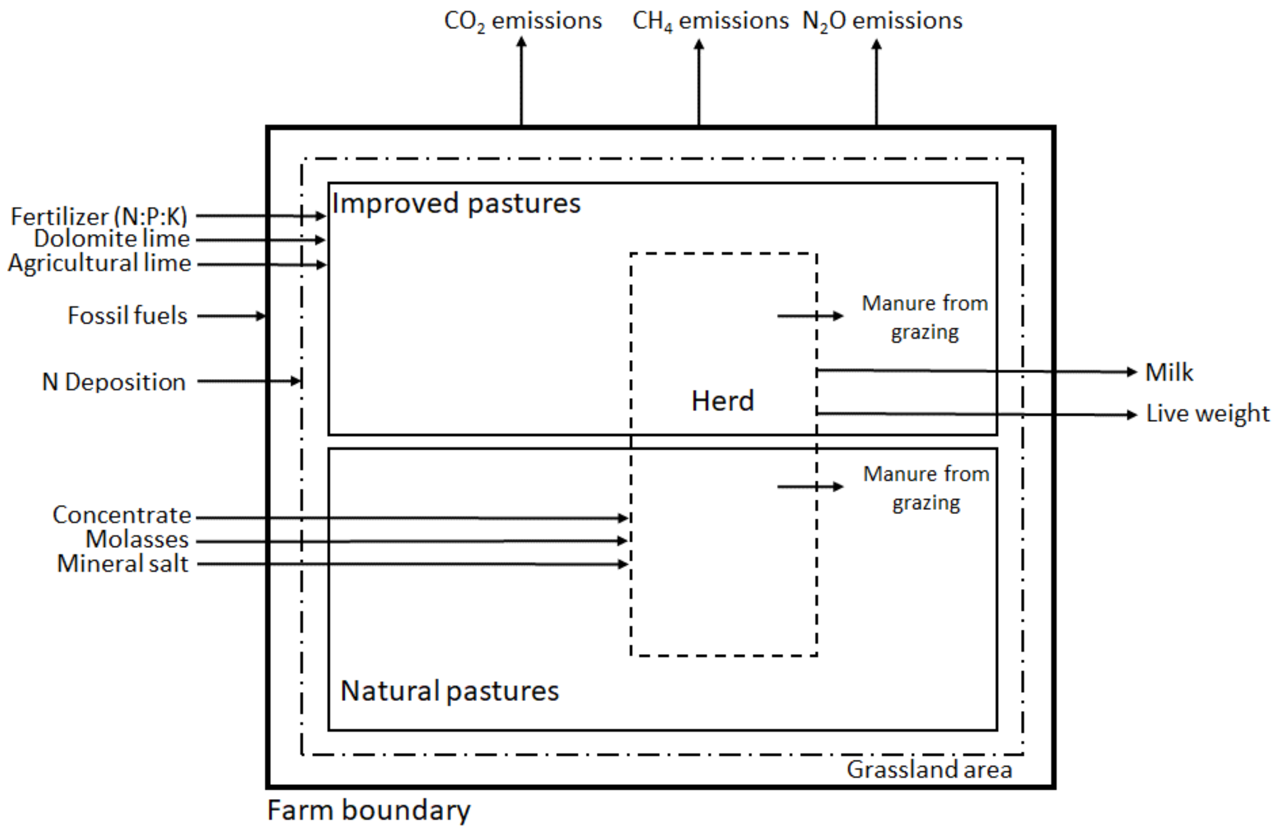

Figure 1. System boundaries and flows accounted for in the estimation of the impact categories in the beef farms in a "cradle to farm-gate" approach.

Table 1. Means for relevant farm variables for three farm clusters obtained after the environmental evaluation of 251 cow-calf farms and 275 fat tening farms in Colombia, and after modelling the scenario analysis.

	Cow-calf farms						Fattening farms					
	Cluster 1, n = 96		Cluster 2, n=45		Cluster 3, n = 110		Cluster 1, n = 119		Cluster 2, n=102		Cluster 3, n = 54	
	Mean		Mean		Mean		Mean		Mean		Mean	
Area, ha	17.7	c	90.2	a	56.2	b	47.7	b	24.6	b	64.5	a
Animal units, no	24.0	b	90.4	a	25.2	b	33.1	b	19.9	c	92.8	a
Stocking rate, AU ha^{-1}	1.9	a	1.3	b	0.7	c	1.1	b	1.6	b	3.0	a
Milk production, kg FPCM cow^{-1} $year^{-1}$	1249.4	a	941.5	b	993.9	b	---		---		---	
Meat production, kg LWG AU^{-1} $year^{-1}$	220.7	a	188.9	b	179.3	b	271.7	a	147.8	c	204.0	b
Meat production, kg LWG ha^{-1} $year^{-1}$	352.6	a	226.4	b	105.4	c	283.3	b	229.4	c	657.9	a
Area of improved pastures, %	12%	a	10%	a	4%	b	28%	a	8%	b	26%	a
Fertilizer application rate, kg ha^{-1} $year^{-1}$	19.1	c	66.1	a	30.3	b	28.3	a	40.9	a	87.5	a
Feed purchased, % of DMI	1.8%	b	8.0%	a	2.0%	b	1.3%	c	2.3%	b	6.5%	a
Dry matter production, Ton ha^{-1} $year^{-1}$	10.5	a	9.6	b	9.3	b	11.0	a	9.2	b	10.3	a
Diesel consumption, L ha^{-1} $year^{-1}$	10.9	b	33.4	a	11.2	b	13.3	b	12.6	b	17.3	a
Carbon footprint, CO_2-eq $kgFPCM^{-1}$	1.87	b	2.0	a	2.3	a	---		---		---	
Carbon footprint, CO_2-eq $kgLWG^{-1}$	10.3	c	11.6	b	14.5	a	9.9	c	18.7	a	13.4	b

Variable means with different letters across rows are significantly different at $P < 0.05$

Abstract code: 301

Environmental indicators of coffee cultivated in Sao Paulo State, Brazil

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Abstract

Purpose This is an ongoing study, which has the aim of updating the previously LCA study of the coffee production in Brazil in order to estimate environmental indicators, namely carbon footprint, primary energy demand and abiotic depletion – fossil of coffee production in different regions of the state of Sao Paulo, Brazil.
Methods The scope was to evaluate the coffee production systems located at São Paulo State, which have different climatic conditions. The Brazilian coffee producer regions evaluated were Mococa, Franca and Divinolândia. The varieties of coffee beans evaluated in this study were Tupi, Mundo Novo, Catuaí, Bourbon, Obatã and red Icatu. The system boundaries considered the stages from raw material extraction until the farm gate, i.e. a cradle-to-gate system. Farm specific data were combined with agricultural production data to elaborate a coffee production inventory and the environmental indicators. The data were obtained from three coffee producers for the crops 2016/17 and 2017/18. The functional unit adopted was 1,000 kg green coffee produced.
Results and discussion A reduction of fertilizers and electricity consumption was observed when these results are compared with the values published in the study developed for the crops 2001/02 and 2002/03. However, an increase of diesel and limestone consumption was observed when these results are compared with the previous study. Approximately 70% of the CO_2 emissions was due to field emissions related to urea and limestone applications. Brazilian land is acidic and needs correction of pH by application of limestone. Urea was responsible for approx. 65% of PED and ADP fossil, 20% due to diesel, and 15% due to phosphate.
Conclusions A reduction in the GHG emissions (carbon footprint) and energy use were observed for the green coffee produced in the crops 2016/17 and 2017/18 in relation to the study developed for crops 2001/02 and 2002/03 due to the reduction of fertilizers and electricity consumption.

Keywords: green coffee, carbon footprint, energy use, LCA, labelling communication

Introduction

Brazil is the largest coffee producer and exporter, in addition to be the second largest consumer of coffee worldwide. In the 2018/19 harvest, Brazilian production reached 49.31 million 60 kg bags (2,958.6 million kg), with a productivity of 27.20 bags (1,632 kg) per hectare in a production area of 1.81 million hectares. Of the total coffee harvested in the 2018/19 harvest, Arabica coffees reached a production of 34.30 million bags (2,058 million kg), which represent 69.5% of the harvest, while Conilon coffees, reached production of around 15.01 million bags (900.6 million kg), corresponding to 30.5% of this harvest (CONAB, 2019).

The world market shows a trend for labelling, and certification of products and production systems regarding environmental criteria has become one of the requirements for importation and commercialization of products (Rocha and Caldeira-Pires, 2019).
LCA study of green coffee produced in Brazil for the 2001/02 and 2002/03 crops (Coltro et al., 2006) showed regional differences in coffee cultivation, identifying large variation in the consumption of energy, water, fertilizers, pesticides and correctives among the farms evaluated, including properties located in the same producing region (Coltro et al., 2012).
This is an ongoing study, which has the aim of updating the previously LCA study of the coffee production in Brazil in order to estimate environmental indicators, namely carbon footprint, primary energy demand and abiotic depletion – fossil of coffee production in different regions of the state of Sao Paulo, Brazil. A larger number of farms are being evaluated with the aim of generating LCI for the Brazilian database of life cycle inventories (SICV Brasil).

Material and methods
The study was developed in accordance with the recommendations of the international standards ISO 14040 and 14044.
The scope was to evaluate the coffee production systems located at São Paulo State, which have different climatic conditions. The Brazilian coffee producer regions evaluated were Mococa, Franca, Divinolândia and Garça. The varieties of coffee beans evaluated in this study were Tupi, Mundo Novo, yellow Catuaí, Bourbon, Obatã and red Icatu.
The system boundaries considered the production of fertilizers, correctives, electricity as well as the production of diesel used by the machineries and the transport of the inputs until the farm, i.e. a cradle-to-gate system was adopted. The transport distances were doubled when the truck returns empty.
Farm specific data were obtained from three coffee producers for the crops 2016/17 and 2017/18.
The functional unity adopted was 1,000 kg green coffee produced.
Data storage and modelling were performed employing the GaBi6 Product sustainability software program. The following impact categories were evaluated: Climate change (global warming potential for a 100-year perspective – GWP_{100}, excluding biogenic carbon) and Abiotic depletion (ADP fossil) according to CML 2001 – April 2013 method (Guinée, 2002); Primary energy demand (PED) from renewable and non-renewable resources (net calorific value) taking into account direct and indirect fuel consumption. GHG emissions due to fertilizers and limestone applications were estimated according to IPCC models (IPCC, 2006).

Results and Discussion
The life cycle inventory of green coffee production was estimated, and it is shown at Table 1.
A reduction of fertilizers and electricity consumption was observed when these results are compared with the values published in the study developed for the crops 2001/02 and 2002/03. However, an increase of diesel and limestone consumption was observed when these results are compared with the previous study (Coltro et al, 2003). These differences probably are related to the higher yield of the crops 2016/17 and 2017/18 (ranging from 1,080 kg ha^{-1} to 2,520 kg ha^{-1}) compared to the crops 2001/02/ and 2002/03 (ranging from 780 kg ha^{-1} to 2,580 kg ha^{-1}), besides changes in agricultural practices along the years.
The GWP_{100} and the energy use (primary energy demand and abiotic depletion – fossil) were estimated, and the results are shown in Figure 1. On average, approx. 2,000 kg CO_2-eq., 13,000 MJ of primary energy demand and 11,500 MJ of ADP fossil were associated to the production of 1,000 kg green coffee. The crop 2017/18 showed lower emissions than crop 2016/17, which is attributed to the higher yield of crop 2017/18 (1,964 kg ha^{-1}) than crop 2016/17 (1,823 kg ha^{-1}) since coffee is a biennial crop.

Table 1. Summary of the LCI of green coffee production for the reference crops 2016//17 and 2017/18 (FU = 1,000 kg).

Parameter	Unit	Average ± SD	Min. – Max.	2001/02 and 2002/03*
Diesel	kg	129.4 ± 10.5	44.2 – 306.2	94 (5 – 331)
Fertilizers total	kg	514.9 ± 128.8	305.6 – 753.1	911 (11 – 3,583)
N	kg	254.1 ± 43.9	198.4 – 350.7	----
P_2O_5	kg	73.7 ± 51.9	0.0 – 125.0	----
K_2O	kg	187.1 ± 33.1	107.1 – 324.1	----
N,P, K**	kg	262.3 ± 63.4	155.6 – 412.0	274 (1.3 – 927)
Limestone	kg	828.9 ± 129.2	0.0 – 1,458.3	622 (200 – 4,480)
Electricity	MJ	406.8 ± 387.3	0.0 – 1378.6	646 (36 – 1,934)

* Coltro et al., 2006; ** Sum of the active elements of N, P and K

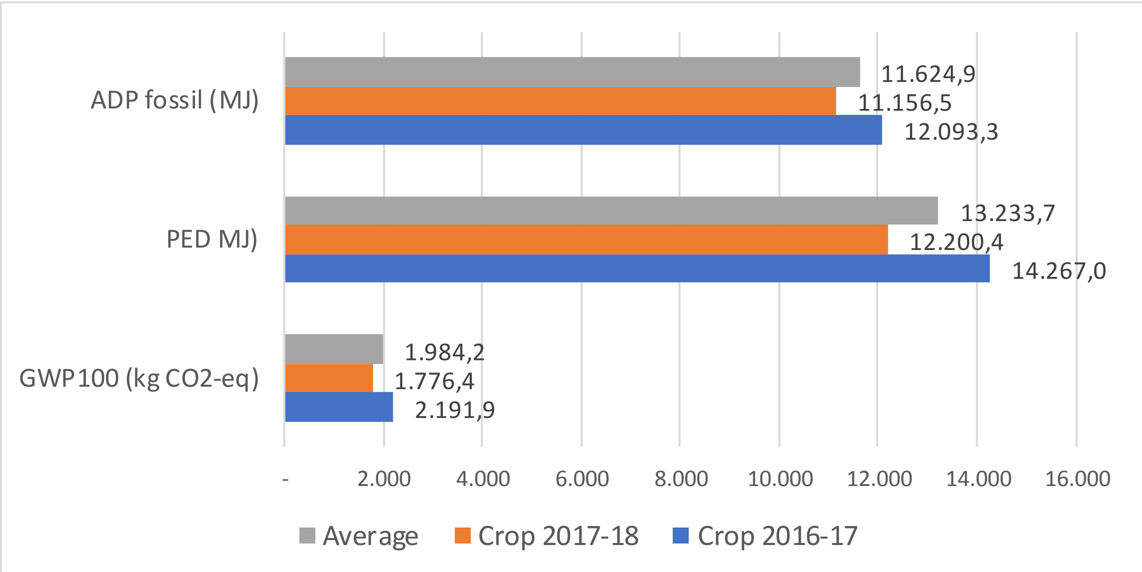

Figure 1. Environmental indicators of green coffee cultivated in São Paulo Brazil, for the reference crops 2016//17 and 2017/18 (FU = 1,000 kg).

GHG emissions of this study are lower than results obtained by Noponen et al. (2012), which found 2,550 – 3,120 kg CO_2-eq 1,000 kg^{-1} green coffee. The results are in the lower range of the results obtained by Giraldi-Díaz et al. (2018), which found 1,890 – 2,820 kg CO_2-eq 1,000 kg^{-1} green coffee. Approximately 70% of the CO_2 emissions was due to field emissions related to urea and limestone applications. Brazilian land is acidic and needs correction of pH by application of limestone.
Urea was responsible for approx. 65% of PED and ADP fossil, 20% due to diesel, and 15% due to phosphate.

Conclusions

A reduction in the GHG emissions (carbon footprint) and energy use were observed for the green coffee produced in the crops 2016/17 and 2017/18 in relation to the study developed for crops 2001/02 and 2002/03 due to the reduction of fertilizers and electricity consumption. On average, approx. 2,000 kg CO_2-eq., 13,000 MJ of primary energy demand and 11,500 MJ of ADP fossil were associated to the production of 1,000 kg green coffee. These results indicate changes in agricultural practices along the years with the adoption of practices in agreement with the sustainable development. These data will be useful for labelling communication.

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Food-related health and sustainability disparities in the US

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Abstract

Purpose: Numerous demographic and socioeconomic factors influence the quantity and quality of foods consumed, which can lead to health and environmental disparities. Here we investigate the variability in the healthiness and environmental sustainability performance of self-reported dietary patterns for Americans. More specifically, we characterize the nutritional health burden and environmental impacts for multiple indicators of dietary patterns for adult Americans in 2016 by gender, ethnicity, income, and physical activity.

Methods: We used a nationally representative sample of Americans aged 25+ years old (N=13,331) from the National Health and Nutrition Examination Survey (NHANES) 2011-2016 database to determine self-reported dietary patterns by gender (Male/Female), ethnicity (White, Black, Hispanic, Asian, Other), poverty-income ratio level (PIR: low, moderate, high), and physical activity level (PA: sedentary, moderate, vigorous). For each dietary pattern, we estimate health burden in minutes of healthy life using the Health Nutritional Index (HENI), an epidemiology-based nutritional assessment tool based on 15 dietary risk factors. We also determine the cradle-to-farm gate or processing gate climate change, land use, and blue water use impacts for each dietary patterns using life cycle assessment (LCA), accounting for food loss and waste.

Results and discussion: Differences in the type and quantify of foods consumed by demographic groups were reflected in their healthiness and environmental performance. Females followed healthier diets by 14.7 minutes/pers/d that generated lower environmental footprints by ~30% in all indicators compared to males. Asians had the healthiest diets (HENI=41 minutes/pers/d) with the lowest land footprint (2.8 ha-yr/pers/d), while Blacks had the lowest carbon (3.4 kg CO_2e/pers/day) and water footprints (212 L/pers/d). HENI scores indicated healthier diets increased with income but we found minor differences in the environmental performance of diets by PIR status. In regards to physical activity, the healthiness of diets increased slightly with activity level. Differences were more profound for environmental footprints due to higher overall food intake with increased activity levels. The HENI scores for the USDA recommended diets were higher by at least 27 minutes/pers/day of healthy life gained compared to reported dietary patterns and resulted in lower carbon and land footprints by at least 25% and 50%, respectively. However, healthy diets have higher water footprint than current US diets.

Conclusions: Our findings highlight important nutrition and environmental disparities of diets in the US, especially by gender and ethnicity. Adherence to healthy dietary patterns could substantially benefit most Americans and the environment, but would require more water usage, pointing at the need for water saving methods in agriculture production. It is crucial that future dietary guidelines for Americans are data driven and take into account both health and environmental considerations, especially for water use.

Keywords: *Dietary patterns; disparities; nutrition; human health; sustainability*

Introduction

Food choices have significant consequences on human health as well as contribute to environmental degradation (Tilman and Clark 2014; Willett et al. 2019). An increasing number of studies have focused on quantifying these diet-related impacts in the US, investigate trade-offs between environmental and nutritional aspects of diets, and identify "win-win" diets. Studies have focused on consumed dietary patterns (Soret et al. 2014), self-reported diets (Conrad et al. 2018; Rose et al. 2019), modelled diets (Gephart et al. 2016; Willits-Smith et al. 2020), and recommended healthy diets (Hallström et al. 2017; Hitaj et al. 2019). While many studies have reported lower environmental impacts associated with heathy diets, a recent systematic review concluded that not all healthy dietary patters offer such co-benefits, with the Healthy US-style dietary pattern recommended by the US Department of Agriculture generating environmental impacts that are similar or higher than those of the average American diet (Reinhardt et al. 2020).

Interpersonal characteristics such as gender, ethnicity, and socioeconomic status are well known factors that influence the quantity and quality of foods consumed in an individual's diet. Although, the nutritional disparities of US diets by these factors have been studied expensively, little is known about their healthiness and environmental sustainability potential. The primary aim of this study is to characterize the nutrition-related health burden and life cycle carbon, water, and land footprints of distinct self-reported dietary patterns for American consumers. The secondary aim of this study was to quantify the benefits, if any, of US diets transitioning to any of the healthy dietary patterns recommended for Americans.

Material and methods

Dietary patterns for Americans

We determined dietary patterns for Americans based on the What We Eat in America component of the National Health and Nutrition Examination Survey (WWEIA/NHANES) database for the years 2011-2016 (National Center for Health Statistics 2018). The database recorded self-reported 24-h recall food intake data for ~5800 foods from a national representative sample of 13,331 adults (+25 years old, excluding pregnant or lactating females). Using this information we developed daily dietary patterns by demographic factors such as gender (Male/Female), ethnicity (White/Black/Hispanic/Asian/Other), economic status defined by the poverty-income ratio (PIR: Low/Moderate/High), and physical activity level (PA: Sedentary/Moderate/Vigorous).

Nutritional assessment

We evaluated the nutritional health performance of each dietary patterns using the Health Nutritional Index (HENI). HENI is an epidemiology-based model that quantifies the net health burden in minutes of healthy life lost (-) or gained (+) associated with the 15 dietary factors (beneficial: fruits, vegetables, legumes, milk, whole grains, nuts and seeds, calcium, fiber, omega-3, and polyunsaturated fats; detrimental: red meat, processed meat, sugar-sweetened beverages, trans fat, and sodium) from the Global Burden of Disease (Stylianou 2018; Stylianou et al. 2020). For a given dietary pattern i, $HENI_i$ is calculated as:

$$HENI_i = 0.53\left[\sum_{r,detrimental} DRF_r \cdot (d_r^{diet_i} - TMRL_r) + \sum_{r,beneficial} DRF_r \cdot \min(d_r^{diet_i}, TMRL_r)\right]$$

(Eq. 1)

where DRF_r is the marginal age- and gender-adjusted nutritional characterization factors of risk r for US adults reported in $\mu DALYs/g_{intake}$ of dietary risk, $d_r^{diet_i}$ is the cumulative daily intake of risk r in diet i reported in g/pers/d, and $TMRL_r$ is the theoretical minimum risk levels for risk r reported in g/pers/d. The constant of -0.53 is a unit conversion factor from µDALYs to minutes of healthy life[1]. DRF estimates were obtained from Stylianou et al. (2020). Daily intake levels by risk components were determined using the approach by Fulgoni et al. (2018). TMRLs indicate upper and lower intake limits below (beneficial risks) and above (detrimental risks) which daily intake levels for a given risk pose increased risk of developing an adverse health effect. TMRL estimates were obtained from the Global Burden of Disease (Gakidou et al. 2017).

Environmental assessment
We characterized the cradle-to-farm gate or processing gate climate change, land occupation, and blue water use impacts based on food-specific estimates from ~5,800 foods in the WWEIA/NHANES database using life cycle assessment (LCA). Food estimates were determined by combining standardized food recipes from the U.S. Department of Agriculture (USDA) Standard Reference (SR) database (SR28 2016), with the Loss-Adjusted Food Availability (LAFA) 2017 database (ERS/USDA 2017), with life cycle inventories (LCI) from Ecoinvent v3.2, World Food LCA Database v3.1, and ESU World food database (listed in order of priority). Carbon and land footprint were estimated using the Impacts World+ (default region). To calculate blue water footprints we utilized information developed by the Water Footprint Network (Mekonnen and Hoekstra 2010, 2012).

Results and discussion
In figure 1A, we present the HENI scores for select US dietary patterns by gender and ethnicity. These scores should be compared to the global burden of disease reference diet (GBD) which assumes an ideal diet where intakes for all risks are at TMRL (HENI=124.9 minutes/pers/day, left bar in the graph), i.e. all beneficial components at their maximum intake and zero detrimental component intake. Females (HENI=24.3 minutes/pers/d) followed healthier diets compared to men (HENI=9.6 minutes/pers/d), due to eating less food overall and in particular processed meat, sodium, sugar sweetened beverages (SSB), and trans fat. Looking at dietary patterns by race, Asians had the healthiest diets with a HENI score of 40.9 minutes/pers/d, Blacks had the least healthy diet at 8.8 minutes/pers/d, and for Whites the HENI score was 17.1 minutes/pers/d. The HENI score of Asian diets was driven by higher intake of fruits, seafood, and whole grains and lower intake of processed meat and SSB. People with high income had the healthier diets (HENI=21.2 minutes/pers/d) compared to people with the low income (HENI=6.3 minutes/pers/d), primarily due to different intakes of nuts, SSB, and vegetable. For physical activity, the healthiness of the diets increased with activity level. When evaluating the four healthy dietary patterns recommended by USDA in 2015, standardized at 2000 kcal/pers/d, we found substantially higher HENI scores ranging from 68.7 (US Healthy) to 86.3 (Vegan) minutes/pers/d compared to the reported dietary patterns for Americans. This suggests that recommended healthy dietary patterns could indeed improve the health of Americans, yet, their HENI scores are lower than the ideal GBD diet partly due to lower daily energy intake, indicating that there is room for further improvement of 50 additional minutes of healthy life to gain, in particular by further increasing whole grain consumption.
In figure 1B, we present the daily carbon footprint for select US dietary patterns by gender and ethnicity. Overall, environmental footprints in our analysis were positively associated with daily energy intake. The diets of females generated lower environmental footprints by ~30% in all indicators compared to males. Asians had the lowest land footprint (2.8 ha-yr/pers/d), while Blacks had the lowest carbon (3.4 kg CO2e/pers/day) and water footprints (212 L/pers/d). The carbon, land, and water footprints for Whites were estimated at 4.0 kg CO2e/pers/day, 3.1 ha-yr/pers/d, and 235 L/pers/d, respectively. Household income had little influence on the environmental performance of diets, while environmental footprints increased with physical activity, due to the consumption of more

[1] 1 µDALYs $= -1 \times 10^{-6} \cdot 365 \frac{days}{year} \cdot 24 \frac{hours}{day} \cdot 60 \frac{minutes}{hour} = -0.53$ minutes of healthy life

food. Generally, carbon and land footprints were primarily driven by beef intake. In contrast, the water footprint of diets was driven by the amount and type of plant-based foods. Recommended diets for Americans generated lower carbon and land footprints compared to current dietary patterns ranging between 1.9-2.7 kg CO2e/pers/day and 1.1-1.5 ha-yr/pers/d, respectively. However, transitioning to healthy dietary patterns requires a 50% increase of water footprint on average. This points at the need for the generalization of water saving methods in agriculture production, targeting in priority healthy foods such as nuts and seeds.

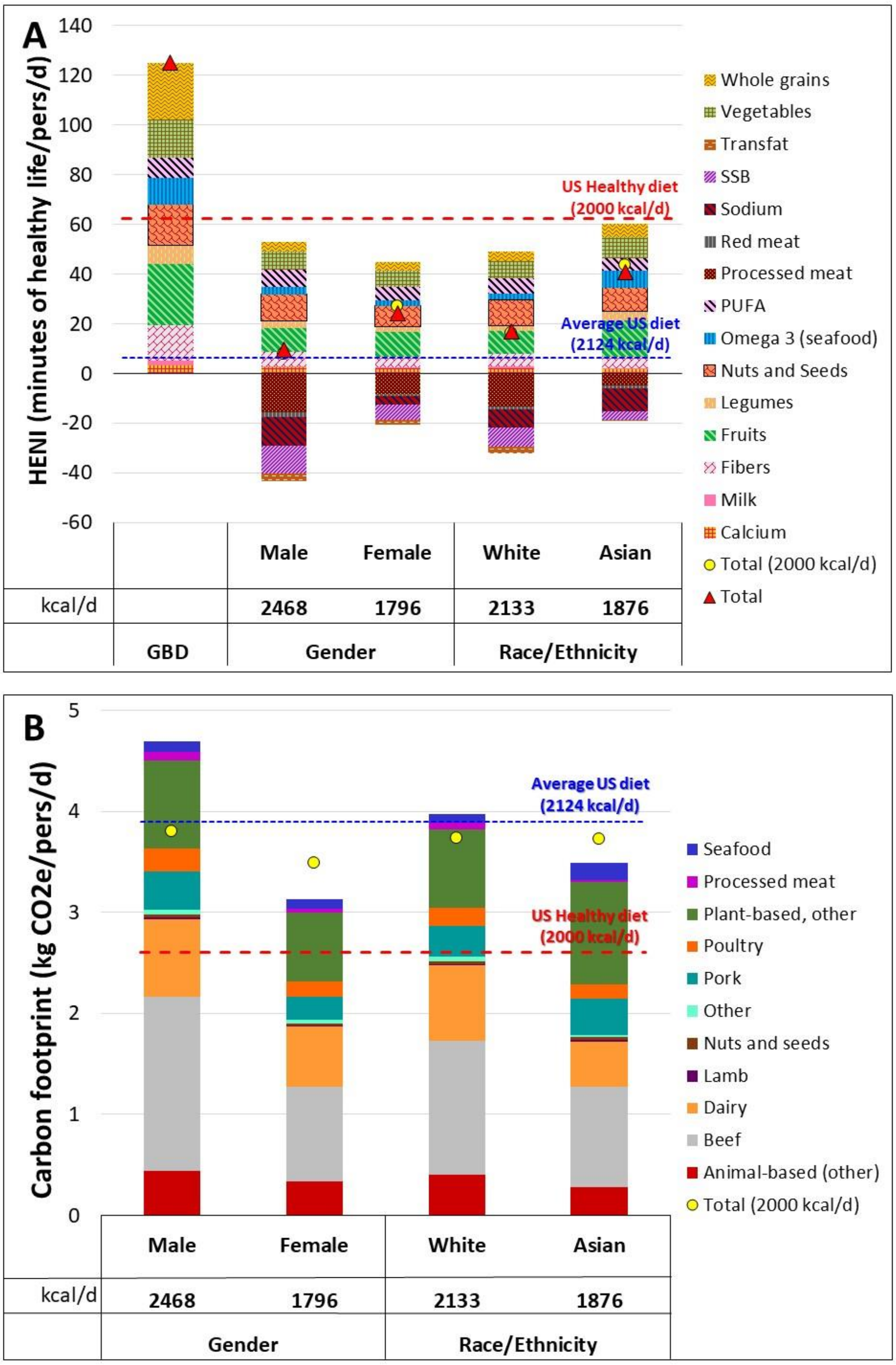

Figure 1: Nutrition-related health burden **(A)** and carbon footprint **(B)** of various dietary patterns. Yellow circles in both figures represents total estimates adjusted for 2000 kcal/d.

In the present study, we characterized dietary disparities in the US and evaluated the potential improvements offered by healthy recommended dietary patterns. Dietary patterns by demographic groups were determined using data from a large survey of a nationally representative sample of Americans. Our analysis uniquely combined health and environment assessments of dietary differences, comparing performances in the same units of health burden when possible. However, our findings are not without limitations. Dietary patterns were determined based on weighted averages of self-reported food daily intakes from a single day that can be prone to reporting bias and might not be representative of an individual's average diet. HENI scores in our analysis only consider dietary risks reported in the GBD studies, which might not cover the latest epidemiological findings that associated dietary risks with health outcomes. Furthermore, while HENI scores were corrected for intake levels that pose no additional risk of adverse health effect (TMRLs), our analysis did not account for the multicolinearity of dietary risks, which might result in overestimating the absolute value of HENI scores when multiple risk components contribute to the same health outcome burden. While relative results between diets are expected to be robust, to ensure the reliability of absolute nutritional estimates, there is a need for a diet level approach that accounts for the multiplicative nature of risk. The reported environmental impacts correspond primarily to food production processes and supply chain losses and waste. Expanding the system boundaries of the food system by including impacts from processing, packaging, distribution, retail, and storage might increase the absolute carbon footprint estimates of the different dietary patterns. Commodity-specific spatial variability of water footprints was considered in the present study when US-specific data were available; however, within country spatial considerations have been shown to be important and could improve our estimates (Henderson et al. 2017). Finally, it should be clarified that dietary patterns investigated in the present paper correspond to varying daily energy intakes that range from 1796 kcal/pers/d (females) to 2468 kcal/pers/d (males) while the daily intake of the healthy recommended dietary patterns is by default set at 2000 kcal/pers/d. Adjusting for caloric differences did not substantially affect HENI scores but explained differences in environmental footprints. More specifically demographic group-specific footprints range from 3.2 (black) to 3.8 (males) kg CO2eq/2000 kcal/d and 2.7 (female) to 3.1 (male) ha-yr/2000 kcal/d for carbon and land use, respectively, which remained higher than the healthy dietary pattern footprints. Calorie-adjusted water footprints by demographic group varied between 200 (black) and 287 (asian) L/2000 kcal/d and were still lower than those of the healthy dietary pattern. In addition to the demographic characteristics examined in the present study, other interpersonal attributes, such as body size, may also influence daily energy intake and consequently environmental footprints and should be investigated in the future studies.

Conclusions

In this study, we evaluated the performance of demographic-specific diets for Americans using four diverse indicators: nutrition-related health burden, carbon footprint, land occupation, and blue water use. We found prominent disparities for all indicators between dietary patterns, especially by gender and race. Overall, women and Asian diets are healthier and are more environmentally friendly. However, adherence to healthy dietary patterns could provide substantial co-benefits for all indicators, except for water footprint. Our study provides new insights that could inform refined dietary guidelines by demographics and highlight the need for the consideration of water usage optimizations.

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Scan level cradle-to-grave life cycle assessment of pulses in the United States

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Abstract

Purpose: The objective of this study was to perform a scan-level attributional LCA of pulse crops in the United States using national average production and consumption practices for the most commonly grown peas, lentils, chickpeas, and dry beans.
Methods: A functional unit for cradle-to-grave supply chain of pulses 250 g of dry pulses, cooked and consumed in a US household. The model was divided into four stages: cradle-to-farmgate, processing, retail, and consumption. Pulse production methods and related data were obtained from expert opinion and from crop budgets and extension documents. Crop yield was obtained from USDA-NASS. Electricity consumption at processing stage was estimated based on technical specifications published by manufacturers of commonly used processing equipment. Burden at retail stage was allocated to pulses using occupied shelf space. It was assumed that cooking pulses at a consumer stage involved open vessel cooking on electric stove.
Results and discussion: Global warming potential for 250g (dry basis) of pulses consumed in a US household was 5.99, 6.21, 2.40, and 1.39 kg CO2e for chickpeas, dry beans, field peas, and lentils, respectively. The land use measured in m^2a crop eq ranged between 3.18 for chickpeas and 1.92 for field peas. Water consumption was estimated at 0.0356, 0.0355, 0.0141, and 0.0092 m^3 for chickpeas, dry beans, field peas, and lentils, respectively. Fossil fuel scarcity, expressed as kg oil eq ranged between 0.34 and 1.51 kg oil eq per 250 g (chickpeas: 1.46, dry beans: 1.51, field peas: 0.59, lentils: 0.34 kg oil eq). Freshwater and marine eutrophication ranged between 0.0019 and 0.0082 kg P eq, and 0.0001 and 0.0005 kg N eq respectively.
An important and somewhat unexpected outcome of the cradle to grave assessment is the very large contribution of cooking – from 80 to 95% of GWP, depending on the quantity cooked and was attributed to open vessel cooking on an electric stove and emissions from electricity generation. This was also evident from greater GWP and fossil fuel scarcity observed for dry beans and chickpea varieties that require longer cooking time.
Conclusions: The study highlighted consumer stage as the hotspot in pulses life cycle. Sensitivity of impact categories to mass of pulses cooked and cooking method provides an opportunity to evaluate possible approaches to reduce cradle-to-grave impact of pulses.

Keywords: *Life cycle assessment; pulses; environmental impact; cradle-to-grave*

Introduction

Food supply sector contributes 19 to 29 percent of global anthropogenic greenhouse gas (GHG) emissions and agriculture is the largest contributor of CH_4 and N_2O emissions (MacWilliam et al. 2018). Agriculture currently depends on a few major crops such as corn, rice, and wheat. Overreliance on few major crops to meet the demands of growing populations could be agronomically, environmentally, and economically perilous. Therefore, diversification in crop production is important as a measure to improve pest and nutrient management, food production, and overall sustainability of the agriculture sector.
Pulses, when included in crop rotation, can play a major role in achieving these objectives by breaking disease and insect cycles and improving soil fertility (MacWilliam et al. 2015). Pulses, which include

leguminous crops such as dry beans, field peas, chickpeas, and lentils, have an ability to fix atmospheric nitrogen to meet most of their nitrogen demands therefore, requiring substantially less synthetic N compared to other commodity crops (Franzen 1998; Schatz and Endres 2009; Oberle and Keeney 2013; Washington State University 2015; Kandel et al. 2018). This reduced reliance of pulse crops on synthetic N fertilizer offer various environmental and agronomic benefits. Environmental impacts associated with production and application of synthetic N fertilizers can be mitigated by including pulses in crop rotation. Inclusion of pulses also benefits following cereal crop in terms of improved yield and protein content (MacWilliam et al. 2015).
In terms of human health, pulses are excellent source protein and can improve nutrient quality of human diets. On fresh weight basis, pulses contain 18 to 36 percent protein and are rich in nutrients, vitamins, and minerals (FAO 2016). Furthermore, high levels of complex carbohydrates and fiber can help improve nutrient balance score of food (Chaudhary et al. 2018) by increasing fiber, protein, folate, zinc, iron and magnesium content of human diet while also reducing saturated and total fat (Mitchell et al. 2009).
While LCA studies of pulse production are available for Canada and a few other parts of the world, few studies exists specific to US pulse production. Gustafson (2017) conducted the most recent LCA of US pulse production using survey data collected in six states and covering five pulse crops. However, this study did not follow many of the commonly used and internationally standardized methods of conduction life cycle assessment and included only two impact categories. The results for the two categories considered were aggregated for all types of pulse crops with distinction made only between irrigated and non-irrigated crops. Furthermore, the study was 'cradle to farmgate' and did not consider post-farmgate processes, which are needed to provide a wholistic picture of the sustainability of pulse crops.
Therefore, the objective of this study was to perform a scan-level 'cradle to grave' attributional LCA of pulse crop production in the US using national average production and consumption practices for the most commonly grown peas, lentils, chickpeas, and dry beans.

Material and methods

Goal, scope, and functional unit

The primary goal of this study was to evaluate impacts associated with cradle-to-grave supply chain of pulses in the United States with a functional unit of 250 g (dry weight) of pulses cooked and consumed in the US household. The system boundary was cradle to grave and included four stages: crop production and associated upstream processes, processing of harvested crop, storage of packaged product at the retail stores, and purchase, cooking, and consumption of pulses by the consumer. Consumption of pulses away from home was excluded from the study. The system boundary excluded processing and consumption of various finished products containing pulses. An ISO 14044 allocation hierarchy (ISO 2006) was followed in this study for allocation of inputs and emissions. We primarily used a revenue-based approach for allocation where necessary. For the retail stage however, allocation based on shelf space occupied was used.

LCA Model

Process model representing production and consumption of four types of pulses: chickpeas, lentils, field peas, and dry beans; was modeled in OpenLCA (GreenDelta). Background processes involved in production, processing, retail, and cooking of pulses were modeled using EcoInvent 3.4 (Wernet et al. 2016) LCA database.

Crop production

Crop production methods and related data were obtained from expert opinion and from crop budgets and extension documents published by the universities, while crop yields were obtained from USDA-NASS survey data. Data provided by experts included fertilizer application rates, seeding rates, and information about types of chemicals used and their application rates. Production practices for pulses vary with state and crop variety. In absence of specific data lentils, field peas, and chickpeas were modeled as no-till dry land (Miller, personal communication, 2019) and dry beans were modeled as conventionally tilled dry land (Washington State University 2015). Nutrient loss in the form of direct and indirect emissions from nitrogen fertilizer applications and leaching and runoff of soluble phosphorus from phosphate application were estimated using IPCC tier-1 method (IPCC 2006) and a method provided by (Potter et al. 2006), respectively. Seed and fertilizer production processes in the EcoInvent database were modified to use US electricity grid and transportation distances.

Processing stage

Transportation distance of 100 km, reported for wheat O'Donnell (2008), for northwest and central United States was adopted for this study. Accounting for 25% losses during grading, decorticating, and splitting (Patras et al. 2011) and 12.5% losses in the form of debris and stones (half of processing losses), electricity consumption was estimated for 1.52 kg of pulses brought in for processing and for 1.33 kg of pulses processed post-destoning and debris removal, per kilogram packaged product, using technical specifications of equipment (Buhler Inc.) and an approach presented by Stossel (2018). Conditioning prior to decortication, required for chickpea and field pea, was modeled as addition of water at the rate of 10% (w:w), soaking for 4 to 8 hours, and subsequent drying to 7 to 11% moisture content (Wood and Malcolmson 2011). Processed pulses were packed in 6.06 g of LDPE bag per kg of final product.

Retail stage

Transportation data specific to pulses were absent. Therefore, transportation distance of 452 km published for food manufacturing industry in Commodity Flow Survey was adopted for this study (Bureau of Transportation Statistics 2017). Electricity consumption and land occupation by retail sector were obtained from 2017 Annual Retail Trade Survey (US Census Bureau 2017) and from (Walmart Inc. 2019), respectively were allocated to a kilogram of pulses (0.06% allocation) using consumer facing shelf space area at a supermarket (proprietary data). Wastage at retail stage was 5.88% for legumes (USDA-ERS 2017).

Consumer stage

Current dietary consumption of 0.285 dry cups per week of legumes reported in USDA dietary guidelines (USDA 2014) and plate wastage of 10% (USDA-ERS 2017) were used to set input and output of a consumer stage. Average transportation distance of 5.52 km (USDA-ERS 2015) travelled by US consumer for grocery shopping was allocated to each pulse variety using proportion of total food expenditure spent towards purchasing each variety (USDA-ERS 2018). For this study cooking pulses involved boiling them in an open vessel on an electric stove with average power of 2100 J/s (Direct Energy). Total energy consumption for cooking pulses was directly proportional to amount of water used and simmering time required. The simmering time varied between 19 minutes for lentils and 90 minutes for dry beans and chickpeas. Dishwasher electricity and water use (Appliance Standard Awareness Project 2017) were allocated to pulses using economic allocation used for transportation process.

Results

Global warming potential for 250g (dry basis) of pulses consumed in a US household was 5.99, 6.21, 2.40, and 1.39 kg CO_2e for chickpeas, dry beans, field peas, and lentils, respectively. The land use measured in m^2a crop eq was 3.18 for chickpeas, 2.79 for dry beans, 1.92 for field peas, and 3.16 for lentils. Throughout the cradle-to-grave processes, water consumption was estimated at 0.0356, 0.0355, 0.0141, and 0.0092 m^3 for chickpeas, dry beans, field peas, and lentils, respectively. Fossil fuel consumption using ReCiPe 2016 is reported as fossil fuel scarcity, and expressed as kg oil eq. The fossil fuel depletion score ranged between 0.34 and 1.51 kg oil eq per 250 g of pulse crop (chickpeas: 1.46, dry beans: 1.51, field peas: 0.59, lentils: 0.34 kg oil eq). Freshwater eutrophication, resulting primarily from phosphorus fertilizer application, was 0.0082, 0.008, 0.0033, and 0.0019 kg P eq for chickpea, dry bean, field pea, and lentil, respectively. Marine eutrophication on the other hand was relatively low ranging between 0.0001 kg N eq for lentil and 0.0005 kg N eq for chickpea and dry bean. For field pea marine eutrophication score was 0.0002 kg N eq for 250 g of pulses cooked and consumed.

Discussion

The contribution analysis revealed an important and somewhat unexpected outcome of the cradle-to-grave assessment. The consumer stage contributed at least 81% of overall impact observed for fossil fuel scarcity, freshwater eutrophication, global warming potential, and marine eutrophication. Open vessel cooking requires first brining water to boil and then simmering pulses for 19 to 90 minutes, which increases electricity consumption. The burden of electricity production, which in US relies heavily on fossil fuels, is transferred to the consumer stage increasing its contribution to overall impacts. This was also evident from GWP and fossil fuel scarcity impacts which corresponded with cooking time for individual pulse variety (greatest for dry bean and chickpea and lowest for lentil). Contribution of crop production to freshwater and marine eutrophication was 2.4 and 1.6%, respectively. This small contribution of crop production to these impact categories was attributed to relatively low fertilizer use in pulse crop production.
The impact categories were also highly sensitive to mass of pulses cooked in each batch. In this analysis, a batch of pulses cooked was equivalent to current weekly dietary consumption of pulses reported in USDA (2014). Therefore, the functional unit of 250 g (dry weight) of pulses used in this study required cooking multiple batches of 0.285 dry cups of pulses. Initial analysis indicated that increasing the mass from current weekly intake to 1.11 kg reduced GWP significantly (Table 1).

Table 1. Results for scan level cradle-to-grave LCA for open vessel cooking scenario indicating sensitivity of impact categories to mass of pulses cooked

Pulse variety	Global Warming Potential (kg CO_2 eq) for 250 g of pulses consumed			
	Amount cooked (kg/batch)	GWP	Amount Cooked (kg/batch)	GWP
Chickpea	0.062	5.99	1.11	0.75
Dry bean	0.064	6.21	1.11	0.85
Field pea	0.066	2.40	1.11	0.33
Lentil	0.066	1.39	1.11	0.35

Conclusion

The study highlighted hotspots in the cradle-to-grave supply chain of pulses. The consumer stage, particularly cooking method and mass of pulses cooked in each batch, were responsible for large GWP and fossil fuel scarcity observed in the study. Our initial analysis indicated that adopting pressure cooking instead of open vessel cooking and increasing mass of pulses cooked in each batch reduced GWP. This analysis provides possible opportunities to lower overall impact pulses.

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Environmental and nutritional impacts of reformulating foods with pulses

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Abstract

Purpose: Incorporating low cost pulses, that are rich in nutrients and low in fertilizer requirements, into daily food items, can improve the nutritional and sustainability profile of national diets. This presentation will focus on the nutritional and environmental impacts of incorporating Canadian lentil flour into cereal-based food products.

Methods: Canadian-specific production data and macro- and micronutrient data were used to calculate environmental footprints (carbon, bluewater, water scarcity, land use and biodiversity) and nutrient balance score (NBS) for traditional and reformulated pan bread, breakfast cereal and pasta.

Results and discussion: NBS was improved by 13.6, 92.7 and 26.5% for reformulated pan bread, breakfast cereal and pasta, respectively. Decreases in life cycle carbon footprint were realized, with 7.6, 16.5 and 30.7% reductions for reformulated pan, bread, breakfast cereal and pasta. However, an increase in impact was shown with reformulated products when bluewater, water scarcity, land use and biodiversity impacts were assessed, due to the lower yields with lentil compared to wheat.

Conclusions: The results and framework of this study are relevant for food industry, consumers, as well as global and national policy-makers evaluating the effect of dietary change and food reformulation on multiple nutritional and environmental targets.

Keywords: Pulses; nutrition; sustainability; life cycle assessment; carbon footprint; food; carbon footprint; bluewater; water scarcity; land use; biodiversity

Introduction

The International Year of Pulses in 2016 provided an opportunity to highlight the environmental, nutritional and economic advantages of increasing production and consumption of pulses around the world. Pulses are typically consumed in lower amounts than what is recommended in dietary guidelines, and strategies need to be developed to increase the consumption of pulses in order to achieve nutritional and environmental goals related to food. One underutilized strategy that needs further exploration is the potential of reformulating food products with pulse ingredients in order to improve nutritional and environmental outcomes.

This study assesses the nutritional and environmental outcomes of three cereal-based food products that have been reformulated with Canadian-grown lentil flour as a replacement for refined wheat flour. The nutritional quality of the traditional (without lentil flour) and reformulated (with lentil flour) foods was assessed by utilizing the Nutrient Balance Concept (Fern et al. 2015). Multiple environmental impacts (carbon, bluewater, water scarcity, land use and biodiversity) of 1 kg and 1 serving of traditional and reformulated products was determined by accounting for all inputs during the cultivation, milling, and manufacturing stages. To minimize uncertainty, environmental footprint assessments were based on production methods and datasets corresponding to lentil and wheat production in Western Canada.

Methods

Formulations for bread, pasta, and breakfast cereals made with whole lentil flour were obtained from the Canadian International Grains Institute (Winnipeg, MB, Canada) (Table 1). These formulations were used as a theoretical guide, and were tested for performance and acceptability by the Canadian International Grains Institute. The baseline formulations contained a combination of whole lentil flour and refined wheat flour, and were characterized as "reformulated foods" in this study. The proportion of whole lentil flour relative to the total flour in the reformulated products was 15% for the pan bread, 53% for the breakfast cereal, and 30% for the pasta.

Table 1. Mass of raw ingredients (g) required for the production of 1 kg of traditional and reformulated pan bread, breakfast cereal, and pasta.

Ingredient (g)	Pan Bread		Breakfast Cereal		Pasta	
	Traditional	**Reformulated**	**Traditional**	**Reformulated**	**Traditional**	**Reformulated**
Whole lentil flour	0	83.25	0	536	0	301.69
Refined wheat bread flour	555.00	471.75	0	0	0	0
Refined all-purpose wheat flour	0	0	1011.00	475.33	0	0
Durum semolina flour	0	0	0	0	1005.64	703.95
Water	391.36	391.36	53.33	53.33	251.41	251.41
Sugar	22.36	22.36	53.33	53.33	0	0
Shortening	22.36	22.36	0	0	0	0
Salt	7.27	7.27	5.33	5.33	0	0
Yeast (fresh)	22.36	22.36	0	0	0	0
Milk powder	11.18	11.18	0	0	0	0
Dough conditioner	11.18	11.18	0	0	0	0

The nutritional quality of traditional and reformulated foods was determined using the nutrient balance concept (NBC) (Fern et al. 2015). The nutrient composition of lentil flour was obtained from independent nutritional analysis of whole lentils (Silliker Canada Co., Markham, ON, Canada), and it was assumed that nutritional losses were minimal during the milling process. The nutrient composition for unenriched refined flours used in this study was obtained from the US Department of Agriculture (USDA) Food Composition Database (Release 28).

Crop production, milling, processing, and manufacturing data corresponding to Western Canadian conditions were used, when possible. When not available, existing LCA inventory databases provided geographically generic crop inventory data. Three supply chain stages for were considered for the LCA component of this study: (a) Crop cultivation (lentil and wheat), (b) Milling (converting grains into flour) and, (c) Product manufacturing (converting flour and other ingredients into the final product).

Greenhouse gas emissions from the cultivation stage of lentils and wheat in Western Canada were obtained from reports prepared for the Canadian Roundtable on Sustainable Crops (CRSC, 2017). They found that the carbon footprint of 1 kg of dry lentils and wheat produced in regional unit 30 of the province of Saskatchewan is -0.116 and 0.060 kg CO2eq., respectively after accounting for the positive effect of Western Canadian cropping practices (reduced tillage and reduced summerfallow) on soil organic carbon (SOC). Without accounting for SOC, the carbon footprint of 1 kg lentils and wheat in the same growing region is 0.216 and 0.272 kg CO2eq., respectively.

In most of the census divisions within Saskatchewan, lentils and wheat are rain-fed and the bluewater footprint of lentil and wheat is zero. Calculations from Ding et al. (2018) were utilized to estimate the water requirements for irrigated lentil and wheat in Saskatchewan. Accounting for total weighted production, 0.67 liters of bluewater and 6.67 m^2 of cropland is used to produce 1 kg of lentils in Saskatchewan, while 0.31 liters of bluewater and 3.38 m2 of cropland is used to produce 1 kg of wheat in Saskatchewan. The Available Water Remaining (AWARE) method proposed by Boulay et al. (2018) was utilized to assess the impact of lentil and wheat production on regional water scarcity.

Ecoregion-specific characterization factor values provided by Chaudhary & Brooks [30] were used to translate the land footprint into impacts on biodiversity. These characterization factors give the potential species extinctions to per m^2 of land uses and were calculated through the countryside species-area relationship model (cSAR).

Results and Discussion

Pan bread, breakfast cereal, and pasta reformulated with whole lentil flour have a 24%, 153%, and 56% higher Qualifying Index (QI) respectively, than corresponding traditional formulations. The increase in QI drove an increase in the NBS across all foods, with the greatest increase observed in breakfast cereals (traditional: 30%; reformulated: 58%; +93%) followed by pasta (traditional: 43%; reformulated: 55%; +28%) and pan bread (traditional: 47%; reformulated: 54%; +15%). In terms of individual nutrients, replacing unenriched wheat flour with whole lentil flour increased the amount of 22 out of 27 essential nutrients considered in each product, while the remaining 5 nutrients considered either remained the same, or decreased marginally.

Products reformulated with whole lentil flour had a lower carbon footprint than the traditional products (Table 2). Reformulation with whole lentil flour decreased total GHG emissions by 7.6% for pan bread, 16.5% for breakfast cereal, and 30.7% for pasta. The reduction in carbon footprint for the three food products was driven by the low carbon footprint of Canadian lentils compared to Canadian wheat.

The contribution of each production stage was different for the carbon footprint of each food product. Milling contributed the least to the carbon footprint of all three food products. For traditional pasta, the cultivation of wheat represented 50% of the total greenhouse gas emissions, while manufacturing represented 36% of emissions. However, for traditional pan bread and breakfast cereal, the high energy requirements during manufacturing stage was the largest contributor to the total carbon footprint at 68% and 80%, respectively. Cultivation of wheat represented 21% and 13%, respectively of the carbon footprint of traditional pan bread and breakfast cereal.

Typically, cultivation of wheat would represent a higher proportion of the carbon footprint for these three food products, however, the wheat and lentils produced in this growing region of Canada (Regional Unit 30 – Southern Saskatchewan) have a particularly low carbon footprint. This low carbon footprint is due to environmental factors which reduce the emission of nitrous oxide (semi-arid, cool temperate) and cropping practices which have been proven to sequester soil organic carbon (reduction of summerfallow and no-till) in this environment. These results highlight the importance of collecting data and utilizing methodologies which can account for local environmental conditions and practices.

Table 2 Environmental footprints of one serving of traditional and lentil flour reformulated wheat-based products

Product	Greenhouse gas (g CO_2 eq)	Bluewater (Liters)	Water scarcity (L world eq)	Land use (m^2)	Biodiversity (PDF~)
Pan bread, traditional*	15.566	0.047	0.280	0.186	4.627E-15
Pan bread, reformulated*	14.376	0.049	0.294	0.206	5.313E-15
Breakfast cereal, traditional*	18.578	0.014	0.085	0.135	3.371E-15
Breakfast cereal, reformulated*	15.505	0.020	0.120	0.188	5.133E-15
Pasta, traditional*	15.857	0.057	0.341	0.381	9.495E-15
Pasta, reformulated*	10.993	0.066	0.396	0.463	1.224E-14

*serving size of pan bread = 75 g , breakfast cereal = 30 g , pasta = 85 g (dry)
~ taxa-aggregated potentially disappeared fraction

The impact of reformulation was the opposite for bluewater, water scarcity, land use and biodiversity, with impacts being larger for reformulated than traditional products. Bluewater and water scarcity impacts increased by 5%, 41% and 16% for reformulated pan bread, breakfast cereal, pasta, respectively, compared to the traditional food products. Reformulation with whole lentil flour increased land use impacts by 11% for pan bread, 39% for breakfast cereal and 21% for pasta, while biodiversity impacts increased by 15%, 52% and 29%, respectively.

These increases in impact were largely driven by the lower yields of lentil compared to spring wheat in Saskatchewan. The yield of lentil in regional unit 30 of Saskatchewan is 1.71 tonnes/ha compared to 2.68 tonnes/ha for spring wheat in the same region. However, it is important to note that although lentil is a low yielding crop, the adoption of lentil in the semi-arid regions of the Northern Great Plains of North America has enabled a shift to continuous cropping. This in effect has increased the productivity (total yield) of cropping systems compared to previous cropping systems which included periods of fallow in order to conserve soil moisture. Pulses in particular have been shown to improve the productivity of these cropping systems, and it is important to consider and develop methodologies which reflect this benefit which can be neglected with current methods. The reliance on bluewater for irrigation in this production region is also very low, with only 0.1% of the lentil and wheat production area produced under irrigation in Saskatchewan (crop production data from Government of Saskatchewan).

Conclusion

These results highlight the importance of considering multiple nutritional and environmental indicators when evaluating the impacts of changes to foods or dietary patterns. In this case, nutritional quality and carbon footprint improves, but we must also consider the implications of increased water and land use impacts when these products are reformulated.

In conclusion, reformulation of foods and diets should continue to be considered and assessed, as the nutritional and environmental impacts of increased consumption of pulses can be significant.

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Development of quality assured regionalized life cycle inventories and assessments for Canadian peas and lentils production in public LCI databases

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Abstract

Pulses, including peas and lentils, are nutritionally beneficial foods that are high in protein and fiber and low in fat. They also have relatively low environmental footprints than other protein sources. Hence, there is an increasing interest in the potential role of such products in support of healthy and sustainable diets. Peas and lentils currently account for a significantly growing share of agricultural production in Canada with 80% of pulse production being exported around the world that accounted for $2.7 billion in revenue generation in 2018. Pea and lentil production in Canada primarily occur in the western Canadian provinces, a large geographical area with a wide variety of soil and climatic conditions as well as heterogeneous management practices, characteristics input types and amounts, and yields. Large demand shifts are also observed amongst consumers in increasing transparency and knowledge of reported sustainability impacts of agricultural products beyond direct environmental impacts, which contribute to climate change, fossil fuel depletion, local air pollutants, and local water scarcity. To date, however, there have been no ISO (14044) compliant, regionalized LCAs conducted of Canadian pea and lentil production to enable understanding potential differences in environmental performance within and between growing regions, identify sustainability best management practices, and compare Canadian pulse products to other agricultural products on a rigorous basis.

The current study entailed developing regionalized, ISO 14044-compliant life cycle inventories (LCIs) and assessments for peas and lentils for incorporation into the Canadian Agri-food Life Cycle Data Centre (CALDC), a publicly available LCI data repository, as well as the Ecoinvent database. Publicly available LCI data were first identified and screened for data quality in order to determine key data gaps using decision tree parameters for temporal, geographical and technological representativeness and availability of metadata vis-a-vis ILCD and ecoSpold2 data format requirements.

On this basis, the additional data required for regionalized LCIs were collected via surveys to Canadian pulse growers. LCI models were then developed at the ecozone, provincial and regional scale. Life cycle impact assessment (LCIA) of these models indicated non-trivial heterogeneity in the environmental footprint of pea and lentil production. These regional variations in environmental impacts of agri-food commodities have also been reported worldwide. Thus, underscoring the necessity for regionalized modelling of agricultural products in support of sustainable production and consumption initiatives. Moreover, these LCIs also represent the different activities of the region under study using up-to-date and high-quality data addressing concerns of data availability and uncertainty, particularly when adding spatial information to LCA that is a challenging yet inherent necessity. The LCIs resulting from this study will enable stakeholders to include Canadian pea and lentil products in future research using quality-assured, publicly available data sets, while the results of the LCAs will support Pulse Canada and pulse industry constituents in sustainability management, marketing and communication initiatives.

Keywords: *Life cycle assessment, Pulse crop, Regionalization, Life cycle inventory, Agri-food, Peas, Lentils.*

Introduction

Pulses, with high protein and fibre, and low-fat nutritional attributes, are nutritionally beneficial and cost-effective foods (Ojiewo et al. 2015). Pulses represented 6% of field crop area in Canada in 2011, which is 11 times the area planted in 1981. The Prairie Provinces are the major pulse producers in Canada, accounting for about 96% of Canadian pulse production in 2017. In 2015, Canada exported 6 million tonnes of pulses with an economic value of more than $4.2 billion. Pulses are nitrogen-fixing crops that may also improve the environmental sustainability of annual cropping systems when included in crop rotations – in particular with respect to reducing GHG emissions. The incorporation of pulse in rotation include influencing soil organic carbon (SOC) levels due to the amount of C returned to the soil in crop residue (Campbell et al. 2000), and lower pesticide and fertilizer requirements than cereals, which directly impact GHG and other emissions related to the manufacture and application of these inputs (Lemke et al. 2007). The inclusion of pulse crops in rotation with grain crops also has economic implications in terms of pulses' ability to reduce the synthetic nitrogen fertilizer requirements of the rotation and overall improvements in rotational yield and quality of the grain (MacWilliam et al. 2014). Hence, there is a growing desire from industry, academia and governments to better understand the potential environmental impacts of whole pulses and pulse ingredients in food systems alongside their nutritional benefits. There is substantial heterogeneity in the impacts of agricultural production. In order to understand the influences of regional parameters and local factors on the results of agricultural LCAs, recent studies (Nitschelm et al. 2016) have highlighted the importance of building regional life cycle inventories for agricultural products. Such regionalized resolution is essential to differentiating among agricultural products on the basis of environmental attributes, identifying appropriate sustainability improvement opportunities, and enabling communication with respect to their sustainability benefits and impacts.

In order to enable accurate representation of Canadian pulse crops in the context of life cycle-based sustainability measurement and management activities, it is hence essential to develop high quality, regionalized data inventories that are representative of Canadian production conditions, and to incorporate these inventories into publicly available life cycle inventory databases. To date, ISO 14044 compliant LCAs have not been reported for Canadian pulses, nor are sufficient data to enable such studies currently available. Hence this study aims to (a) develop regionalized life cycle inventories (LCIs) for Canadian peas and lentils suitable for incorporation into public LCI databases and (b) undertake and report LCAs for Canadian peas and lentils.

Material and methods

The LCIs and LCA developed in this work were based on a traditional ("attributional") LCA modelling approach, which focuses on quantifying environmental flows directly associated with a given product. They were developed in compliance with the requirements of the ISO 14044 international standard for life cycle assessment.

The goals/objectives of this study are:

1. To develop ISO 14044-compliant regionalized (i.e., at reconciliation unit, ecozone, province, and prairie provinces scale) life cycle inventories for pea and lentil production in the Canadian prairie provinces (i.e., Alberta, Saskatchewan and Manitoba), and submit these to LCI databases including the CALDC and ecoinvent.
2. To perform ISO 14044-compliant LCAs in order to quantify the resource and environmental impacts of pea and lentil production, using regionally-resolved, temporally and technologically current data. Pulse production accounts for a significant and growing share of agricultural production in Canada. Eighty percent of pulse production occurs in the western Canadian provinces of Alberta, Saskatchewan, and Manitoba - a large geographical area encompassing a wide variety of soil and climatic conditions. In this study, typical pea and lentil production systems were considered to include farming practices related to soil preparation, seeding, fertilizer application, pest management/agri-chemical application, harvesting and crop drying activities. The specific technological aspects of the pulse production systems as modelled were based on information collected from farmers using a life cycle inventory survey. The overall scope of this attributional LCA is cradle-to-farm gate, meaning it

included all stages from the extraction of raw materials, to the production and drying of the peas or lentils on a Canadian farm, but does not include subsequent "downstream" storage, distribution, consumption and end-of-life stages. The major processes included in the life cycle inventory models of the pea and lentil production systems are represented in a flow diagram (Figure 1).

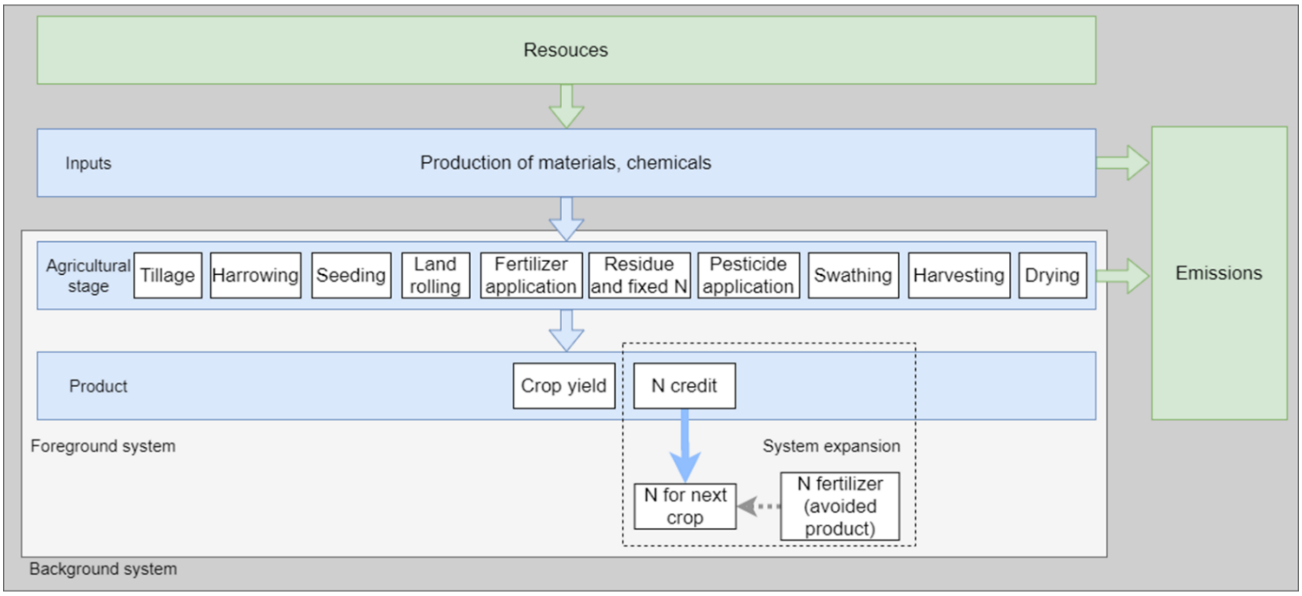

Figure 1. System boundaries for pea and lentil production models.

The foreground processes in this study refer to those occurring directly on farm, including soil preparation, seeding, fertilizer and pesticide application, harvesting, and crop drying. The background processes are those that provide inputs to farm-level activities, such as the production of the fertilizer, pesticides, etc., and all related life cycle processes, resource use and emissions. Farm-level emissions of carbon dioxide (CO2), direct and indirect nitrous oxide (N2O), and other reactive N species emissions (i.e. NH3, NOx, NO3) from fertilizer to air, leaching to ground water and run off to surface water were calculated using the Canadian version of DeNitrification DeComposition (DNDC) model (Dutta et al., 2017). Life cycle inventory models for pea and lentil production at each defined scale were developed and assessed using OpenLCA 1.10.2, an open-source LCA modelling software created by Green Delta (available at http://www.openlca.org/download). The IMPACT World+ LCIA methods suite was chosen for this study with the impact categories of: climate change, mineral resources use, fossil and nuclear energy use, terrestrial acidification, freshwater eutrophication, freshwater ecotoxicity, particulate matter formation, water scarcity, land occupation – biodiversity, photochemical oxidant formation, ionising radiation, and ozone layer depletion. Finally, data quality analysis included a contribution analysis, uncertainty analysis and sensitivity analysis. Sensitivity analysis included the methods of determining soil carbon sequestration and fertilizer emissions, the inclusion of an N credit from N fixation by pulse crops, and the choice of impact assessment methods.

Results and Discussion

The main contributors to the impacts of pea and lentil production were fertilizer and fuel use. This was consistent across all regions and levels of regional aggregation. Fertilizer production required large amounts of water, land and mineral resources, and was responsible for many of the resulting emissions during the processing stages that contributed greatly to acidification, ionizing radiation and ecotoxicity emissions. Fertilizer application on the farm also resulted in field-level emissions such as N_2O, P and NH_3, which contributed to climate change, eutrophication and acidification impacts. Fuel extraction and production contributed greatly to the demand for water, land and fossil energy resources. The combustion of the fuel on the farm emitted e.g., CO_2, NOx and particulate emissions that contributed to climate change, photochemical oxidation, ozone layer depletion and particulate matter formation. Although the trends were similar, there were variations in results between different crop types, regions, and levels of aggregation.

While there were some variations between crops, regions and levels of regional aggregation, the same trends were seen in terms of the highest contributors to the estimated impacts. Adopting best management practices may enable reducing impacts. This could include, for example, implementation of soil N testing, crop rotation decisions, adoptions of reduced tillage or no tillage strategies, or other reductions in mechanized field operations. Uncertainty related to data quality was consistent across all regions and aggregation scales, so these differences reflect foreground data variability. This means that there was more variability in the survey responses from farmers within the same province, and the prairies as a whole, than there was between farmers in the same ecozones. Given the high impacts of fertilizer production, reducing fertilizer inputs via adoption of "4Rs" management practices would be one strategy to reduce resource use and emissions. In addition, changes to land management practices could be used in combination with lower fertilizer inputs to reduce the field-level emissions associated with fertilizer application and land management. Prior studies have shown that inclusion of dry pea and lentils in rotations can lower environmental impacts compared to crop rotations without pulses, mainly due to the nitrogen fixation associated with pulse crops. The influence of the N credit from pulses in reducing system-level impacts, as modelled in the current study, further support these findings.

Conclusions

Across all levels of aggregation, fuel and fertilizer were identified as hotspots for potential reductions in emissions and resource use. Our results indicate that farming practices are more closely related to soil and climate conditions than to physical boundary generated standards and regulations. Moreover, the application of the process-based model DeNitrification DeComposition (DNDC) in this study enabled predicting the impact of varying agricultural management practices between the different geographical scales and regions (ecozones) on net GHG emissions by analyzing the interactions between management practices, primary drivers (climate, soil type, crop type, etc.), and biogeochemical reactions.

Acknowledgements

The authors would like to thank Pulse Canada for the financial support towards this study.

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Topic 10:
New Models
and Databases

Abstract code: 264

Introducing a novel approach in life cycle assessments: propagating uncertainty and variability separately using two-dimensional Monte Carlo simulations

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Abstract

Purpose Life Cycle Assessments are still most often being reported as deterministic while reality is uncertain and variable. The origin and implications of uncertainty and variability are different and thus a clear distinction would lead to more realistic results and decisions. Two-dimensional Monte Carlo (2DMC) simulations is introduced as a possible novel approach in LCA for propagating uncertainty and variability separately.
Methods The chain of the Belgian apple from orchards till consumer disposal of food waste was used as a case study, comparing two apple cultivars (Jonagold and Kanzi) and two consumer packaging methods (bulk and pre-packed per 6 apples). For each parameter included in the chain descriptions, it was determined whether it was deterministic, uncertain, variable or uncertain ánd variable, and an appropriate representative distribution was selected. 2DMC propagates uncertainty and variability separately from their distributions, making it possible to (*i*) assess the robustness of the calculated impacts' central tendency, and to (*ii*) calculate uncertainty, variability and overall uncertainty ratios, which points at the implications when one aims to refine the results through future research.
Results and discussion The results in this study show no overlapping curves between the 2DMC results of bulk and pre-packed apples, and Jonagold and Kanzi. The central tendency indicates that Jonagold bulk apples are environmentally preferable. Regarding the ratios, for Jonagold it is more relevant to reduce uncertainty by gathering more reliable data, while reducing the variability in the bulk and pre-packed apples and in Kanzi apples is only possible by making direct changes in the production process.
Conclusions and recommendation 2DMC is a useful approach in LCA to take uncertainty and variability separately into account. We recommend to always conduct a 2DMC when comparing two products or processes, if data quality allows to do so. First to see if the curves of the two 2DMC results overlap in any way. This helps to judge the significance of the central tendency of the impact. Second, to know which steps to take if the curves do overlap or if some or all ratios turn out to be relatively high.

Keywords: *LCA; uncertainty; variability; two-dimensional Monte Carlo*

Introduction

An actual shortcoming in Life Cycle Assessment (LCA) stems from results still quite often being reported as deterministic, while reality is uncertain (i.e., lack of knowledge) and variable (i.e. natural heterogeneity) (Hauschild et al. 2018). The combination of the two is called overall uncertainty (Pouillot et al. 2016). While uncertainty can be reduced by gathering more knowledge, this is not the case for variability (Hauschild et al. 2018). Thus, separating them allows to understand which steps can be taken to reduce the overall uncertainty of the model.

In general, if the range of LCA results is dominated by uncertainty, more reliable data may be needed before one can robustly conclude that one product has a significantly different environmental impact then another. In contrast, results with a high degree of variability demonstrate true differences among alternative production processes, supply chains, etc. This information can further guide system optimization, product development or policy (Steinmann et al. 2014). This distinction makes it clear why it is so important to separate uncertainty and variability. By mixing them, we cannot see which one mainly contributes to the overall uncertainty, leading to the loss of useful information and decisions being based on less representative calculations.

However, the distinction between uncertainty and variability is not always clear and often treated alike in LCA. This issue is especially relevant for agri-food LCA's because of their inherently variable inventory data, e.g., different soil types, weather conditions, consumption patterns, etc. (Notarnicola et al. 2017). Some attempts are being made at distinguishing between variability and uncertainty in LCA, often using one-dimensional Monte Carlo simulations (1DMC) as part of the approach (Steinmann et al. 2014). Though, 1DMC can only propagate variability *or* uncertainty when simulating, e.g. an agri-food chain as part of an LCA, but cannot propagate both separately at the same time. This could potentially be done by conducting two-dimensional Monte Carlo simulations (2DMC), as has been applied in quantitative risk assessment (Pouillot et al. 2016). The aim of the present contribution is to introduce 2DMC in LCA as a possible novel approach for propagating uncertainty and variability separately.

Material and methods

2DMC simulates the distributions representing uncertainty *and* the distributions representing variability separately, so they can be assessed separately in the output as well (Pouillot et al. 2016). The uncertain parameters are randomly sampled and fixed from their distributions while performing 1DMC with random variable parameters (*m* iterations). This process is repeated several times (*n* realisations), resulting in 2D model outputs (Pouillot et al. 2016). As a case-study, the method is implemented in an updated and slightly modified (e.g. pesticide production was taken into consideration) version of an existing LCA of the Belgian apple, developed at our team, which describes the apple food chain from orchards till consumer disposal of food waste (Goossens et al. 2017, 2019). Calculations were performed using SimaPro 9.0.0.49 (Pré Sustainability, the Netherlands), JMP Pro 15 (SAS Institute Inc., NC, USA) and Excel 2016 (Microsoft, WA, USA). The ILCD method was used as impact assessment method.

Regarding the cultivation phase, 973 orchards of a relatively long time ago created (around 1970) and popular cultivar Jonagold (and its mutants) was considered next to 36 orchards of the young cultivar (from 2004) Kanzi. Data from the Farm Accountancy Data Network was used (Departement Landbouw en Visserij 2018). Uncertainty was accounted for in the fertilizer's emission calculations (e.g., emission factors), in the conversion to MJ for the energy carriers and through surveys conducted among apple growers on how certain they would be when giving the amount of fertilizer, pesticides, energy and water products they used during cultivation. Variability was accounted for in the fertilizer's heavy metal content and in the amount of different products used in different orchards, taking correlations into account. Thus, the data on the amount of products used was uncertain ánd variable due to the grower's certainty when providing the data and due to different orchard management practices, respectively. For Jonagold, 774 fertilizers, 245 pesticides, 14 energy carriers and 4 water sources were taken into consideration, while for Kanzi there were 121 fertilizers, 141 pesticides, 9 energy carriers and 4 water sources.

Regarding the post-harvest chain, bulk apples were compared to pre-packed apples (per 6), based on data gathered through literature and through auction and retail surveys. 120 parameters were considered of which 52 were categorised as deterministic (e.g. EuroPoolSystem size H plastic crate weight), 42 as variable (e.g. km of consumer transport), 17 as uncertain (e.g. cold room kWh) and 9 as uncertain ánd variable (e.g. losses at auction). To synthesize the 2DMC results, variability, uncertainty and overall uncertainty ratios are calculated as described in Pouillot et al. (2016), using combinations of the median and 97.5th percentile of the uncertainty and variability dimension.

Results

Fig. 1 and 2 show the results of the post-harvest chain and cultivation chain respectively for two different impact categories. Each curve represents the variability within the chain for one dimension of uncertainty. The dispersion of the different curves shows the influence of uncertainty, while the steepness is an indication of variability.

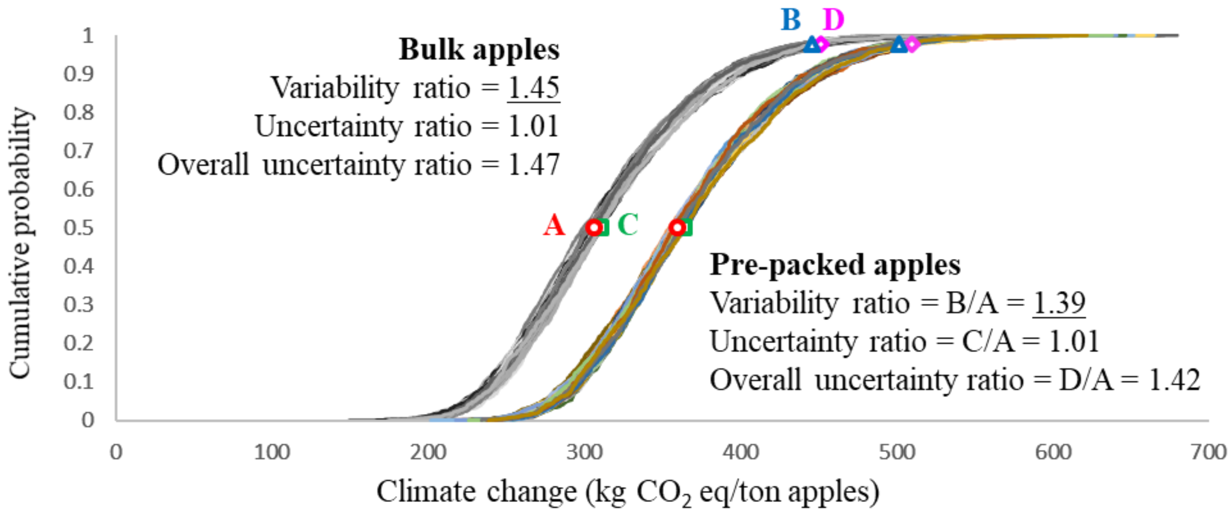

Fig. 1 2DMC LCA results with ratios of climate change for the post-harvest chain of 1 ton bulk (greyscale curves) and 1 ton pre-packed apples (coloured curves) with 1000 iterations and 100 realisations each. A and B are taken at the median of uncertainty, while C and D are at the 97.5th percentile of uncertainty.

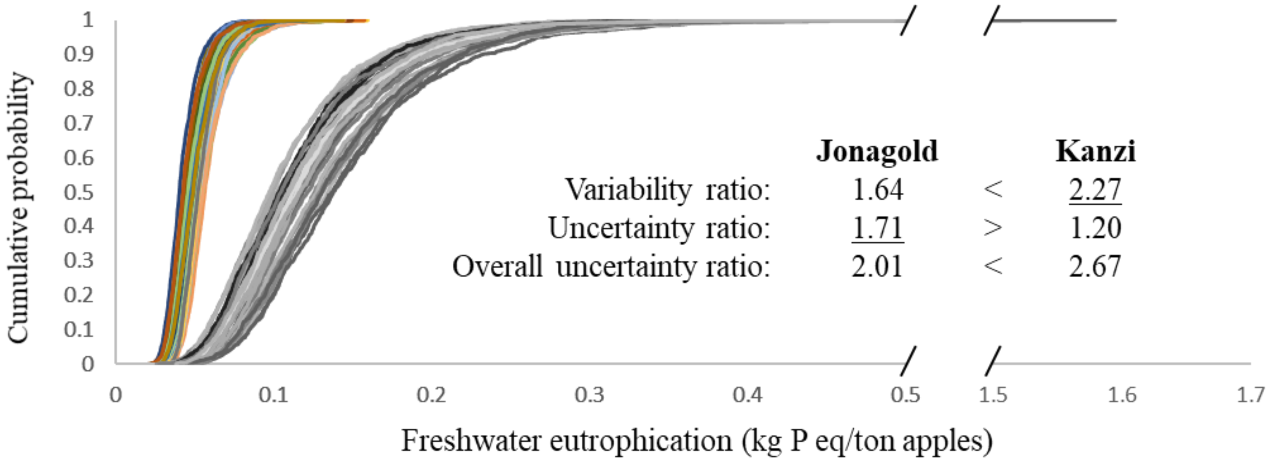

Fig. 2 2DMC LCA results with ratios of freshwater eutrophication for the cultivation chain of 1 ton Jonagold (coloured) and Kanzi apples (greyscale curves) with 1000 iterations and 100 realisations each.

Discussion

As far as the authors are aware, this is the first time 2DMC was conducted in LCA as a way to separately examine data uncertainty and variability in LCA inventories and subsequent LCIA.

Firstly, the results of the post-harvest case study (fig. 1) show that the curves of the two products do not show any crossing or overlap. The median impact of climate change can always be reduced by switching to a larger share of bulk apples. Secondly, the ratios show that variability is dominating in the overall uncertainty. This implies that it would be a waste of time to try to diminish uncertainty by collecting more information through further measurements or consulting experts. Instead, the results indicate that reduction of the overall uncertainty could be achieved by changing the physical system, e.g. reducing transport by sorting at the auction instead of another facility (identified by analysing the underlying calculations of fig. 1).
As was the case for the post-harvest chain, also the 2DMC of the cultivation chain (fig. 2) showed no overlap between the curves of the different apple varieties. The median results show that switching to Jonagold would help lower the impact of freshwater eutrophication. However, the ratios indicate that for Jonagold, more precise emission factors, more accurate measurements, etc., should be gathered for lowering the overall uncertainty ratio. While for Kanzi, it would be more relevant to study how the different orchards are managed, in which productive stage they are in and where they are located. It is plausible that the management of the new Kanzi apple is not as uniform and efficient yet as it is for the established Jonagold apple, leading to more variability and a generally larger impact.

Conclusions
2DMC is a useful approach in LCA to take uncertainty and variability separately into account, allowing decisions makers to judge the significance of the results. We recommend to always conduct a 2DMC when comparing two products or processes, when the data quality allows it. First to see if the curves of the two 2DMC results overlap in any way. If not, a first conclusion can be made on which product/process would always be preferable for a certain impact category based on a central tendency, without disregarding the data uncertainty and variability. For the results presented in this study, buying Jonagold bulk apples seems to be the best advice to give to a consumer.
Then the ratios should be considered, especially if there is an overlap between the results or if the ratios are too high according to the decision maker and more precision is needed. In those cases, the ratios indicate which steps to take to reduce the overall uncertainty, leading to more robust results and decisions. In this study, gathering more knowledge (and thus reducing uncertainty) is especially relevant for Jonagold apples, while for bulk and pre-packed apples, and Kanzi apples it is more pertinent to examine the production process.

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Abstract code: 127

The development of a farm-to-fork food impact database

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Abstract

There are many studies reporting on the environmental impact of food products worldwide. However, such studies often use different sources, system boundaries, scope, assumptions, calculations methods and/or background datasets which makes comparison between them very difficult and time consuming. To overcome this problem, Blonk Consultants has developed a series of models to quantify the environmental impact of food consistently and transparently. The models are adjustable to cope with different requirements set for each project or product.

The whole farm-to-fork database is modelled according to the life cycle assessment (LCA) methodology. Each life cycle is modelled according to the requirements set by international standards for each life cycle stage. One example is the Guidelines for Product Environmental Footprint Category Rules (European Commission 2018a). This standard determines which activity data should be included and how certain emissions should be modelled for the cultivation. By including publicly available data to the models, the model can collect data from these sources. One example is using FAOstat crop statistics (FAO 2018) for the yield of all cultivations. Using large publicly available statistics has multiple advantages: it saves time on data collection, makes the model flexible, is transparent, and easy to update when new data is available.

All life cycle stages are constructed in SimaPro LCA software, in which the life cycle stages are linked to each other. Once completed, the environmental impact of all products in scope can be generated and the results can be shared in Excel. Or alternatively the whole model including all life cycle stages on unit process level can be shared if the end-user has a SimaPro license. On unit process level the user can review the modelled life cycle stages, including comments, sources and methodologies used for emission modelling. The user is also able to perform different types of analysis or construct alternative scenarios to further increase its understanding on the impact of food products.

Keywords: farm-to-fork; LCA food; food database; environmental impact of food

Introduction

There are many studies reporting on the environmental impact of food products worldwide. However, such studies often use different sources, system boundaries, scope, assumptions, calculations methods and/or background datasets which makes comparison between them very difficult and time consuming. To overcome this problem, Blonk Consultants has developed a series of models to quantify the environmental impact of food consistently and transparently. The models can be altered easily to fit with goal and scope of each project. Some of the main choices that need to be made include: the system boundary of the project (e.g. cradle-to-grave ("farm-to-fork"), or cradle-to-retail), geographic region (e.g. Netherlands, Belgium or Europe) and the products in scope. Next to these there are additional settings that work on life cycle stage level, some of them are discussed in the next section.

Material and methods

The most important life cycle stages that are included in the farm-to-fork model are shown in Figure 1. How these life cycle stages are modelled in described in the next paragraphs. It is important to note that the life cycle of the food product can differ greatly among each other, this is illustrated with the different flows in the figure.

Figure 1: Graphic illustration of the most important life cycle stages included in the farm-to-fork model

- Crop cultivation: is modelled on country level, using the Agri-footprint (AFP) 5.0 methodology (Van Paassen et al. 2019a, b). The methodology is compliant to the criteria for crop cultivation, defined by the European Commission (European Commission, 2018c). Most important criteria include crop specific activity data for yield, water use, land use, land use change, synthetic fertilizer use, organic fertilizer use and pesticide use. Other requirements are ammonia, nitrous oxide, carbon dioxide, nitrate, and phosphorus emissions from this activity data.
- Post harvesting: some of the post harvesting activities include drying of cereals, deshelling of nuts or oil-bearing crops and sorting fruits before shipment.
- Market mix: food products and raw materials are sourced from all regions around the world. Based on production (FAO 2018) and trade statistics (FAO 2019) of individual commodities a weighted average market mix for the country in scope is constructed. This connects agricultural activities abroad with food consumption within a certain country or region. Combining the sourcing information of food items with default transportation distances between countries, which are specified in Annex 6 of the PEFCR for feed (European Commission 2018b), the total transportation requirements are determined.
- Processing: some agricultural materials need additional processing before they can be used as food(ingredient). For each processing activity the following aspects are inventoried: inputs, outputs, energy use, emissions, and waste flows. Most processing activities for feed and food are mentioned in the AFP methodology reports (Van Paassen, Braconi, Kuling, Durlinger, & Gual, 2019a, 2019b) and Optimeal (Broekema, Blonk, & Koukouna, 2019).
- Animal production: meat, milk and eggs are products of animal production systems. For each animal system specific feed composition, feed conversion rates, energy inputs, wastes and enteric and manure emissions are included. Data for animal herding and emission modelling are mentioned in the AFP methodology reports (Van Paassen et al. 2019a, b) and Optimeal (Broekema, Blonk, & Koukouna, 2019).
- Food production: some food products are composite products that are produced according to

a specific recipe. Recipes, energy use and water use for these products are reported in Optimeal (Broekema et al. 2019) and included in the models.

- Packaging: environmental impacts of packaging are included by adding specific information regarding mass and packaging materials. A percentage of packaging material is of recycled origin. Recycled content of packaging materials is based on the information of the PEF packaging working group (PEF Packaging Working Group 2018).
- Distribution: is modelled according to the PEFCR guidance (European Commission 2018a). The guidelines include defaults for energy use, water use, transport distance to distribution and refrigerant emissions specific for a product types based on default storage times and volumes.
- Retail: is modelled according to the PEFCR guidelines (European Commission 2018a). The guidelines include defaults for energy use, water use, transport distance to retail and refrigerant emissions specific per product types based on default storage times and volumes. Additionally, food losses are included which are specified per products group (e.g. fruits & vegetables).
- Preparation: this life cycle stage includes energy use for different types of cooking techniques, cutting losses (unavoidable losses), "raw-to-cooked" losses and end-of-life (EOL) modelling of food losses and disposed packaging. EOL of packaging materials is based on the circular footprint formula reported in the PEFCR guidance (European Commission 2018a).
- Consumption: the consumption stage includes avoidable losses after the food has been prepared. EOL of these losses are modelled based on the different disposal routes proposed by the PEFCR guidance (European Commission 2018a).

The default farm-to-fork model described above, following the PEF guidelines, is representative for the geographic European region. However, it is possible to use country or company specific data to adjust the geographic representativeness of the database.

Results

All life cycle stages are constructed in SimaPro LCA software, in which the life cycle stages are linked to each other. Once completed, the environmental impact of all products in scope can be generated and the results can be shared in Excel. An example of this is shown in Table 1, which shows the carbon footprint of food products on the Dutch market from cradle-to-retail and cradle-to-grave ("farm-to-fork"). This example only shows the carbon footprint results, but it is also possible to perform other kinds of footprints using the same data. Other environmental impact categories that are often considered for food products are: water footprint, land footprint, acidification, and energy use. Many other impact assessments exist and can be used as well.

Table 1: Carbon footprint of multiple food items on the Dutch market from farm-to-fork and cradle-to-retail

	cradle to end-of-life			*cradle to retail*		
product	**kg CO_2eq/kg incl. Land Use Change**	**kg CO_2eq/kg due to Land Use Change**	**kg CO_2eq/kg excl. Land Use Change**	**kg CO_2eq/kg incl. Land Use Change**	**kg CO_2eq/kg due to Land Use Change**	**kg CO_2eq/kg excl. Land Use Change**
alaska pollock fish	8,8	< 0,01	8,8	7,4	< 0,01	7,4
apple with skin	0,5	< 0,01	0,5	0,4	< 0,01	0,4
banana	0,8	< 0,01	0,8	0,4	< 0,01	0,4
brown beans (glass/can)	1,9	< 0,01	1,9	1,5	< 0,01	1,5
brown rice	1,7	< 0,01	1,7	2,1	< 0,01	2,1
butter (unsalted)	12,2	1,3	10,9	11,4	1,2	10,2
carrots	0,8	< 0,01	0,8	0,4	< 0,01	0,4
cauliflower	1,4	0,1	1,4	0,7	0,03	0,7
cheese Gouda 48+	13,1	1,4	11,7	12,7	1,4	11,4
chicken (with skin)	13,6	6,2	7,4	6,8	3,3	3,5
cod fish	7,0	< 0,01	7,0	5,7	< 0,01	5,7
eggs	4,3	1,6	2,7	3,6	1,6	2,0
herring (soused)	2,8	< 0,01	2,8	2,5	< 0,01	2,5
mackerel	2,2	< 0,01	2,2	1,9	< 0,01	1,9
minced meat (35% beef cattle: 65% dairy cattle)	30,0	2,0	28,0	23,6	1,6	22,0
orange	0,8	< 0,01	0,8	0,5	< 0,01	0,5
pork	12,4	2,9	9,5	7,8	1,9	5,9
potatoes	0,9	< 0,01	0,9	0,4	< 0,01	0,4
rye bread	1,4	< 0,01	1,4	1,3	< 0,01	1,3
salmon fillet (aquacultured)	6,9	1,7	5,2	5,6	1,5	4,2
semi-skimmed milk	2,0	0,2	1,9	1,9	0,2	1,7
skimmed milk	2,0	0,2	0,2	1,8	0,2	1,7
steak (100% beef cattle)	57,2	2,7	54,5	42,7	2,0	40,7
tofu	5,8	2,2	3,4	4,1	1,9	2,2
vegetarian burger (average)	3,8	1,2	2,6	2,8	1,0	1,8
white bread	1,2	0,03	1,2	1,0	0,03	1,0
white rice	1,8	< 0,01	1,8	2,4	< 0,01	2,4
whole grain bread	1,0	0,02	1,0	0,9	0,02	0,9
whole milk	2,1	0,2	1,9	2,0	0,2	1,8

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Alternatively, the whole model including all life cycle stages on unit process level can be shared if the end user has a SimaPro license. On unit process level the user can review the modelled life cycle stages, including comments sources and methodologies is used for emission modelling. The user is also able to perform different types of analysis or construct alternative scenarios. This would empower the user to further increase its understanding on the environmental impact of food production chains.

Discussion

Great effort has been put in modelling all parts of the life cycle database using publicly available data, but some parts still require more attention and improvement. Collecting data on processing and food production is still a very time intensive exercise. This is because there is not a lot of data publicly available for these life cycle stages. Additionally, there are some limitations in the current way of working, these include:

- Variability and uncertainty are not captured yet in most life cycle stages because there is not a lot of data available to assess these aspects.
- Current food datasets do not take seasonality into account. This is because the production data and trade statistics used are annual averages. Trade flows of for example fruit changes throughout the year depending on the seasons worldwide. But only the annual average is used currently.
- Difference between cultivations used for food or feed could not be determined with current statistics used for the food datasets. For example, some countries tend to cultivate cereals for

human consumption (e.g. bread) instead of feed, and vice versa.

- Data quality ratings are not fully implemented in all the models. This means that there is currently no data quality rating for each food product. Blonk Consultants is working on implementing data quality rating in all models and wishes to include this rating in a future release.
- Products from the food database are not fully compliant to the PEF guidance and all Product Environmental Footprint Category Rules (PEFCRs). This is because the type of allocation is not consistently applied for all PEFCRs, even for products that are used in multiple PEFCRs. This means using the PEFCRs as a starting point would lead to an inconsistent database. For the purpose of food databases, we at Blonk Consultants value consistency over fully compliance to the PEF guidance and PEFCRs.

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Abstract code: 45

Comparing models for the joint use of Life Cycle Assessment and Data Envelopment Analysis

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Abstract

Purpose: The joint use of Life Cycle Assessment (LCA) and Data envelopment Analysis (DEA) has received great attention for eco-efficiency assessment. Despite this, there are methodological aspects that have been scarcely analyzed, such as the use of different DEA models. This is more evident in the beekeeping sector, where no previous studies using LCA+DEA methodology have been conducted. Therefore, the main aim of this work is to assess eco-efficiency of beekeepers through the LCA and DEA methodology comparing two DEA models.
Methods: The four-step method is employed. In this method, the first and second step refer to the performance of inventory and environmental characterization, respectively. The third step corresponds to eco-efficiency assessment. While in the four step the procedure for factor targets for reduction is performed. The four-step method is applied twice. In the first one, the third step considers the use of the BCC DEA model, while in the four step the factor targets according to this DEA model are calculated. In the second one, the third step is performed using the FDH DEA model and the four step is calculated employing the targets provided by this model.
Results and discussion: The BCC model identified 15 inefficient beekeepers. For these beekeepers the average inefficiency level is 49%. On the contrary, the results obtained by FDH model indicate that only two beekeepers are inefficient. For these beekeepers, the average inefficiency level is 53%. The different number of inefficient beekeepers identified by the two DEA models is due to that the BCC model seems to be more restrictive in relation to the FDH model. From a practical point of view, the BCC model allows determining an efficient mix of inputs or outputs based on the actual inputs or outputs level of the set of benchmarks. While the results obtained with the FDH are easier to implement since the inefficient beekeepers should be compared only with one efficient beekeeper.
Conclusions: This study evaluates eco-efficiency of beekeeping sector using two DEA models. It identifies differences from a theoretical and practical point of view for decision makers. These models were evaluated following four-step method in a beekeeper case study.

Keywords: *Environmental sustainability; Eco-efficiency; Beekeeping; Climate Change; Model comparison.*

Introduction

Honey has many benefits for human health, such as curative, antibiotics and antiviral properties (Hilmi et al. 2011). However, the beekeeping sector generates environmental impacts and low production (Affognon et al. 2015). One way to deal with both aspects is through the joint use of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA), also namely LCA+DEA methodology. LCA allows evaluating the environmental impact of products or services during its life cycle (ISO 2006). DEA is a non-parametric tool that uses linear programming to evaluate the efficiency of organizational units, also called Decision Making Units (DMUs). A DMU is efficient if its score is 1 (or 100%) and inefficient otherwise. Furthermore, in general terms, a DEA model can be oriented to input or output. Input oriented seeks to minimize the inputs while maintaining the outputs constant, whereas output oriented aims to maximize all outputs while maintaining the inputs constant (Cooper et al. 2007).

The use of LCA+DEA provides some practical advantages such as it provides quantitative benchmarks that direct the performance of any system towards environmental sustainability (Rebolledo-Leiva et al., 2017). This methodology has been structured in different methods, i.e. the three-step, the four-step and five-step method. However, the four-step method has been widely less explored (Vásquez-Ibarra et al. 2020). This is more evident in the beekeeping sector, where according to our knowledge, there are no previous studies that employ this method for eco-efficiency assessment.

The joint use of LCA and DEA has increased during the last decade. Despite this there are some methodological aspects that have been poorly explored, for instance, the use of different DEA models. In this sense, only Feijoo et al. (2017) employed the five step method to evaluate three DEA models (CCR, SBM and EBM). Moreover, as pointed out by Vásquez-Ibarra et al. (2020) most of the researchers employed a DEA model without considering its implications in an eco-efficiency context. Furthermore, a wide variety of DEA models have been employed, among them the BCC appears as one of the most used. However, other models such as the FDH (Free Disposable Hull) has not been used. FDH model can be considered as a special case of DEA models, since it relaxes the convexity assumption related with that operating target point for an inefficient beekeeper which can be determined by a combination of the operation point of other efficient DMUs (Dionne 2001). Therefore, the aim of this study is to assess eco-efficiency of beekeepers through the LCA and DEA methodology comparing two DEA models from a theoretical and practical point of view.

Material and methods

This study employs the four-step method proposed by Rebolledo-Leiva et al. (2017), applied to 31 Chilean beekeepers located in Maule Region. The honey production in Chile reaches 12,000 tons yearly, from which about 85% is exported (ODEPA 2015). Most of this honey produced come from Maule Region, in central of Chile, which presents one of the largest number of hives and honey production.

The four-step method is performed as follows:
i) Life cycle inventory description: the inputs considered by this study are feeding, medication, fuels, electricity and disposable material. While the output is honey produced. Table 1 shows the main statistics parameters regarding the life cycle inventory.

Table 1. Life cycle inventory for the beekeepers under study.

	Feeding (kg)	Medication (kg)	Fuels (kg)	Electricity (kWh)	Disposable material (kg)	Honey produced (kg)	Climate change (kg $CO_{2\text{-eq}}$)
Mean	1866.6	15.4	489.1	13.2	9.3	4134.8	1167.2
Maximum	8494.0	81.0	3168.0	73.8	39.6	22000.0	3618.0
Minimum	0.0	0.1	0.0	0.0	0.7	280.0	152.8
Standard deviation	1961.7	21.6	736.1	14.4	8.9	4861.6	834.2

ii) Environmental characterization for each unit: this study follows a cradle-to-gate approach and the functional unit is 1 kg of honey. The environmental impact category analyzed is climate change (CC).

The impact assessment method is ILCD v. 1.0.8 2016 midpoint. The software employed is the Open LCA 1.7.0, while the database employed is Ecoinvent v. 3.3.

iii) Eco-efficiency assessment: we evaluate two DEA models to assess the eco-efficiency: the BCC model (Banker et al. 1984) and the FDH (Deprins et al. 1984). Both models consider an output orientation since we seek to maximize honey production. The CC is considered as an undesirable output of the system for which the multiplicative inverse transformation proposed by Golany and Yaakov (1989) is used. For further details about both DEA models please refer to (Cooper et al. 2007).

iv) Factors target procedure to achieve environmental reduction: briefly, in this step the output or input targets for the inefficient beekeepers are calculated. These are based on the benchmarks and intensities of inefficient beekeepers which are provided by the DEA models in step 3, as proposed Rebolledo-Leiva et al. (2017).

Results

Figure 1 presents efficiency level obtained by BCC and FDH DEA models for each beekeeper. The BCC model identified 16 efficient beekeepers and 15 inefficient beekeepers. For the inefficient beekeepers the efficiency level ranges from 23% to 94% with an average of 49%. For these beekeepers the CC could decrease an average of 449%, while the honey produced could increase an average of 249%. This would be reach by an average increase of 10% of feeding and an average reduction of 6%, 3% and 1% in the inputs of medication, transport and electricity, respectively.

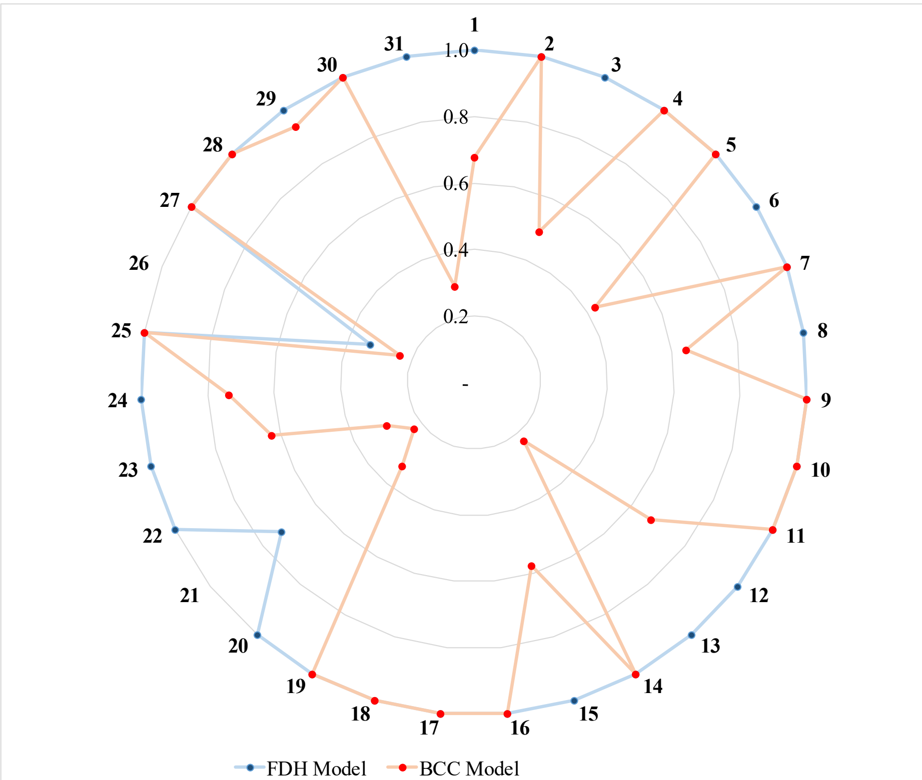

Figure 1. Eco-efficiency level obtained through the FDH and BCC DEA models

The results obtained by FDH model indicate that 29 beekeepers are efficient and only two beekeepers are identified as inefficient, i.e. beekeepers 21 and 26. The average efficiency level for inefficient beekeepers is 53%. For each of these both beekeepers, FDH model provides benchmarks (best practices). The benchmark of beekeepers 21 and 26, are beekeepers 15 and 14 respectively. In this sense, inefficient beekeepers have to study and incorporate the operational practices of their benchmarks in order to be eco-efficient.

Discussion

Results obtained present high difference in the number of efficient or inefficient beekeepers identified by both DEA models. From a theoretical point of view, this could be since the BCC model seems to be more restrictive in relation to the FDH model (Lim et al. 2016). This is explained by the mathematical formulation of both models. Despite both DEA models include constraint which guarantee that the DMUs are compared with similar DMUs in scale and size (assuming variable returns to scale), in the case of FDH, the constraint is formulated using binary variables. Therefore, the computational technique to solve FDH program considers the mixed integer programming problem compared to the BCC DEA model with a linear programming problem (Lim et al. 2016). Furthermore, the shape of production possibility set in FDH is stepwise while the production possibility set of BCC DEA model is based on linear combination of inputs and outputs (Lim et al. 2016). Finally, the number of benchmarks for inefficient DMUs can vary depending the model used. For instance, FDH model provide only one benchmark for an inefficient DMU since the intensities determined through the model are binary. On the contrary, BCC model can provide more than one benchmarks since it does not consider intensities as binary variables.

From a practical point of view, the BCC model allows determining an efficient mix of inputs or outputs based on the actual inputs or outputs level of the benchmarks. This implies that an inefficient beekeeper must consider the combination of all its benchmarks, through the use of the intensities. On the other hand, the results obtained with the FDH could be easier for implementation by the inefficient beekeepers since they should perform their operating target point based solely on the operating point of one efficient beekeeper. In this context, decision makers could employ both models in steps. First using FDH model in order to identify the most critical inefficient beekeepers and consequently improve operational and environmental performance of these beekeepers. Afterward, managers could apply BCC model due to the targets are greater than those founded by FDH model, and consequently it requires a greater effort by beekeepers in order to reach them.

Conclusions

This work compares two DEA models for eco-efficiency assessment following the four-step method of LCA+DEA methodology. To do this, a set of 31 Chilean beekeepers were evaluated. The input considered are feeding, medication, fuels, electricity and disposable material, while the outputs are classified into desirable (honey production) and undesirable (climate change). The DEA models compared were the BCC and the FDH.

The results show that the number of inefficient beekeepers identified by BCC models is grater that those obtained with the FDH model, 15 and 2 respectively. The average efficiency level for inefficient beekeepers obtained with the BCC model is 49%, while with the FDH model is 53%. The wide difference in the number of inefficient beekeepers could be due to the BCC models is more restrictive in relation to the FDH model. Another difference observed was that BCC model allows determining an efficient mix of inputs or outputs based on the actual inputs or outputs level of the set of benchmarks, while the results obtained with the FDH are easier to implement since the inefficient beekeepers should be compared only with one efficient beekeeper.

Acknowledgements
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Abstract code: 55

AGRIBALYSE v3.0, the French LCI database: opening a new dialogue between agriculture, food and nutrition data.

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Abstract

The AGRIBALYSE database has provided LCI data for French agricultural productions since 2013. The new version v3.0 published in 2020 opens a broad new potential through a major enlargement of its scope. The database evolves from cradle to farm gate to cradle to consumer plate, combining a production-based approach and a consumption-based approach. LCIs for 2 500 consumer products are provided in the new database, mirroring the French public nutritional database (named 'CIQUAL'), with the same system boundaries and nomenclature. This innovative and ambitious work has required to overcome several methodological challenges. It also opens vast potential and diversity of use, hopefully bringing LCA in the heart of sustainable agriculture and food strategies in France and inspiring other countries.

Keywords: *Agriculture, food, LCA, nutrition,*

Introduction

The AGRIBALYSE database has provided LCI data for French agricultural productions since 2013. The aim for developing partners (governmental bodies, research and professional associations) has been since the beginning to support eco-design and better environmental information to consumers, by providing a public method and benchmark database. Available on SimaPro and openLCA, Agribalyse is widely used in France and more broadly by LCA agriculture and food experts working on eco-design of farming practices and food industry. Together with other initiatives such as the Product Environmental Footprint (PEF), World Food LCA database, or Agri-footprint® it has contributed to a larger use and acknowledgement of LCA's relevance for food sustainability.

The new version v3.0 published in 2020 opens a broad new potential through a major enlargement of its scope. The database evolves from cradle to farm gate to cradle to consumer plate, combining a production-based approach and a consumption-based approach. LCIs for 2 500 consumer products are provided in the new database (Table 1), mirroring the French public nutritional database (named 'CIQUAL'), with the same system boundaries and nomenclature.

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*

Material and methods

The AGRIBALYSE 3.0 version builds upon its previous version and on the work of the ACYVIA project for food processing, as well as on other complementary initiatives (Ecoinvent, WorldFood LCA Database, FoodGES, PEF) for imported products and downstream stages (logistics, packaging, retail, home preparation).

The project faced many challenges, major ones being the wide spectrum of food items and the potential variability of content (recipes, raw material, packaging etc.) of each food item. The strategy for taking up these challenges was to build a robust and homogenous architecture for the new database, starting with a "simplified content", using proxies for data gaps, and to allow for continuous improvement with time. Considering the large database scope, priority has been given to transparency, systematic methodologic approach, focus on hotspots (agricultural phase in particular) rather than looking for a high accuracy of individual processes. In addition, an effort has been made to provide reliable Data Quality Ratings, aligned with PEF guidelines, for each of the 2500 food items at consumer, reflecting precision, time representativeness, and the use of technical and geographical proxies. Finally, a strong review process was implemented at different development stages, by RIVM, GreenDelta and Koch Consulting. Review was conducted at global database level, at product group level and for individual samplings, based on midpoint and endpoint EF indicators.

The database is published as unit processes in LCA software, allowing transparency and user adaptation of LCIs for more accurate analysis. The methodology is fully described in the documentation (Koch and Salou 2020; Asselin et al. 2020) available with abundant complementary information on the AGRIBALYSE webpage (ADEME 2020).

Results

A vast quantity of agricultural data is available in the database, reflecting different plant and livestock production systems (eg: dairy production based on grass or maize silage; indoor/outdoor livestock etc.). These processes correspond to past AGRIBALYSE v1.3 data which have been updated (e.g.: some emission models, new fruit and vegetable products, organic agriculture products) using the MEANS-InOut software.

For the food LCIs "at consumer", only the most common, conventional farming system has been considered. For imported food, the most important countries of origin were considered. Archetypes and categories were built to define packaging, logistic and use phases. Key ratios for processing (raw ingredient to food ratio), edible losses and cooking (raw to cook ratio) were defined. Product (e.g. orange for grapefruit) and country (e.g. Spanish tomato for Moroccan tomato) proxies were used. Out of the 2800 CIQUAL products available, we were able to provide LCIs for 2494 products, as, for some products, lack of data (e.g lobster, mushrooms, honey) did not allow us to provide relevant modeling.

Figure 1 provides a few examples of results of high interest for agriculture and food professionals. Similar results are available for all 2500 products, with possibility to "zoom in, zoom out" within the value chain.

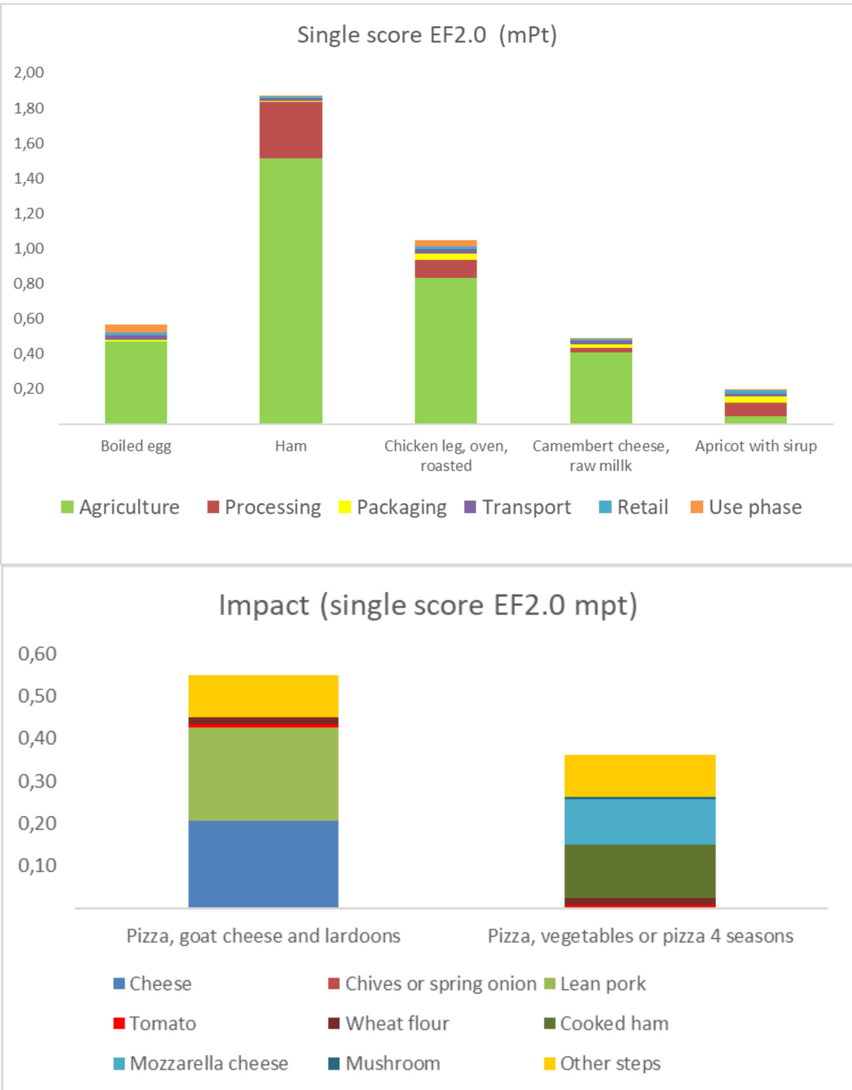

Figure 1. Example of single score of a few food products and contribution analysis

The DQR item also provide guidance on the quality of each of the food items included in the database (Figure 2).

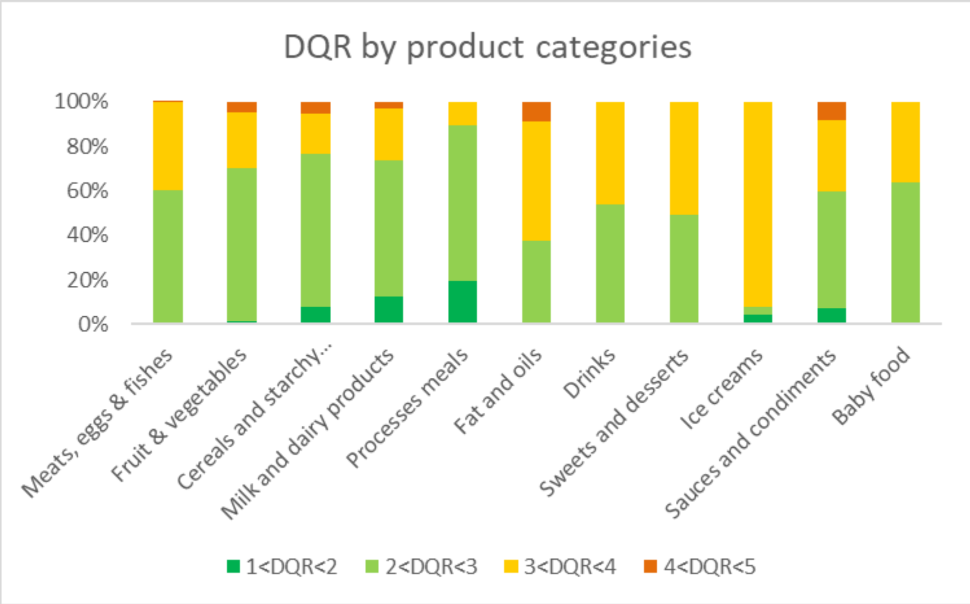

Figure 2. DQR of Agribalyse 3.0 database

Discussion and Conclusion

AGRIBALYSE v3.0 is, to the best of our knowledge, the largest LCA agriculture and food database publicly available, covering almost all food categories consumed in a major European country. Due to its transparency, we believe that our data can be used/adjusted for other European countries where data is lacking. The data is expected to be widely used for hotspot analysis and "first approach benchmark", by agro-food companies involved in eco-design projects and by digital players developing environmental information at product or recipe level (e.g.: Open Food Facts, Marmiton, Yuka). Due to the connection to corresponding nutritional data for each food item in CIQUAL, we expect it to be used as well by nutritionists and catering companies wanting to provide more sustainable menus, and more broadly by the education and research community.

This new version is a major step, but not the end of the story, as many improvement options have already been identified. To mention just a few: pesticide and water consumption aspects, more accurate recipes, accounting for the variability of agriculture production systems (organic products, in/off season products etc.). ADEME, INRAE, and AGRIBALYSE partners will address those challenges in the future versions in order to support the development of more sustainable food systems in France and inspire other countries and regions.

Acknowledgments

This work has been possible thanks to the active support of more than 100 agronomy, food and environmental experts who have contributed at some point in the database development during last 10 years. It has largely beneficiated from support of the French Technical Institutes and all members of Agribalyse steering committee. Jérome Mousset (ADEME) also brought significant inputs to this article.

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Sustainability assessment test under real time condition (SustainFarm)

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Abstract

Purpose Food production along the entire value chain aims to be as sustainable as possible for all three dimensions of sustainability (economic, social and environmental). Detailed quantitative information about the sustainability of the farm's primary production can be obtained by the use of a set of indicators.

Methods The sustainability method SALCAsustain, as described in Roesch et al. (2017) was applied under real-time conditions on typical Swiss farms for two years (2016 and 2018) of operation. The method computed 21 indicators (13 environmental impacts, six economic indicators and two social indicators) which were analysed statistically. A reduced set of indicators were presented to the participating farmers. In addition, feedback interviews were conducted to gain more insight into feasibility, use and acceptance of the applied method.

Results The correlation analysis carried out showed that the number of environmental indicators may be reduced. In view of the time-consuming data collection this fact could represent a simplification. The evaluation of the questionnaires pointed out that sustainability is important, especially the economic dimension. The evaluation showed that mid- and longterm benefits prevail for farmers when assessing the farm's overall sustainability using SALCAsustain.

Conclusions Sustainability assessment has shown to be highly relevant at the farm-level but also for food production along the entire value chain. For a large number of farms an implementation of such a sustainability method would be only possible with further digital data acquisition, with a reduction of the indicators or the use of default values.

Keywords: *Sustainability assessment, farm-level, real-time condition*

Introduction

Food production along the entire value chain aims to be as sustainable as possible for all three dimensions of sustainability (economic, social and environmental). In order to provide sound information on this issue, detailed quantitative information about the sustainability of the farm's primary production are required. This aim can be achieved by using a set of indicators that describes the sustainability of agricultural production at farm level. Therefore, an on-farm pilot testing based on the method SALCAsustain was performed.

Material and methods

The sustainability method SALCAsustain as describedin Roesch et al. (2017) was applied on twelve farms of three typical Swiss farm types (animal-intensive, arable, mountain farming) for two years of operation (2016, 2018). In addition, three dairy farms were analyzed for the operating year 2018. The method computed 21 indicators (13 environmental impacts, six economic indicators and two social indicators, table 1). It required the collection of a comprehensive dataset which was considerably

larger than the dataset the farmer has to collect for the government in order to receive subsidies (e.g., applied farm management practices). All data were checked for plausibility. A correlation analysis was performed for identifying possible synergies and trade-offs as well as possible simplifications.
A reduced set of indicators were presented to the farmers and two individual in-depth feedback interviews were conducted in order to get more statements about feasibility, use and acceptance of the applied method.

Table 1 shows the 21 indicators calculated by the sustainability method SALCAsustain

Dimension	Indicator	Dimension	Indicator
Environmental	Non-renewable energy resources	Economic	Profitability: Earned income per family labour unit
	Phosphorus		Profitability: Total return on capital
	Potassium		Liquidity: Cashflow-turnover rate
	Water requirement (fresh water)		Liquidity: Dynamic gearing ration
	Land use		Stability: capitalization ratio
	Greenhouse gases (CO_2, CH_4, N_2O)		Stability: equity-to-fixed-assets ratio
	Eutrophication aquatic	Social	Workload in terms of time
	Eutrophication terrestrial		Landscape diversity and aesthetics
	Acidification aquatic		
	Acidification terrestrial		
	Ecotoxicity		
	Biodiversity		
	Soil quality		

Results
The study showed that the sustainability method SALCAsustain is feasible under real time condition: complete datasets at the farm level could be collected and the set of suggested sustainability indicators could be computed. The data collection and the quality control was very time-consuming. The correlation analysis (Figure 1) showed that the set of environmental indicators may be reduced as they are partly highly correlated. E.g., the energy requirements per hectares AUU (EBha) and the global warming potential per hectares AUU (THPha) showed a very high correlation
The significance of the indicators was checked using various analyses. It was found that the indicators are sufficiently sensitive to changes in management and provide plausible and meaningful results.
The evaluation of the questionnaires pointed out that the topic of sustainability is relevant for the participating farmers. They these benefits in assessing the overall farm's sustainability for achieving a more sustainable food production. The farmers were most interested in the economic indicators, followed by the social ones. In order to learn from the best, the exchange with farmers with similar interests and production branches was highly desired. The farmers recognize the value of a sustainability assessment in relation to their medium to long-term work.

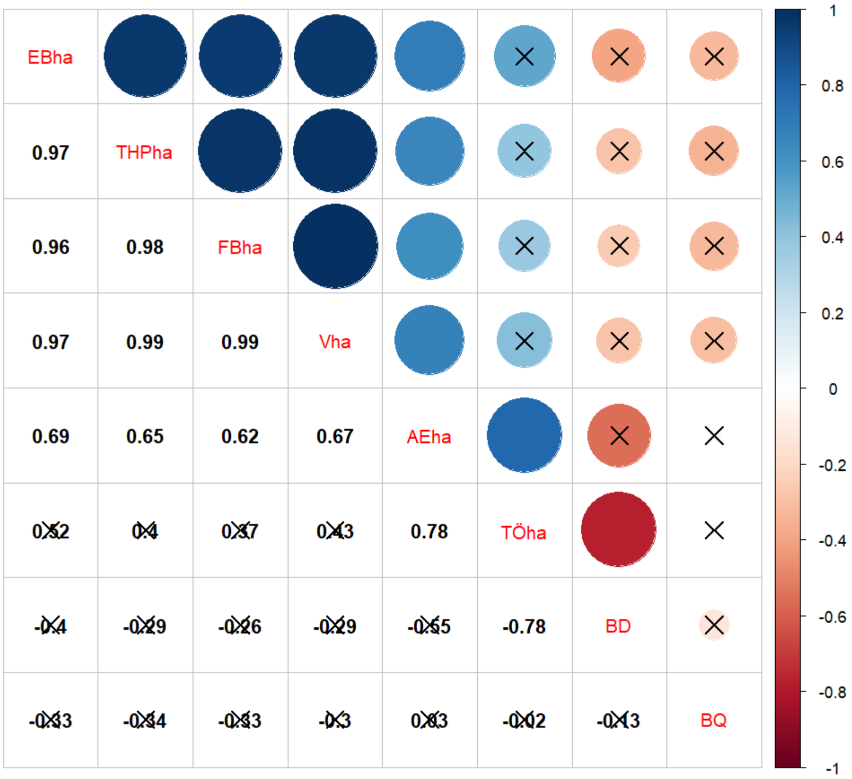

Figure 1: Correlation matrix (Spearman correlation) for ecological impact indicators. Data: All farms, test phase 1, year of operation 2016. Insignificant coefficients (at the 95% significance level) are marked with a cross. The correlation coefficients are shown graphically (upper triangular matrix with legend on the right and as numerical values (lower triangular matrix).
With AUU: Agricultural utilised area: EBha= Energy demand per ha AUU, THPha= Global Warming Potential per ha AUU, FBha= Space requirements per ha AUU, Vha= Acidification per ha AUU, AEha= aquatic eutrophication per ha AUU, TÖha= terrestrial ecotoxicity per ha AUU, BD= Biodiversity, BQ= Soil quality.

Discussion

The sustainability method SALCAsustain has shown to be applicable for assessing the overall sutstainability of Swiss farms. However the data collection is very time-consuming. The amount of data and the form in which it is available play a central role. There are currently various efforts throughout Switzerland to electronically record and manage agricultural operating data. It is therefore recommended to direct these efforts in the overall context of the digitization of Swiss agriculture. Depending on the size of the sample, the number of indicators examined and the number of survey years, the sustainability method SALCAsustain could generally be used for benchmarking, extrapolation or monitoring.

Conclusions

The assessment of the overall sustainability is crucial at the farm level but also for food production along the entire value chain. The method SALCAsustain provides a comprehensive picture of the expected farm's overall sustainability. The study showed that different stakeholders rate the relevance of the analyzed indicators differently: E.g., for farmers, practice directions are advantageous which, however, often require even more detailed data acquisition. An application of the method SALCAsustain for a large number of farms is only achievable with increased digital data acquisition,

with a reduction of the indicators or the use of default values.
Depending on the application of such a sustainability assessment, the following implementation options are possible in practice: i) By limiting the number of indicators, less, but still farm-specific statements can be made, ii) by simplifying the calculation of the indicators, less input data is required. The reduced informative value has the following disadvantage: the indicators tend to be less sensitive to certain changes in operational management and parts of sustainability are not taken into account.

Acknowledgements
We thank MGB Switzerland (https://www.migros.ch/de/genossenschaften/migros-zuerich.html), Estavayer Lait SA (http://www.elsa.ch/) and IP-SUISSE (www.ipsuisse.ch) for their financial support.

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Abstract code: 283

How connected are we? Collaboration among food LCA practitioners and influences on methodological attributes: Preliminary analysis

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Abstract

Purpose: The growing body of food life cycle assessment (LCA) research provides opportunities to compare and synthesize results from numerous research groups. Variation in study goals, scope, and methods presents a challenge in understanding and comparing the outputs from diverse groups. This study aims to identify communities of authors within the network of food LCA researchers and explore scope and methodological variation between communities that may influence the comparability of their results.

Methods: We used Social Network Analysis (SNA), a technique to analyze connections between actors in a network, to identify groups of food LCA researchers based on their history of academic collaboration. Our network of researchers was built from co-authorship records in the Scopus database and limited to assessments of seafood and livestock systems. We assessed the extent to which key methodological differences between studies reflect those patterns: product class assessed, scope of system boundaries, and choice of allocation method.

Results and discussion: From 383 food LCA case study papers assessing fishery, aquaculture, and livestock systems, we produced a list of 1,143 unique authors. Among these authors, we identified five major communities of researchers based on their history of co-authorship. These communities each vary in the product classes they assess and the scope and methods of their modeling. The extent to which this variation is an effect of researcher community rather than product system type or another factor requires further analysis.

Conclusions: We present preliminary results from a SNA of food LCA researchers. Our analysis will be useful in understanding the patterns of collaboration and cooperation among the LCA community, in finding opportunities to encourage collaboration between diverse schools of thought, and in identifying challenges in methodological comparability when aggregating and synthesizing the outputs of diverse research groups.

***Keywords**: Social network analysis; Scientific collaboration; Methodology; Allocation; Livestock; Seafood*

Introduction

Social network analysis (SNA) is the application of graph theory to understand connections between actors in social structures. Applied to scientific communities, these networks can reflect connections within a group of researchers or a particular field and may be structured on instances of co-authorship and/or citations between individuals. SNA has previously been applied, for example, to fields of agricultural economics (Popp *et al.*, 2018), low/no-fossil carbon transition (Zou *et al.*, 2017), and greenhouse gas emissions quantified using life cycle assessment (LCA) (Zhong *et al.*, 2019). The objectives of these studies have varied: Popp *et al.* investigated the most well-connected authors, Zou *et al.* identified the strongest rates of collaboration by institution and country, and Zhong *et al.* explored research trends that produced the highest rates of collaboration.

The breadth of extant literature in published academic journals presenting LCA case studies of food products has expanded rapidly in recent years. These studies assess a wide variety of food products from around the world and employ a similarly varied set of methods to model environmental performance of food products at different stages in their supply chains. Efforts in recent years have sought to draw larger conclusions from the collective body of food LCA research and to synthesize, harmonize, or otherwise aggregate and compare their results (*e.g.* Tilman and Clark, 2014; Nijdam *et al.*, 2012). A common challenge when approaching these meta-style analyses is the methodological inconsistency across different case studies. This may necessitate limitation of study inclusion or lead to conclusions being drawn from comparisons between studies that are methodologically incomparable.

Here we present preliminary findings from a SNA applied to a subset of published food product LCAs. We establish a network of LCA authors based on their history of co-authorship, identify communities of authors within the network, and explore scope and methodological variation between communities that may influence the methodological comparability of their studies.

Methods

We reviewed literature and gathered published journal articles presenting food LCA case studies from fisheries, aquaculture, or livestock. We identified articles primarily via multiple Scopus searches with LCA- and food-related keywords, and subsequently reviewed papers and bibliographies for additional case study papers. After producing the list of food LCA case study papers, we identified all unique authors having contributed to those articles and extracted a full authorship history for each author from the Scopus database using the *pybliometrics* Python library by Rose and Kitchin (2019) and a Scopus API key.

Using the authorship histories of food LCA case study authors, we established a network of co-authorship wherein each node represents a unique author and each edge represents the occurrence of at least one paper, which did not itself need to be a food LCA case study, on which two authors collaborated. The strength of edges was not weighted by the number of co-authorships between authors nor by the type, age, or any other characteristic of the shared papers—a choice which ultimately affects the structure of the network and on which future sensitivity analyses can be conducted. We undertook analysis of the co-authorship network using the *NetworkX* Python library

(Hagberg *et al.*, 2020). We used a modularity maximization algorithm (Clauset *et al.*, 2004) to identify communities of authors with high rates of collaboration within each community and low rates of collaboration between communities. From the total set of identified communities, we selected the five largest communities for further analysis.

We categorized our network of food LCA case studies by assigning a community to each study if it included at least one author from one of the five major communities. If a paper included authors from multiple communities, it was included in analysis for each relevant community but for representation and visualization purposes was assigned the community of the author who was listed first. We then undertook preliminary analysis to investigate scope and methodological differences between the identified communities. We reviewed each paper to determine: the class of product being assessed (fishery, aquaculture, or livestock); the scope of system boundaries (up to dock or farm-gate or including post-production activities); and the use of biophysical or economic allocation methods or system expansion to avoid allocation.

Results and discussion

We identified a total of 383 published journal articles presenting fishery, aquaculture, or livestock LCA case studies. These papers had a total of 1,143 unique authors from 391 unique institutions in 45 countries. Modularity-based community detection identified 12 communities of at least 10 authors each with a demonstrated history of collaboration. The five largest communities, which were selected for further analysis, each contained between 122 and 188 authors and together accounted for over two thirds of all authors in the network.

241 (63%) of the published studies were connected directly or indirectly by their shared authors, and 300 (78%) included at least one author from one of the five major communities (Figure 1). Of those, 250 included authors from only one of the major five communities while 50 (17%) represented instances of collaboration between the major communities of researchers. Shared authorship amongst food LCA case study papers does not strictly follow the community structure based on co-authorship history: some authors may share a history of collaboration but have not worked together on food LCA case studies specifically.

Of the total 383 papers, almost 80% presented case studies of livestock systems while the remainder assessed seafood products. Almost all seafood LCA studies were undertaken by researchers in the three largest communities while most, including one of the major communities, assessed only livestock products (Figure 2).

System boundaries varied markedly between the five communities of researchers. 72% of published articles for which system boundaries could be ascertained focused on the feed and/or production stages alone while 28% extended consideration to post-production activities. Those communities which were more likely to assess seafood products were also the most likely to extend system boundaries to include post-production stages.

Instances of either co-product allocation or system expansion to avoid allocation were identified for 198 (52%) case study papers. In all but one of the major communities, economic allocation was the most commonly applied method, although the extent to which biophysical allocation or system expansion were employed did vary. The same communities that accounted for most of the seafood LCA case studies together also accounted for a disproportionate number of instances of both biophysical allocation and system expansion.

It is important to be able to differentiate the effect of community influence on methods from the effect of other parameters. From our results, for example, there is an apparent connection between the application of LCA to seafood systems and the use of biophysical allocation and extended system boundaries by researchers undertaking those studies. We need to undertake further cluster analysis to establish whether it is the product class that is most influencing those decisions, rather than the community of researchers. Expanding our analysis to include studies of agricultural and horticultural products will also help to further illustrate any potential variation between studies of different product classes either within or between researcher communities.

Conclusions

Identifying the extent to which research community structure influences the methods and results of food LCAs is important in determining how successfully the outputs of diverse groups can be compared and aggregated. SNA can also help identify those authors that are most central in each of their respective communities and potential opportunities for inter-community collaboration. Such collaborations would help explore the methodological choices in which communities most vary and would ultimately lead to a more connected network of food LCA researchers—though not necessarily a more methodologically consistent one.

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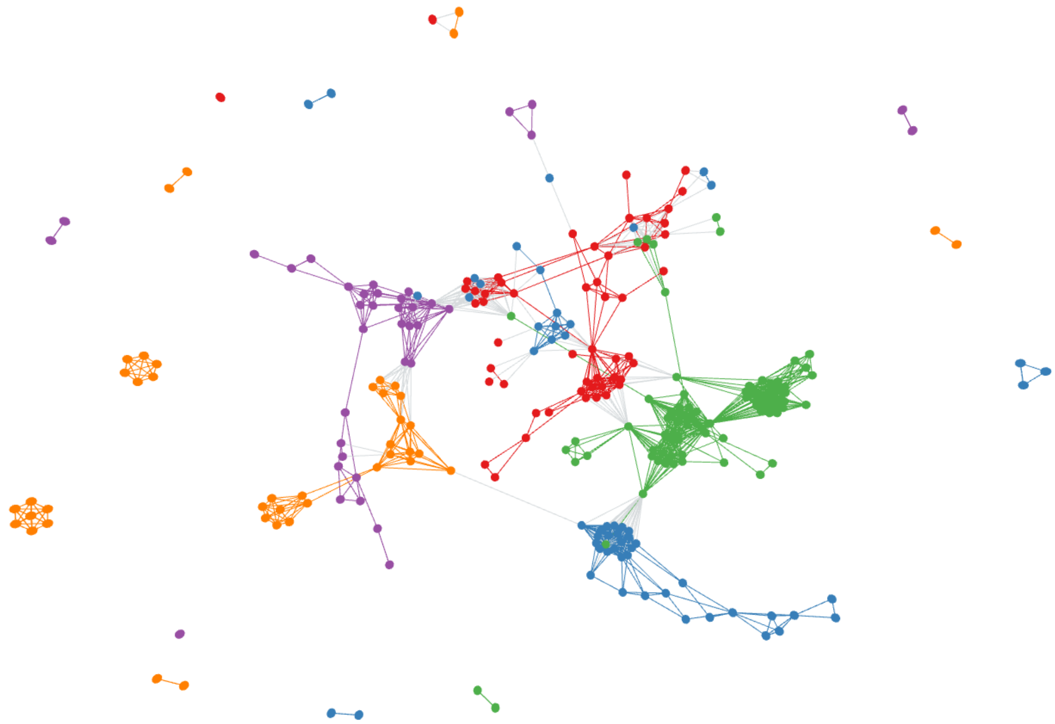

Figure 1. Network visualization of 300 food LCA case study papers linked by shared authorship and coded by author communities, including only papers from the five largest researcher communities. Node colours represent community assignment of authors giving preference to the community of the first author. Instances of intra-community co-authorship between papers are similarly coloured.

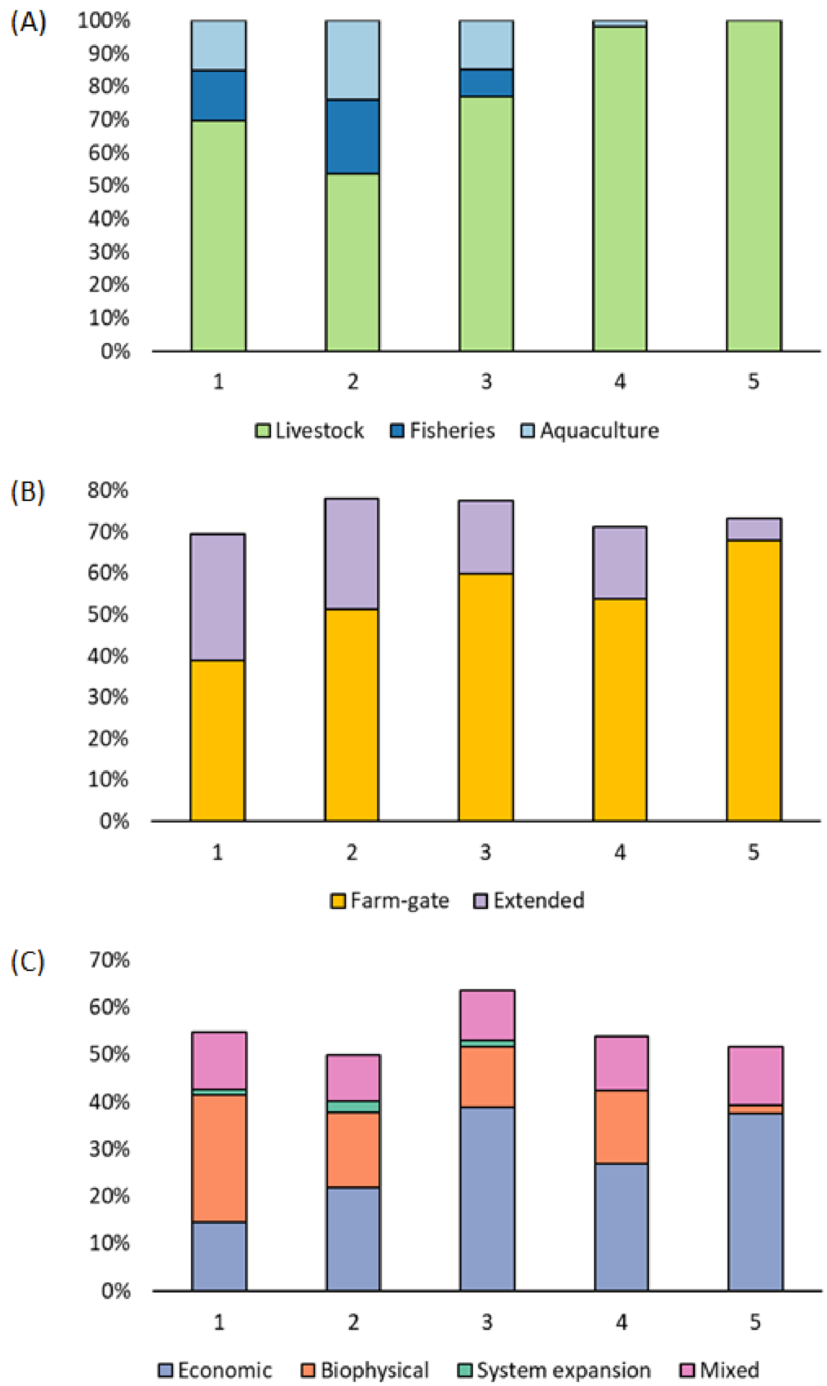

Figure 2. (A) Product classes assessed by researchers in each major community; **(B)** Relative proportion of studies within each community that limited system boundaries to farm-gate or included processing or other post-production activities, if known; **(C)** Relative proportion of studies within each community employing different allocation methods, if known. Communities are labelled 1-5 in descending order of size by number of included authors.

Abstract code: 198

An Agent-Based Model (ABM) to simulate the influence of farmers' social interaction, risk aversion and environmental consciousness on the environmental impacts of agriculture

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Abstract

Agricultural activities produce relevant environmental impacts and the dynamics of agricultural systems can be overly complex. The decision-making regulating those activities could benefit from using tools that explicitly include farmers' behavioral aspects and sustainability information from a life cycle perspective. Agent-based models (ABMs) have been adopted to simulate various kinds of complex systems, from biological systems to complex coupled human-natural systems (CHANS). When used to simulate man-managed systems, ABMs have the advantage of allowing the consideration of human behavioural aspects into the modelling framework.

The goal of the study is to simulate the impacts of farmers' interactions and their decisions, on cropping activities. Understanding real-life interactions between the agents is crucial to create a viable ABM model. While all farmers may interact with each other, they share information with their geospatial neighbors more frequently. We apply constrained allocation of geospatial information to approximate the geographical distribution of farms in Luxembourg, which is unavailable for confidentiality reasons. A network of farmers is created afterwards, using farm attributes like geographical location and size as well as farmer attributes like age or membership to a certain organization. The strength of the connections may evolve according to the changes of farmers' attributes (age, geospatial info, etc.). They influence farmers' decisions, which reflect on the environmental impacts of their activities.

The results show that information sharing among farmers over the course of the simulation leads to a decrease in average green consciousness (AGC) in a scenario where the initial values of farmers' green consciousness (GC) are based on left-skewed Beta distribution, whereas the opposite happens for right-skewed case. Either way, at the end of the simulation the number of farmers with a GC < 0.2 is lower than it was at the start of the simulation. AGC is between 0.45 and 0.6, which results in selection of the crops with the lowest global warming potential (GWP) among the available ones. Four different ILCD impact categories were used to assess the effects of introducing a social network of farmers. Both scenarios resulted in up to 20% decrease in some categories over the course of the simulation.

Keywords: *Social network analysis, agent-based modeling, farm management, decision support system, life cycle assessment, geographical information systems*

Introduction

Within the communities and markets there are complex relations which Customers and business have constant interactions that can and have been studied from the behavioral science and social network analysis standpoints.

In agricultural systems modelling, it is essential to understand the decision-making process

undertaken by farmers, in order to build a reliable model. As all other individuals, farmers are affected by others when taking decisions and studies found that the opinions of friends, peers, and trusted advisors were highly influential on farmer decision-making behavior (Rose and Morris 2018). The opinions of trusted people could affect farmer behavior through the provision of formal or informal advice, or through the means of social pressure. For that reason, agricultural systems show features of complex systems (Bert et al. 2014). Agent-based models (ABM), considered appropriate to model complex systems including decision-making and interactions at an individual (or agent) level, gained attention in order to model agricultural business.
Appealing to the (GC) of micro decision-makers and practitioners has been considered as a strategy to reduce the environmental burden at the system level. (Marvuglia et al. 2017) studies the GC as a static attribute of farmers and its influence in their decision-making process. However, behavioral change is known to transmit through social networks while revealing itself as an emerging property. Therefore, the focus of this study is to investigate the transmission and emergence of GC within the farmer population in Luxembourg. To achieve this, we combined ABM with social network of farmers to simulate future crop patterns in the Grand Duchy of Luxembourg under pre-defined scenarios. The results of the simulation are then translated into environmental impacts from an LCA perspective. The implementation of a social network of farmers is briefly described. How farmers' GC is affected by their connections as implemented in the model is also discussed.

Materials and methods

ABM – LCA coupling

The model is built upon the simulator described in (Marvuglia et al. 2017). The focus of this paper is on modelling the dynamic interactions between farmers and interpreting the changes in GC arising from these interactions. The LCA model and the ABM are "tightly" coupled, in the meaning discussed in (Baustert and Benetto 2017). The results of the ABM are directly linked to the LCA calculation done with the Brightway2 framework.

Field Allocation

In order to achieve meaningful results, defining the elements of farming business and initializing the model accordingly are of utmost importance. Most of the time researchers are restricted with available data sources and data protection regulations. In our case, we have Geographic Information System (GIS) data available for Luxembourg, which show the fields registered in the national cadaster. However, the information regarding their corresponding farms is unknown. The only information available is the number of farms falling in each farm size-class. This information is available on the national and European statistical bureaus websites (STATEC and EUROSTAT respectively).
Using ABM, we can model the agents such that they can process and exchange information with other agents while making autonomous decisions. This autonomy creates heterogeneity in the model and allows studying emerging behaviors (resulting from the collective interaction of autonomous actions). This heterogeneity allows capturing the diverse personality traits such as risk aversion orientation and other aspects of more complex psychology. The strength of ABM is combining different theoretical assumptions and aspects of human behavior within a computer simulation framework. One of the mechanisms that are most likely to influence the creation of links and interactions between agents is their geographical proximity. Farmers whose farms are close in space are likely to know each other, interact, exchange materials (such as manure) and take advice from each other. Using GIS information in the definition of the agents in ABMs through coupling and embedding is a growing trend in the literature on ABM (Marvuglia et al. 2018). In our model, the geographical information is coded as an attribute of the agents. Our objective in the cases of Luxembourg is utilizing this geographical information to build a first network of connection between neighboring farmers.
However, as mentioned above, we do not know the actual locations of farms due to confidentiality

reasons. In order to circumvent this data limitation, we propose a constrained polygon allocation methodology which resembles a special image segmentation technique, called "seeded region growing" (Adams and Bischof 1994), to create real-like farms that have designated boundaries.
The inputs required for the algorithm are the fields to allocate, average farm sizes broken down in "classes" and the expected total final number of farms in the system. The steps of the algorithm can be summarized as follows:

1. Specify the neighborhood relations between fields. Currently the fields within 200 meters range are defined as neighbor fields. Neighborhood relation is not simply defined as "touching" polygons, because there are fields which are totally separated from other fields, possibly because they are surrounded by canals, roads etc. In order not to leave them out, the distance between polygons are considered when defining neighborhood relations.
2. In order to minimize the error committed when allocating farms to the map, we start allocating the farms that have larger total area. For instance, if we allocate fields using the statistics from 2019, we have 510 farms with area equal to 100 ha or greater. For the sake of this model, we limited the maximum size to 200 ha. Then 510 numbers are randomly chosen from a PERT distribution, which are assigned as thresholds for total areas of each farm.
3. Choose a random field (initial seed) and start agglomerating fields with the neighbors. We assign each field to the same farm, thus increasing the total area, until we reach one of the following two conditions:
    a. We reach the pre-specified constraint chosen from PERT distribution.
    b. There is no neighbor left.

   If we used the neighbors and still had not reached the constraint, then we continue growing using the n-*th* degree neighbors of initial seed until the constraint is met. In this way, the assigned fields are as close as possible to each other, which gives us compact and realistically allocated fields.
4. Iterate step 3 until the number of farms in each class size as presented in the national statistics is reached.
5. Merge the field polygons that belong to each farm.
6. If there are still unassigned fields at the end of the procedure, they are assigned to the nearest farm.

Social Network Analysis

Farmers' interaction has been often studied using network science tools. However, our analysis of farmers' networks of practice differs markedly from previous research because the social network layer is interlinked with the environmental layer, expressed in terms of the impacts created by farmers' activities, studied from an LCA perspective (Barbuto et al. 2019, Wood et al. 2014).
The network is created using mainly two relations: 1) geospatial neighbourhood information of the farms, and 2) farmer clusters that are based on age, farm size and community (i.e. membership to a certain association). In the network, farmers are the nodes, and ties represent relations between them. As the farmers' age increases during the simulation, when they reach the threshold age between one age cluster and the other, they switch to the successive cluster. Each tie has a weight between 0 and 1, that is assigned based on the duration of the tie and relation(s) between the agents. At every time-step (t_i), the decision is taken whether to keep or remove the tie based on the duration and strength of the tie. If the tie is kept for the next time-step, then the weight may be updated based on the new cluster the farmer belongs to. During the simulation, also the farmer's GC is updated. GC is an attribute assigned to each farmer to include heterogeneity in their behavior from the point of view of the consideration that each farmer decides to give to the environmental sustainability of the farming strategy undertaken. This attribute influences the decisions taken by the farmers. It is assigned to each farmer from a pre-defined statistical distribution at the beginning of the simulation. The updating rule of the GC is described in Eq. (1):

$$GC_i^{t+1} = \frac{GC_i^t}{2} + \frac{\sum_{j=1}^{n}(w_{ij} \times GC_j^t)}{2 \times \sum_{j=1}^{n} w_{ij}} \quad \text{Eq. (1)}$$

where GC_{it} is the green consciousness of i_{th} agent at timestep t, n is the number of neighbors an agent has in the network and w_{ij} is the weight of the link between the i_{th} and the j_{th} agent.

Simulation of Cropping Activities

The environment for the analyses is the agriculture surface in Luxembourg. Agents try to maximize their profit, while taking individual GC into consideration.

The simulation steps are:

1. Initialize crop prices and the attributes using national statistics from STATEC for the duration of the simulation. Specify the scenario such that behavioral attributes are assigned to each farmer accordingly.
2. Build network of farmers as explained previously to realize the interactions.
3. Let agents react to stimuli and get the areas under each crop for the timestep t_i.
4. Using the simulated land use changes, the environmental impact for different crop types are calculated using the ILCD (European Comision JRC-IES 2018) life cycle impact assessment (LCIA) method.
5. Update each farmer's GC according to the interactions he has with the other farmers.
6. Decide the presence and the strength (weights) of interactions for the next time step. The farmer clusters are regenerated and, according to new clusters based on age and farm area, the interactions are realized.
7. Go back to step 3 and reiterate the process until the specified simulation duration in the scenario is reached. Each time step in the simulation represents a year.

Results

The initial GC values are assigned from a certain Beta distribution. More details on the role of the GC are provided in (Marvuglia et al. 2014). Once the network is initialized, the ties evolve during the simulation while the average degree centrality (ADC) of the network changes as shown in Figure 1.

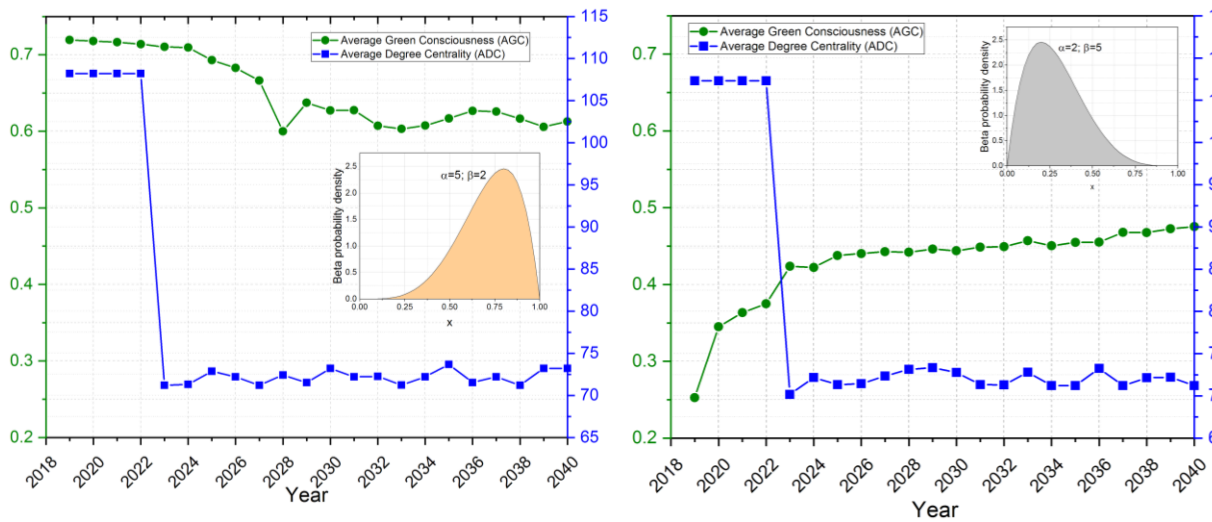

Figure 1: Evolution of ADG and AGC in the network from two different starting distributions of the GC. In each graph, ADG values are read on the left Y axis, while AGC values are read on the right Y axis. The starting distributions and their parameters are represented in the boxes within each figure.

A degree centrality of a node is simply the number of ties it has and ADC corresponds to the average of the degree centralities of all the nodes throughout the network. This evolution also triggers the change in GC. The drop after third year stems from the start of tie removal and creation at that stage. Figure 1(left) and Figure 1(right) show two different evolutions of the AGC, deriving from two different starting Beta distributions. On the left, the AGC from the beta distribution describes a society where few farmers have a low GC, and many of them have a high one, and the one on the right describes the inverse situation.

Figure 2 shows the percentage differences in the scores on four ILCD impact categories with respect to the start year of the simulation (2019).

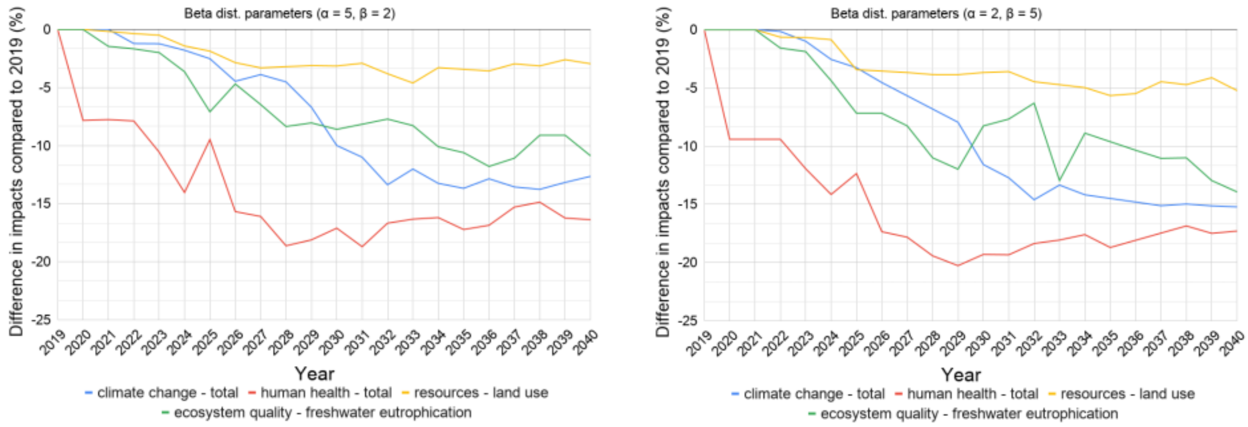

Figure 2: Percentage difference in impact categories from the start of the simulation (2019). (Figure2 –left) and (Figure2 –right) shows the scenario with left-skewed and right-skewed Beta distributions respectively.

Discussion

The addition of social network ties is intended to model the knowledge sharing among farmers. When starting from right-skewed probability density distributions of the GC (majority of agents with low GC), the AGC of the network increases until the end of the simulation (Figure 1-right), while the opposite occurs when the initial distributions of the GC is left-skewed (Figure 1-left). The ADC does not shift in the beginning, but after some links start to be removed it drops to the level where we have long-lasting- clusters and neighborhood ties. The amount of that drop correlates with the number of clusters. As Figure 2 shows, over the years land use and human health related impact categories show significant drops. Farmers with high GC choose the crops with the lowest impacts for the next season (while respecting rotation scheme constraints). Therefore, production of some crops like spelt, grain and maize reduce by 10% on average in the end of the simulation and they are replaced with rye, which shows 20% increase in crop area, due to their high impacts on the categories. Maize for example was replaced in our simulations by rye that has a lower impact on "climate change land use" and "land use change". In either scenario, similar impact categories show drops with different amounts. The amount is usually higher in left-skewed distribution, since AGC is always higher compared to right-skewed one.

Conclusions

The results of our simulations show that fostering environmental protection concerns among farmers has beneficial effects on environmental impacts of crop production that appear already after three to four years and become stable after six years. The effect of GC is amplified when mutual influence mechanisms are implemented. Different strategies of GC promotion will be explored to inform greener agriculture policies.

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management using agent-based models).

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Abstract code: 158

A new model to assess biological resource utilization impacts with a focus on location dependence and parameter sensitivity

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Abstract

In contrast to other sectors, agricultural production is strongly influenced by environmental conditions. As a consequence, as farmers adapt to these conditions, practices differ from location to location, and so do their produce. A common characteristic of impact assessments of bioeconomic production systems is that outcomes are often dominated by only a small number of important processes, which are in turn related to relatively large uncertainties. As a result, calculated environmental impacts of one specific process or product can differ quite significantly depending on the precise management, the location or the used assumptions.
We develop a new modelling framework to assess material flows and impacts of bioeconomic production systems. The framework shall allow for an assessment of alternative usage pathways of biogenic resources, and shall help to identify environmentally friendly food, biomaterials and bioenergy production techniques. As the model is specifically tailored to bioeconomic production systems, it should also make future analysis possible with less effort. A special focus is set on the analysis of important management parameters, and the quantification of uncertainties.
A first model version was developed in the Python programming language. Here, major processes are represented as parameter-dependent functions, where parameters represent management decisions, the location or different methods to compute emissions. Output quantities and characteristics may also be influenced by these parameters. Products are therefore always further specified with attributes relevant for food, material or energetic use (e.g. nitrogen content). Background processes are included by connections to existing life cycle inventory databases.
In this paper the modelling approach is illustrated by a simplified example of biogas production from animal manures and silage maize. It is shown how different parameters influence greenhouse gas emissions and material flows.
Future model development will focus on expanding the model to include more processes, including processes all along the food supply chain, as well as processes of biomaterial and energy production. Furthermore, it is planned to include more indicators and to establish an interlinkage to a statistical or process-based crop model, so that the effects of soil and weather can be captured better.

Keywords: *impact assessment; material flow analysis; bioeconomic production system; uncertainty assessment*

Introduction

Life cycle inventories rely on a collection of unit processes, which convert a set of inputs into a number of defined outputs (main products, side-products, emissions, etc.). This approach enables the assessment of impacts from complex production chains. However, in contrast to other sectors, agriculture is strongly influenced by environmental conditions. Local weather and soil conditions, for instance, determine agricultural yields in each year, which in turn has a strong effect on the environmental impact of production (Boone et al. 2016; Van Stappen et al. 2018). In addition, farmers also adapt their production techniques and management to these conditions. These management decisions, such as on the amount of fertilizer used, together with the natural conditions, determine the quality and characteristics of the products, such as the protein content of the grain. These interdependencies make it problematic to assume fixed conversion processes and uniform products, which neglect management decisions and site-specific conditions.

The large influence of site conditions and management also partly explains a general phenomenon observed for agricultural impact assessments: the range of values computed for specific products can be quite large, and studies on the same subject sometimes come to different conclusions. In a meta-analysis Poore and Nemecek (2018) found that upper estimates of greenhouse gas emissions from beef production (90^{th} percentiles) are more than ten times the values found for lower estimates (10^{th} percentile). Location does not only affect emissions, but may also matters for the severity of impacts. While the location of greenhouse gas emissions is of little importance, for other substances, such as nitrate, the location matters, as it is more problematic in regions that already suffer from nitrogen oversupply and deterioration of the drinking water quality. In this case, site-dependent characterization factors are more appropriate (Potting and Hauschild 2006).

Another characteristic of impact assessments of bioeconomic production systems is that outcomes are often determined by only a small number of processes. For the effect on global warming, this is especially the case when processes involve potent greenhouse gases, such as methane or nitrous oxides. In raw pig manure treatment, for instance, CH_4 emissions from storage are responsible for more than half of the CO_2 equivalent emissions (Willeghems et al. 2016). In such cases, using other methods to calculate greenhouse gas emissions can significantly influence results (Fantin et al. 2015).

It is good practice to conduct uncertainty analysis in life cycle assessments. However, correlations between inputs and outputs, which are determined by the underlying physical or chemical processes, are often insufficiently considered (Heijungs et al. 2019). For agricultural systems, this is strongly related to the properties of the products. The duration of the ensiling period of silage maize, for instance, affects the amount of methane that can be produced (Herrmann et al. 2011), or higher nitrous emissions from manure management earlier on in the production cycle, will likely lead to lower emissions later on.

In order to conduct impact assessments of bioeconomic production systems, which address some of the aforementioned challenges, we are currently developing a novel model framework.

Material and methods

The following requirements define the model development. The model shall allow for an impact assessment of bioeconomic processes. It should thus be able to represent circular systems, such as the recycling of nutrients when manure is used as a fertilizer. In addition, it should consider differences between products from different locations or differently managed processes. Lastly, by allowing for a systematic assessment of production alternatives, management decisions, in combination with a thorough assessment of uncertainties, it should help to identify options for food, biogenic material and fuel production associated with little impacts.

To achieve these targets the following approaches are used for model development. Major processes are represented as parameter-dependent functions, which convert a set of inputs into a number of outputs. These model parameters represent management decisions, the location or different methods to compute emissions. These parameters may also influence the properties of the outputs. Products are therefore always specified by their quantity and associated with their contents (e.g. nitrogen content, CH_4 production potential, etc.), and this information is passed on to other processes later in the production chain. Not so important background processes are included via precompiled databases such as ecoinvent (Wernet et al. 2016).

A first version of this model was developed in Python 3.7 (Python Software Foundation 2019).To facilitate the modelling, a combined approach is used in which the assessed system is defined manually in a configuration file, while required side-products are included automatically based on default values.

The general approach is illustrated at the theoretical and simplified example of biogas production and combustion in a cogeneration unit (see Figure 1) based on three tons of silage maize, six tons of liquid cow manure, and one ton of broiler manure. Information on the content of nitrogen, organic carbon and on the CH_4 production potential was derived from Döhler et al. (2013) and LWK NRW (2014). Emissions for the production of the maize silage were taken from ecoinvent. The biogas plant was modelled similar to Effenberger et al. (2016). Emissions were computed assuming among others a 1% methane leakage from digestate storage and from the combustion process. The biogas digestate was assumed to be used as a fertilizer for plant production.

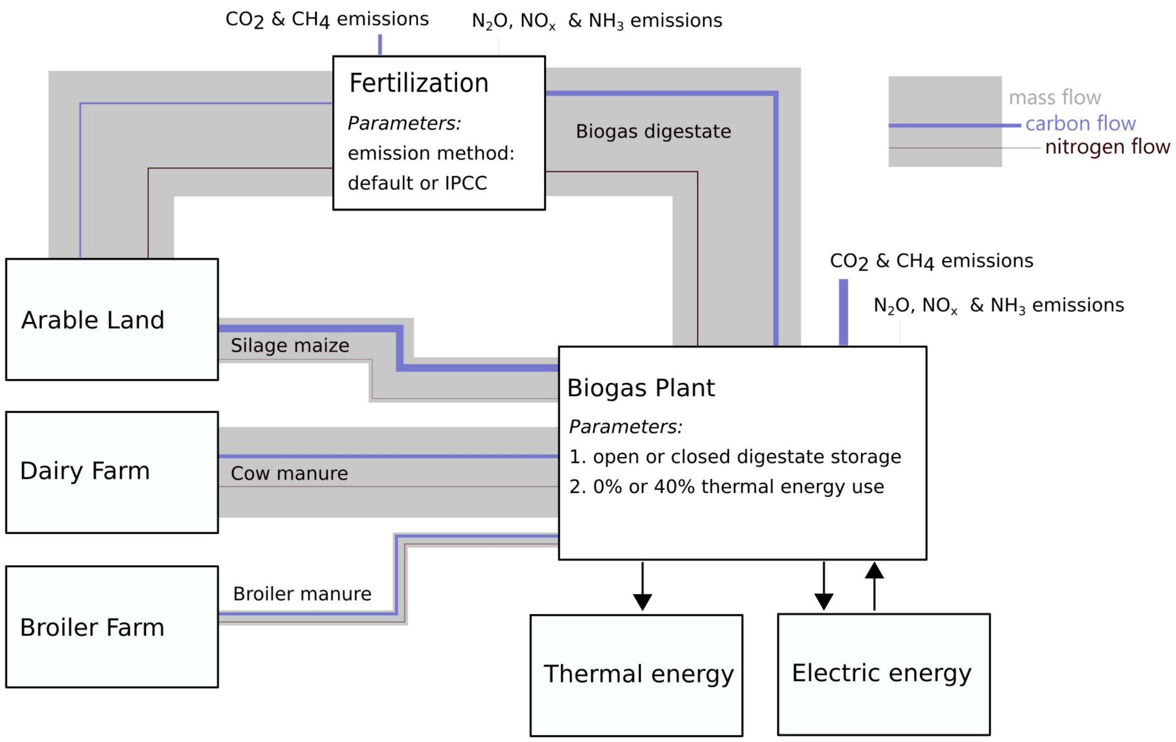

Figure 1: Conceptual approach of the model illustrated at an example of biogas production from silage maize, broiler manure and liquid cow manure. Widths of the lines represent the quantities of total mass flows, and flows of carbon and nitrogen.

To assess the influence of different management decisions and emission calculation methods respective parameters are varied systematically and results are computed for all possible parameter combinations. In the example it is considered whether the digestate storage tank of the biogas plant is an open or closed, which influences emissions of CH_4, N_2O and NH_3 and the amount of biogas that is obtained. Also assessed are two levels of thermal energy usage. Lastly considered are three methods to compute emissions from fertilization mostly based on to the methodology of the German emission inventory (Haenel et al. 2018), the EMEP/EEA air pollutant emission inventory Guidebook 2016 (EMEP/EEA 2016), and the IPCC Guidelines for National Greenhouse Gas

Inventories (Hergoualc'h et al. 2019). This means that a total of 12 (2 x 2 x 3) parameter combinations were assessed in this simplified example.

Results

Figure 1 shows mass flows, and flows of organic carbon and nitrogen for one of the parameterizations of the modelled system. While the liquid cow manure represents the major feedstock of the biogas plant, and the largest mass flow (6 ton fresh matter), due to its low dry matter content of only 10% it consists of only 252 kg of organic carbon. Silage maize contributes the largest share of organic carbon (473 kg) in this example, and broiler manure adds another 209 kg of organic carbon. Of this biogenic carbon, a total of 558 kg are transformed into CO_2 during anaerobic digestion and the combustion of the biogas in the co-generation unit. 2.8 kg of carbon are lost as CH_4 via leakage from the digester, and another 2.9 kg of CH_4 carbon are not fully combusted and emitted from the cogeneration unit (see also Figure 2a).
In terms of nitrogen flows, the dairy and the broiler manure contribute similar amounts (27 kg and 30 kg), while the silage maize leads to a nitrogen flow of 13 kg into the biogas plant. The resulting 8.6 ton of biogas digestate consists of 70 kg nitrogen and 367 kg organic carbon. Of this 62 kg of nitrogen are returned to the field, since gaseous nitrogen losses in the form of NH_3 and N_2O occur after field spreading.

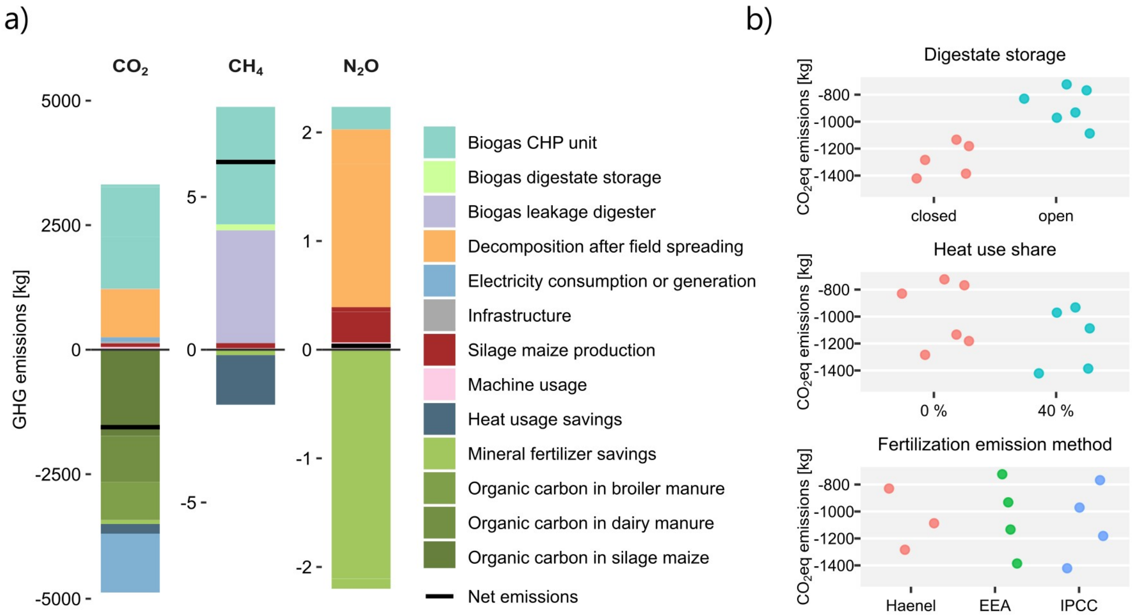

Figure 2: a) Emissions of CO_2, CH_4 and N_2O b) Influence of parameters on CO_2 equivalent emissions

Figure 2b shows that the three assessed parameters have a substantial influence on the CO_2 equivalent emissions. Open digestate storage leads to higher CH_4 and N_2O emissions, two greenhouse gases with a high global warming potential. The effect of the parameters varied in this example on total mass flows and organic carbon contributing to humus formation is relatively low. The amount of nitrogen recycled for plant production, however, ranges between 49 kg and 62, depending on previous gaseous losses.

Discussion and Outlook

The first results show that the general approach of our modelling is working as expected, and that the framework is generally suitable to assess material flows and environmental impacts of bioeconomic production systems. The findings also underline the importance of considering production conditions and management in impact assessments, and we believe that with our new modelling framework we can contribute to the ongoing research in this area.

The chosen approach for the development of the model, however, also presents some challenges. Since unit processes are represented by more or less complex functions which consider the properties of the inputs as well as a number of parameters, the approach is generally more computationally intensive than the usage of processes with a fixed ratio between inputs and outputs. This limits the number of parameters that can be varied at a time, and will also set limitations to the analysis of complex systems. Another challenge is that because the relation between inputs and outputs is not known a priori our approach only allows for calculations downstream the process chain. This means, for instance, that the amount of feedstock needed to produce one kWh of electricity in a biogas plant is not known before the function is executed with the specific input. This makes the consideration of upstream processes a challenging. Approaches such as establishing the process network without quantities once before calculating it again with quantities will probably be needed.

Future model development will focus on expanding the model to include more processes, including processes all along the food supply chain, as well as biomaterial and bioenergy production. To better represent temporal and spatial differences in yields, we have started to include statistical yield data from official sources. However, to better represent effects of edaphic and climatic conditions as well as of management it is planned to establish an interlinkage to a statistical of process-based crop model. And while the model is currently focused on emissions of greenhouse gases and ammonia, it is also planned to include more environmental and economic, context-dependent indicators in the near future.

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Topic 11: Regionalization and Urbanization

Abstract code: 204

Sustainability Assessment of Collaborative Rice Farming: Experience from a case in the North Eastern Thailand

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Abstract

Problem and Aim

Rice is the most important food crop of Thailand. It is a staple food and a raw material for a variety of rice-based products such as flour, noodles and snacks. More importantly, rice is the most exported agri-food product of the country (Ministry of Commerce 2019). Thailand produces a large amount of rice yearly for both domestic use and export purposes. Collaborative farming is one of Thailand's new agricultural policies established in 2016 to facilitate collaboration among small scale farmers to achieve the goals together, i.e. to increase yields, to meet the needs of the market, to lower production cost, and to increase the farmers' bargaining power (Thailand Ministry of Agriculture and Cooperatives 2016). The idea is to shift from traditional agriculture to modern agriculture which means more mechanized farming. This collaborative farming is thought to help move towards sustainable agriculture, which is being emphasized within Thailand's sustainable development goals. This contribution presents the changes in sustainability performance of rice farming before and after implementing the collaborative farming approach, considering a life cycle perspective.

Methods

Life Cycle Assessment and Social Life Cycle Assessment were used to assess the sustainability performances of the collaborative and conventional rice farming. Data were collected from Ubon Ratchathani province of Thailand, which has the largest rice plantation area in the country. The reference unit was 1 hectare of plantation area. System boundary of this study was cradle to mill gate. Stakeholders included in the study were farm owners, workers, machine contractors, locals and suppliers. Sustainability indicators examined included GHG, incomes for different stakeholders, market security, health and safety, social responsibility, assistance with loan and technology development.

Results and Discussion

Normalized results of sustainability indicators examined for the conventional and collaborative rice farming are presented in Fig. 1.
From an environmental perspective, the collaborative farming may result in a slight increase of GHG due to more mechanization. This is caused by the production and the use of fossil fuels in farming machines. From an economic point of view, the farm owners benefit from the collaborative farming approach more than other stakeholder groups. They earn more income as they could reduce production cost. In addition, they have more access to loans and knowledge. Moreover, they have

more market security as there is an agreement between the group of farmers and the rice mills to purchase their products at the agreed prices. In collaborative farming, the farm workers earn a little less than before due to the change from manual to mechanized farming while the machine contractors make more income. The collaborative farming may have more benefit for large scale suppliers than the small scale suppliers as the policy promotes bulk purchase of fertilizers/agro-chemicals. For the social aspect, at the site studied, bio-fertilizer use was promoted to help reduce the production cost which also benefits social responsibility aspect. The change in agricultural practices from manual-based to more mechanized-based does not seem to significantly affect the health and safety of locals as there is no report about this issue from the locals interviewed.

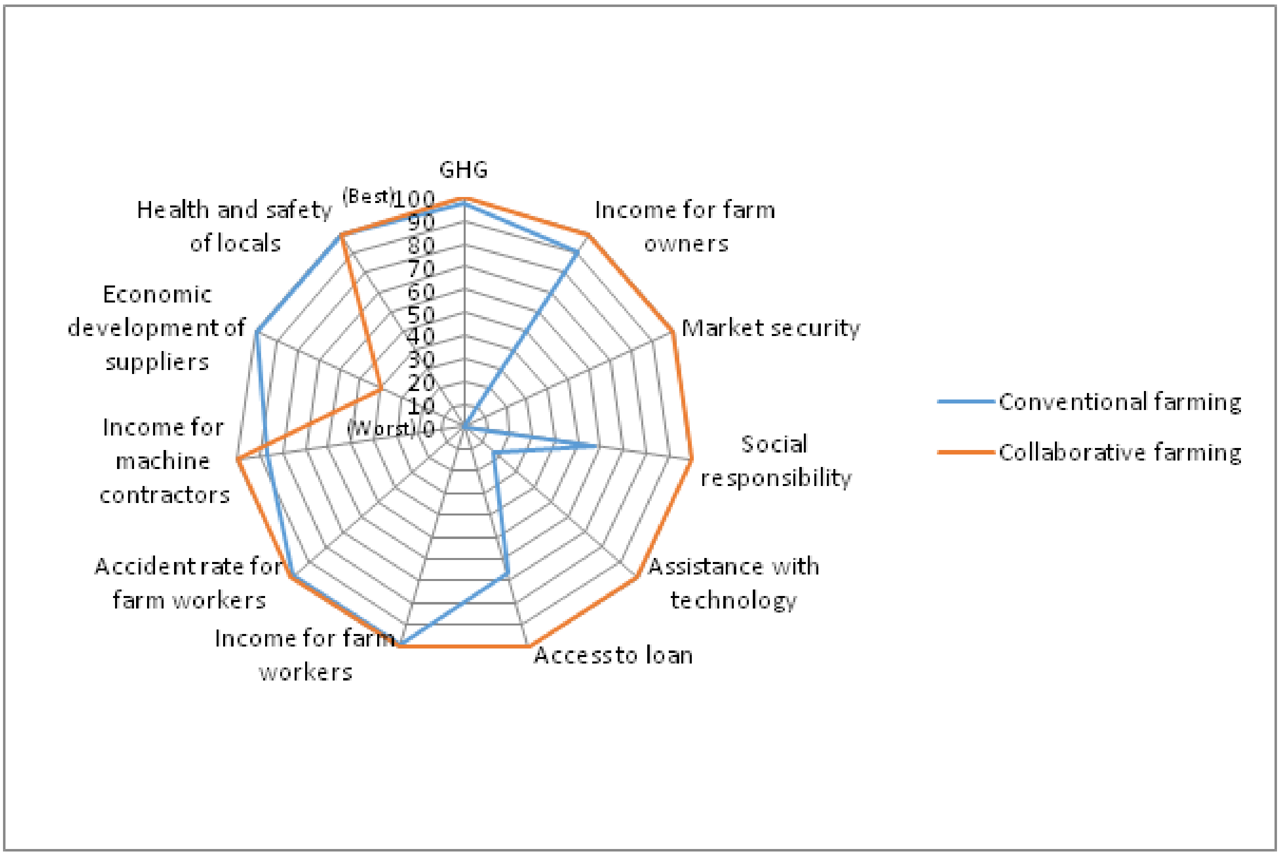

Fig. 1 Comparison of sustainability performance of conventional and collaborative rice farming
Note: Maximum value is normalized into a scale of 100 for each indicator.

Preliminary findings from this study indicate that regardless of system type, large energy requirements in cold regions contribute to reduced profitability and increased environment degradation due to Nova Scotia's reliance on fossil-based energy. It is expected that other system inputs, including fish feed and water, will also impact environmental and economic sustainability. This is comparable to other studies that found that lighting and heating requirements were large and unsustainably costly in cold regions[3]. Overall, it is apparent that optimization of inputs and operational parameters, especially fish feed, lighting and heating, requires additional research, especially in cold regions. Results from this study will provide much needed clarity on the sustainability of aquaponics applications in Canada and in cold climates in general. In optimizing aquaponics, potential for responsibly increasing fish and vegetable production can be developed in the future.

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Abstract code: 12

Lower GHG emission dietary patterns: what is the role of dairy foods?

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Abstract

Purpose Changes to dietary patterns represent one way of reducing greenhouse gas (GHG) emissions. However, in this regard there is conflicting advice about an appropriate level of dairy food intake. In this study, Australian diets with lower GHG emissions and higher diet quality were evaluated. Our purpose was to assess the prevalence of dairy food intake and any relationship between level of dairy food intake and the adequate intake of a broad range of nutrients.

Methods Dietary intake data for Australian adults were obtained from the Australian Health Survey. A subset of 1732 daily diets was identified having 43% lower GHG emissions and 37% higher diet quality score based on compliance with the food group-based Australian dietary guidelines. For each daily diet the intake of dairy foods (milk, cheese, yogurt) and non-dairy alternatives were assessed. Nutrient profiling was also undertaken for 42 macro- and micronutrients in relation to Nutrient Reference Values published jointly by the Australian and New Zealand governments.

Results and discussion Intake of dairy foods was very common among this subgroup of lower GHG emission daily diets as 90% included milk, cheese or yogurt. On average, these diets included 1.53 serves of dairy foods (each serve equivalent to 250 ml of milk). Intake of non-dairy alternatives was much lower at 0.04 serves. Daily diets in the top tertile of dairy food intake were more likely to achieve the recommended intake of a broad range of nutrients, including calcium, protein, riboflavin, vitamin B12, folate, phosphorous, magnesium, iodine and potassium. This subset of diets included 90 diets associated with dairy avoiders. It was found that dairy avoiders rarely consumed enough dairy alternatives to make up for the avoided dairy foods. As such, the likelihood of achieving the recommended intake of a broad range of nutrients was lower.

Conclusions There is a lot of advice going around about lower GHG emission diets. The problem is that many lower GHG emission diets are linked to poor nutritional and health indicators. In the Australia context, lower GHG emission diets have better nutrient profiles when they include dairy foods at levels recommended by the Australian dietary guidelines.

Keywords: *Dietary guidelines; greenhouse gas emissions; micronutrients; protein; public health nutrition; sustainable healthy diet*

Introduction

Australian adults consume around 1¾ serves of dairy foods like milk, cheese and yogurt each day, with each serve being equivalent to 250 ml of milk. This is less than the minimum 2½ serves of dairy foods (or non-dairy alternatives) recommended for those in the 19 to 50-year age bracket by the Australian Dietary Guidelines (NHMRC 2013). Recommendations are higher for teenagers, at 3½ serves, and go as high as 4 serves per day for women above 70. As such, based on official dietary guidance, there is encouragement to increase dairy food intake as milk, cheese and yogurt are an important source of nutrients that tend to be under-consumed across the population. However, a range of studies focusing on sustainability have also appeared that suggest dairy foods should be either avoided, reduced or kept to only one serve per day (e.g. Willett et al. 2019; Behrens et al. 2017; Westhoek et al. 2014; Wilson et al. 2013). Since this represents conflicting advice about dairy foods, there is need for a greater understanding of the role of dairy foods within the context of a healthy and sustainable dietary pattern. In this study, Australian diets with lower GHG emissions and higher diet quality were evaluated. Our purpose was to assess the prevalence of dairy food intake and any relationship between level of dairy food intake and the adequate intake of a broad range of nutrients.

Material and methods

Dietary intake data, collected using a 24-h recall process, were obtained from the Australian Health Survey (ABS 2014). In summary, a subset of 1732 daily diets was identified having 43% lower GHG emissions and 37% higher diet quality score compared to the average Australian adult diet ($P<0.05$). Dietary GHG emission data were obtained from a previous study (Hendrie et al. 2016). The diet quality scores were based on compliance with the food group-based Australian dietary guidelines (NHMRC 2013). For each daily diet the intake of dairy foods (milk, cheese, yogurt) and non-dairy alternatives were assessed. Nutrient profiling was also undertaken for 42 macro- and micronutrients in relation to Nutrient Reference Values published jointly by the Australian and New Zealand governments (NHMRC 2019). A complete description of the methods and data is found in Ridoutt et al. (2020).

Results and discussion

Can a lower GHG emission diet include dairy?

Intake of dairy foods was very common among this subgroup of lower GHG emission daily diets as 90% included milk, cheese or yogurt. On average, these daily diets included 1.53 serves of dairy foods. This is not surprising considering the long cultural tradition of dairy food consumption in Australia. Intake of non-dairy alternatives was found to be much lower, averaging 0.04 serves.

Is the recommended intake of dairy necessary?

The recommended intake of dairy foods (and non-dairy alternatives) described in the Australian Dietary Guidelines (NHMRC 2013) may appear high. However, more than 300 of the daily diets in our lower GHG emission subset achieved this level. Additionally, these diets had the greatest likelihood of achieving the Recommended Dietary Intake (RDI) of a broad range of nutrients (NHMRC 2019). For example, 94% of these diets met the RDI for calcium, 97% met the RDI for protein and a similar percentage met the RDI for vitamin B12 (Table 1). In contrast lower GHG emission diets having only low levels of dairy food intake had much lower likelihood of achieving recommended nutrient intakes. For example, only 5% met the RDI for calcium (Table 1). Results for other nutrients are presented elsewhere (Ridoutt et al. 2020).

Are dairy avoiders achieving recommended nutrient intakes?

The subset of lower GHG emission daily diets also included 90 that were associated with persons who self-identified as "dairy avoiders". On average, these diets included around 0.9 serves of dairy foods and 0.2 serves of non-dairy alternatives. It is important to recognize that in Australia some people strictly avoid dairy foods due to a diagnosed intolerance. However, many "dairy avoiders" are motivated by media or friends to minimize dairy food intake based on perceptions that these foods are unhealthy or fattening (Yantcheva et al. 2015). It was found that "dairy avoiders" rarely consumed enough alternatives to make up for the avoided dairy foods, with only 7.7% meeting the recommendations of the Australian Dietary Guidelines for this food group. Unsurprisingly, the likelihood of achieving the RDI of a broad range of nutrients was also lower (Table 1). If adequately fortified, dairy alternatives can provide an alternative source of dietary calcium. However, dairy alternatives do not generally provide an equivalent profile of nutrients to dairy foods. Our results suggest there may be a need for greater awareness about this.

Table 1 Lower GHG emission daily diets meeting nutrient reference values (%)[a]

Nutrient	Meeting recommended intake[b]	Low dairy intake tertile	Dairy avoiders[c]
Calcium	94.4	5.4	22.2
Protein	97.1	71.6	74.3
Vitamin B12	97.3	46.9	61.3

[a] Results for additional nutrients are presented in Ridoutt et al. (2020). [b] Daily diets meeting the number of serves of dairy foods (and alternatives) described in the Australian Dietary Guidelines (NHMRC 2013). [c] Daily diets associated with individuals who self-identified as "dairy avoiders".

Conclusions

There is a lot of advice going around about lower GHG emissions diets. The problem is that many lower GHG emission diets are linked to poor nutritional and health indicators, higher levels of sugar intake and gaps in micronutrient adequacy (e.g. Payne et al. 2016). In the Australian context, lower GHG emission diets have better nutrient profiles when they include dairy foods at the levels recommended by the Australian Dietary Guidelines.

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***Abstract code:** 171*

Spatially prospective life cycle assessment to cope with scenario uncertainty in inventories: An approach to sustainable procurement of agricultural products

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Abstract

Purpose This study proposes spatially prospective life cycle assessment to cope with scenario uncertainty and applies it to a case study on land-use change in oil palm production to demonstrate the effectiveness and usefulness of the new approach. The scenario uncertainty in this case is classified as epistemic uncertainty, which is pervasive in life cycle inventory data.
Methods Decision situations were first formulated for the spatially prospective approach as the situation that an LCA analyst (as a decision maker) has several options for alternative procurement processes (transformation inventories) under scenario uncertainty in spatial dimensions. A case study on land-use change in oil palm production in South Sumatra was conducted to analyze the decision situations; life cycle greenhouse gas (GHG) emissions from the Dawas Plantation were assessed using the survey data and ecoinvent 3. Five land-use change scenarios into perennial cropland were considered and five scenarios for aggregation processes were assumed, two of which are scenarios under complete ignorance and three are those where the LCA analyst has partial knowledge.
Results and discussion The choice of assumptions had a huge influence on the estimated GHG emissions from the oil palm production. In the case of complete ignorance, there was a wide range in the estimated interval. When the LCA analyst had partial knowledge of the situation, the estimated value of GHG emissions were gradually reduced; as more knowledge was acquired, the estimated value gradually decreased.
Conclusions This study demonstrates that the choice of land-use scenario assumptions had a tremendous influence on the estimated GHG emissions from the oil palm production; this implies that explicit analysis of scenario uncertainty is important for establishing sustainable procurement using LCA.

***Keywords:** prospective LCA, spatial dimension, epistemic uncertainty, market process, land-use change*

Introduction

Sustainable procurement is the purchasing practice that considers all aspects of sustainability, including conservation of tropical rainforests and labor ethics in developing countries. The international standard for which was published in 2007 (ISO20400). Similar terminologies such as green procurement are also used in practice. Labeling schemes and sustainability standards are indispensable for these procurement practices, with life cycle assessment (LCA) playing an important role in its implementation.

However, scenario uncertainty, which is a special type of uncertainty emanating from knowledge imperfections and is classified as epistemic uncertainty in contrast to aleatory uncertainty (Hora 1996), needs to be considered in order for LCA to be implemented in sustainable procurement. This is because scenario uncertainty in LCA of agricultural production systems is pervasive. First, procurement scenarios for agricultural products including spatial information, including agricultural land suitability and details of site-specific agricultural practices, are not completely specified in published life cycle inventory data for agricultural production processes, as inventory data are in general specified at country levels and detailed information is not provided. Second, the origin of agricultural inputs is not necessarily known and details regarding production processes are sometimes confidential. These circumstances inevitably cause inconsistencies in scenario definitions between foreground and background processes or make scenario definitions imperfect (Hayashi 2019). This also implies that the decision maker (analyst) faces difficulties in selecting deterministic scenarios.

This study proposes spatially prospective LCA to cope with scenario uncertainty in life cycle inventory data and applies it to a case study on land-use change in oil palm production to demonstrate the effectiveness and usefulness of the approach. While prospective LCA has been applied to the assessment of emerging technologies, the proposed method is different in that it focuses on spatial dimensions in uncertainties rather than temporal dynamics.

Material and methods

The decision situation for the spatially prospective approach assumes that an LCA analyst (a decision maker) has several options for alternative procurement processes (transformation inventories) under scenario uncertainty in spatial dimensions. The approach can be considered a spatial extension of prospective LCA (Arvidsson et al. 2014), future-oriented LCA (Olsen et al. 2018), and anticipatory LCA (Wender et al. 2014). The analyst has difficulty choosing an option because either the origin of the materials is unknown or the details of production have been concealed by producers. In this case, if the LCA analyst uses proxy or representative inventory data, the problem of foreground–background inconsistency ensues. The inconsistency can be represented using concept mapping, where it can be expressed verbally. If the LCA analyst uses averaged inventory data (such as market processes in ecoinvent 3), the modeling problem under scenario indeterminacy emerges, which can be depicted by network flow diagrams (Figure 1).

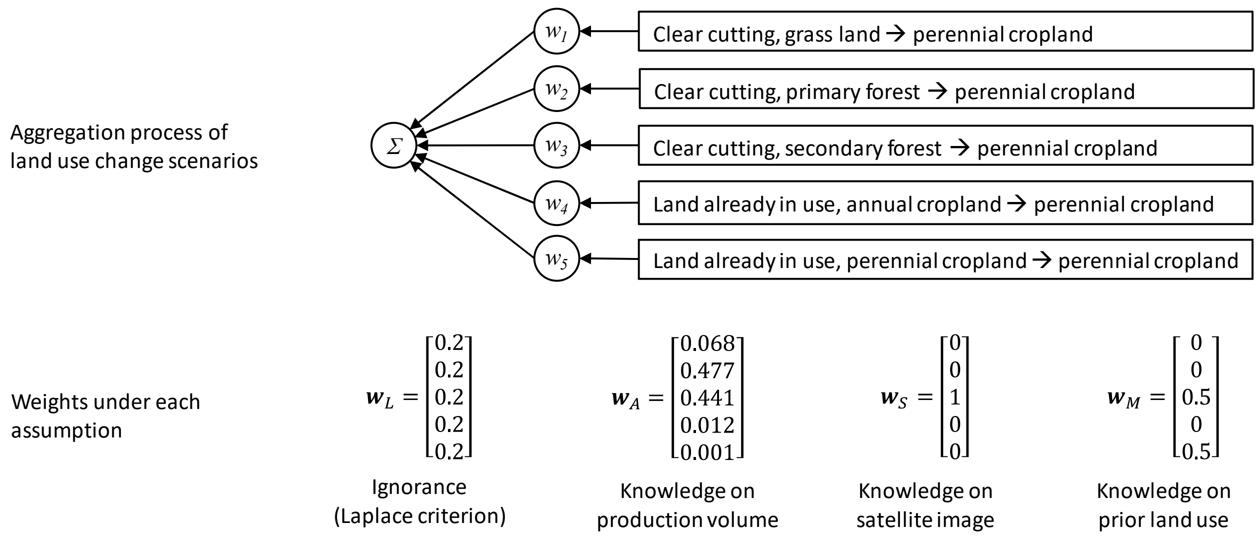

Figure 1 Aggregation process of land-use change scenarios and weights under each assumption

To demonstrate the effectiveness and usefulness of the approach, a case study on land-use changes in oil palm production in South Sumatra was conducted using the survey data and ecoinvent 3. Life cycle greenhouse gas (GHG) emissions from the Dawas Plantation (Hayashi et al. 2020), which is managed by the Indonesian Oil Palm Research Institute (IOPRI), were assessed.

Five land-use change scenarios into perennial cropland, available from ecoinvent 3, were considered. Five scenarios for aggregation processes were then assumed, two scenarios of complete ignorance and three scenarios representative of cases where the LCA analyst has partial knowledge. The first scenario is based on the Laplace criterion ($\boldsymbol{w}_L$), which is a decision rule under the scenario of complete ignorance. The second is based on an estimation of interval values [minimum, maximum], which is also considered a decision under complete ignorance. The third scenario corresponds to the situation where the LCA analyst surveyed production volumes on the country scale and used these values for calculating the weighted average ($\boldsymbol{w}_A$), which is equivalent to the calculation in market processes on ecoinvent 3. In the fourth scenario, the LCA analyst estimated prior land use through checking surrounding forest on a satellite image to conclude that it was secondary forest ($\boldsymbol{w}_S$). In the fifth, the LCA analyst conducted a field survey (or interviews) on prior land use and obtained the information that it was a mix of rubber and secondary forest ($\boldsymbol{w}_M$).

Scenarios uncertainty other than that caused by land-use change (five aggregation scenarios) was not considered in this study because there are no differences among the five aggregation scenarios. The data on production volumes of fresh fruit bunches, fertilizer and pesticide application, and fuel consumption were gathered from the plantation. The seedling production process was also prepared because the plantation has a nursery. Background process inventories in ecoinvent 3 were used in the assessment to get a rough estimate when scenario uncertainty was not considered. In other words, the global dataset was used, although it uses averaging processes. The system model "allocation at the point of substitution" was used.

Results

The choice of assumptions had a tremendous influence on the estimated GHG emissions from the oil palm production (Figure 2). In the case of complete ignorance (interval estimation), there was a wide range in the estimated interval; it ranged from –0.70 to 1.89 kg CO_2 eq./kg fresh fruit bunches (FFB). The value for the Laplace criterion ($\boldsymbol{w}_L$) was smaller than the midpoint value of the interval.

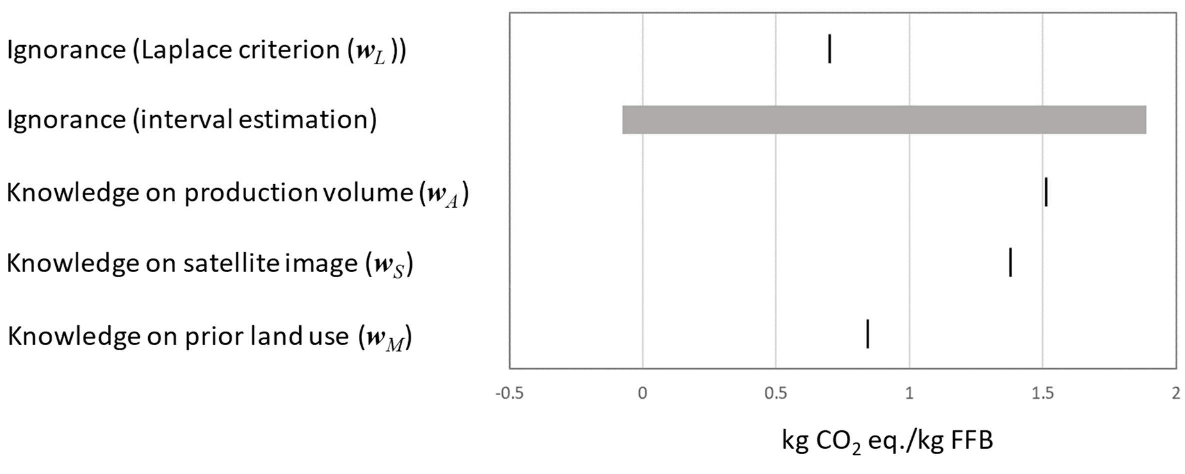

Figure 2 Estimated greenhouse gas emissions for each assumption

When the LCA analyst had partial knowledge of the situation, the value of the estimated GHG emissions gradually reduced; the estimated value of emissions when the analyst had knowledge on production volume ($\boldsymbol{w}_A$) reduced further with knowledge on satellite image ($\boldsymbol{w}_S$), while with knowledge on prior land-use ($\boldsymbol{w}_M$), the value was minimum. Thus, knowledge acquisition reduced the estimated GHG emission value with a substantial difference between the estimation based on $\boldsymbol{w}_A$ and $\boldsymbol{w}_M$ (1.51 and 0.84 kg CO_2 eq./kg FFB, respectively).

The reason for the huge differences is that the percentage of land-use change is dominant; for example, it is 85% in the case of $\boldsymbol{w}_M$. If the emissions from land-use change are excluded, the values of emissions are from fertilizers (45%), seedlings (31%), and direct emissions from the field (19%).

Discussion

Since the scenario where the analyst has knowledge on production volume ($\boldsymbol{w}_A$) is equivalent to the market process modeling in ecoinvent 3, the existence of the huge difference between the estimation based on $\boldsymbol{w}_A$ and that on $\boldsymbol{w}_M$ implies that there is a possibility of diverting from the reality in the current market process modeling in ecoinvent 3. Therefore, the LCA analyst (as the user of the database) should be explicit about the influence of assumptions (knowledge levels of the LCA analyst) on the calculated values for environmental impacts. In other words, the LCA analyst should be explicit about their decisions (choices of weights) that affect huge impacts on the consequences under scenario uncertainty; otherwise, the unreflected decisions may cause unintended consequences which are not consistent with the reality.

Therefore, explicit modeling of scenario uncertainty is imperative in the practice of LCA aiming at sustainable procurement. It is especially applicable to the case of land-use change because scenario uncertainty related to land-use change is far beyond that related to, for example, fertilizer production (Hayashi 2019). Spatially prospective LCA—a decision analytic approach to cope with scenario uncertainty—is potentially an effective tool for establishing sustainable procurement.

As a continuation to this study, the following two research directions appear promising. One is scenario construction in life cycle inventories using micro-statistics. Because of the recent increase in the availability of farm household data, the preparation of inventory data for the micro-level production activities can become possible. It implies that there is a possibility of conducting uncertainly analysis based on distributions of real-world data, without using the pedigree matrix. The other is a theoretical study on scenario construction and selection in the situation where enumerating all possible scenarios is difficult. In this case, the formulation of learning processes for the LCA analyst and the formal definition of information updates can be useful.

Conclusions

This study demonstrates that the choice of land-use scenario assumptions had tremendous influence on the estimated GHG emissions from oil palm production. It concludes that explicit analysis of scenario uncertainty is important for establishing sustainable procurement using LCA. Since scenario uncertainty is inevitably included in databases such as ecoinvent and it is a type of knowledge-based uncertainty, the spatially prospective approach is useful for refining data and decisions through learning, although the use of the term "market" for the calculation process of a weighted average needs to be reconsidered.

Acknowledgements

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Reducing the environmental impact of the Norwegian protein consumption: the effects of switching from the current diet to a plant-based diet

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Abstract

Purpose
The main purpose of the study was to study the environmental impact of 4 plant protein products (faba beans, field peas, oats and rapeseed press-cake) that can be grown in Norway and compare with the impact of the current average protein food consumption in Norway.

Methods
Environmental LCA was used to analyze the 19 currently most consumed protein food sources in Norway and 4 plant protein sources. LCIA methods from CML, ReCiPe and UseTox were used to cover a wide range of impacts on the environment, resource use and health impacts. The studied system was from cradle to after primary processing.

Results and discussion
The average environmental impact of the studied plant protein products was much lower than the average protein consumed in Norway. The ratio of impact varied from 6 to 32 times pr kg protein for the different indicators. This shows that by shifting the diet towards more plant protein can give a large impact on the environment and health, and not only for the climate. The results also indicate that such a shift would not cause a reduction in nutritional content of the diet. Limitations of the study is that the effect of protein quality, antinutrients and pre-crop effects could not be included.

Conclusions
Plant protein products grown in Norway has a significantly lower environmental and health impact than the current protein consumption which is dominated by protein of animal origin (75 %), A shift towards more plant protein would improve environmental sustainability and consumers health, while probably not decreasing the overall nutritional content of the diet.

Keywords: *average diet; Norway; plant protein; animal protein; comparison; LCA*

Introduction
In Norway, the major part (75 %) of the protein consumed originates from animals e.g. beef and poultry or from seafood e.g. salmon and cod. Currently, there is a trend towards reduced intake of animal protein in the Norwegian population in favor of plant protein due to environmental, health and animal welfare concerns.
Several studies conclude (Aleksandrowicz 2016) that plant-rich diets have much lower environmental impact than diets with more animal protein. On a product level, a few studies have included comparisons between "traditional" protein sources such as meat on one hand and beans and other plant proteins on the other Most of these studies have concentrated on only a few impact categories or only one, most often climate impact. Another trend has been to exclude the geographical context. A central question is: If consumption of protein from one source is reduced, what domestic protein

source can take its place?
Thus, there seem to be a research gap concerning comparison of plant protein products with not only a few selected animal protein products, but with the average protein consumption within a defined geographical area and including an extensive range of environmental impacts,
:
The main aim of the study was to compare the environmental impact of a shift from the current consumption of protein foods in Norway to a more plant-based diet with products made from plant protein that can be produced domestically. A simple mass-based unit is often used as functional unit in LCA studies, which means that the function of foods is not directly taken into account. The main function of food and beverages is to provide nutrition, thus using nutrient metrics as functional unit could partly solve this problem. Nutrient indices or units focusing on or more important nutrients, e.g. protein, are possible candidates for nutrient metrics.

Material and methods
The consumption of protein foods was determined based on data from one large food consumption study from Norway (Norkost 3). LCA was made on 19 of the most consumed protein sources (Svanes 2019). The impact of the current consumption of protein foods was calculated as a weighted average of these 19 protein sources.
LCA was also performed on 4 different plant protein sources that have been determined to be the ones most favorable to produce in Norway, with the exception of wheat: faba beans, peas, rapeseed press cake and oats These plant proteins were also seen as favorable to include in the crop rotation for soil quality and fertility. The plant protein impact was calculated as a geometrical average of these four protein sources.
The system boundary included all processes from cradle to gate. "Gate" signifies that primary processing is done, but not secondary processing into products. Primary processing is defined as drying for cereals and pulses and for meat defined as slaughtering and cutting. Packing and further processing are thus not included in the system boundary.

The functional unit was set to:
1 kg product and 1 kg of protein. Also, the nutrient density indicator NRF9.3mass is used as functional unit.

The NRF 9.3mass is based on the NRF9.3 (nutrient rich food) nutrient density indicator developed by Drewnowsky (2010), but instead of using nutritional content in 100 kcal product, 100 g product was the basis used.
The main LCIA method chosen was CML with the following impact categories: global warming potential, acidification potential, eutrophication potential, abiotic depletion potential, elements and abiotic depletion potential, fossil resources and cumulative energy demand. For cumulative energy demand, Cumulative Energy Demand V1.10 by Ecoinvent was used.
The following impact assessment methods from ReCiPe (2016 Midpoint (H), version 1.02) were used: Fine particulate matter formation, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Land use, Mineral resource scarcity, Fossil resource scarcity and Water consumption.
These categories from UseTox (USEtox 2 (recommended + interim) V1.00) were included to further focus on human health and ecotoxicity: Human toxicity, cancer; Human toxicity, non-cancer; freshwater ecotoxicity.

Results
The results show that the plant proteins have, on average, a much lower environmental impact

than the existing protein consumption for all impact categories studied. The climate impact is approximately 10 times higher (see figure 1), and for other important impacts the difference is substantial, e.g. eutrophication (14 times), acidification (17 times), Abiotic depletion potential, fossil (6 times) and Cumulative energy demand (32 times). The difference is the smallest for area use for annual crops, where the existing protein consumption is only double that of average plant protein. However, when including areas for grass production, pastures and leys, the area use for existing protein consumption is almost 4 times higher than for plant protein. On average the (non-weighted) impact is 13 times higher for existing protein consumption for all impacts studied.

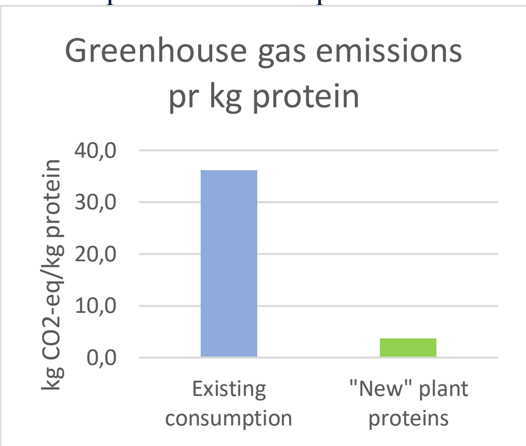

Figure 1. The climate impact of existing protein consumption vs plant protein, pr kg protein.

In figure 2, the nutrient density indicator NRF9.3mass is used as functional unit. The carbon footprint of average plant protein divided by NRF9.3mass is compared with the corresponding result for average protein consumption in Norway. The ratio between the average protein consumption and plant protein is 21, whereas the ratio when comparing results pr kg is 5 and when comparing pr kg protein is 9.
This shows that the higher impact pr kg average protein vs plant protein is not compensated by a higher nutritional content of average protein. In fact, the results indicate that the opposite might be true.

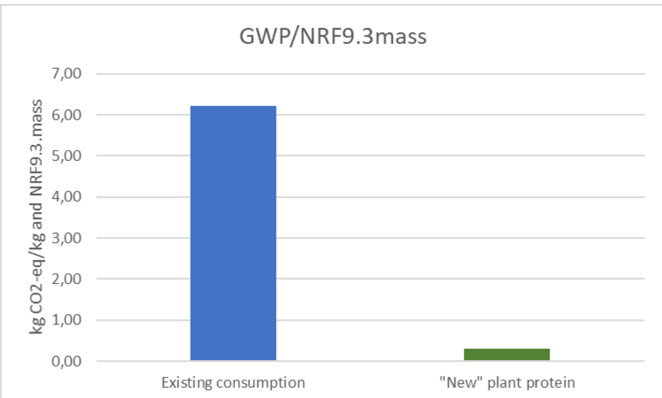

Figure 2. The climate impact of existing protein consumption vs plant protein divided by nutrient density indicator NRF9.3mass.

Discussion

The results of this study for protein consumed in Norway today and for 100 % plant protein average, confirm results from previous studies that the environmental impact of plant protein is lower than that of a diet dominated by animal protein. The novelty of this study is that it shows that not only the

climate impact is higher for animal protein, but also all other impact categories studied. Another novelty is that all products are studied with the same methodology and for Norwegian conditions. A complete transition from animal protein to plant-protein based on Norwegian-grown produce is not possible and would also conflict with other sustainability indicators, but a partial shift is possible, and this would be beneficial for both health and the environment.
Other studies have shown that some of the benefit of plant protein can be lost in the processing step. This can be caused by several effects. The processing in itself can demand a lot of energy (Huesala et al (2020)) and it can produce high amounts of low-value by-products (ibid). The latter effect will be visible in the result of the main product (e.g. a pea protein concentrate) only when using certain methodological choices, e.g. economic allocation, but it is generally poor resource utilization no matter what LCA methodology is used.

Some of the plant protein contain anti-nutrients which can make it difficult to use these products as raw materials for food products. This is an aspect of the function of these products and should ideally be considered in the functional unit in LCA. Because the methodology for doing so has not been developed and because processing can partially eliminate these compounds, the content of antinutritional compounds has not been taken into account in this study.

This study has not included pre-crop effects. When growing either rapeseed, field peas and faba beans, the following year an increase in the yield of cereals and often in protein quality is achieved. Some studies show other effects such as reduced pest pressure and reduced fertilizer use in not just the following year, but also for subsequent years. As pre-crop effects occur outside of the temporal boundary, they cannot be considered in the current methodology. The pre-crop effect is caused by nitrogen compounds left in the soil but also mobilization of P in soil, improved soil structure and the fact that pests that afflict certain crops have far less impact because the large time gap between each time a certain crop is grown in a particular field. This makes it difficult to device an appropriate methodology for the inclusion of the pre-crop effect in LCA methodology.
Further research is needed to consider the protein quality where the total diet is studied, as lack of certain amino acids in one food product can be compensated by adding other foods that supplies the "missing" amino acids. However, the results of using the NRF 9.3 index indicated that the plant-based diet did not result in a diet that is less nutritious than the average protein diet. A further indication that plant protein is not nutritionally inferior to animal protein can be seen from the results of a comparison of the content of 21 nutrients between meat (average of lamb, beef, pork and chicken) with plant protein (the four mentioned protein sources). Plant protein products had higher amount of 14 nutrients, meat of 7 nutrients.

Conclusions

The study clearly demonstrates that plant protein grown in Norway has a much lower impact than the average protein consumed in Norway. The difference is not reduced, but rather increased when taking nutrient content into consideration.
The study did not consider protein quality or the content of antinutrients. The reason is that this can be modified by processing and mixing with other foods. It is likely that bringing these factors into the equation will favor animal protein vs plant protein.
Another factor that was not included in the calculations was pre-crop effects. The reason was limitations in methodology. Taking pre-crop effects into account would further decrease the environmental impact for plant protein and make it more favorable vs animal protein.

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Abstract code: 36

Life Cycle Assessment of Vertical Farming: Application for Basil Production in Colruyt Group Prototype Farm

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Abstract

Purpose: Around 10% of European greenhouse gas emissions come from agriculture (European Environment Agency). Vertical farms are promoted as an option and complement to conventional agriculture. Vertical farming has benefits and inconveniences compared to other cultivation methods. It is essential to go beyond the assessment of global warming potential when dealing with vertical farms. One of the reasons for this study is to evaluate the potential impact of upscaling vertical farming, by studying current technologies and by comparing them with possible large-scale production.

Methods: This study assesses the environmental impact of basil using a Life Cycle Assessment (LCA) method. The project started from a proof-of-concept (PoC) and evolved to a prototype farm. A basil product from the prototype farm is the subject of this study. LCA functions as a guide for the eco-design process for technical, conceptual, configurational and operational aspects of cultivation systems. LCA is a versatile and consolidated way to analyse and quantify the potential impacts of a product. It helps to identify and communicate environmental, social and economic hotspots. It is used inside organisations for decision-making or in the design phase. The validity of results and accuracy and reliability of conclusions lay directly on data quality and relevance of assumptions.

Results and discussion: The most relevant life cycle stages from highest to lowest contribution to the single score result are: final consumption, packaging and its end-of-life, selling point, building, energy consumption for heating, cooling, ventilation and water distribution, led-materials and electricity for lighting, losses at production, equipment & machines for production, substrate and its end-of-life, nutrition and co_2 consumption, distribution, rainwater and water collection equipment, seeds. To design the farm, Colruyt Group has developed a step-by-step eco-design approach. The approach is part of a continuous improvement process, where a list of eco-design actions is provided.

Conclusions and recommendations: The implementation of the actions identified at the PoC level in the prototype farm led to a reduction of the environmental impact with 17% from PoC to prototype farm. The additional steps identified at the prototype level could potentially reduce the single score with an extra 7% (from prototype to full farm). There are also several improvements to the prototype that cannot be quantified and not reflected in the single score results. Broadening the involvement of stakeholders (e.g. consumers) in the eco-design process will most definitely generate more environmental improvements.

Keywords: *urban farming; LCA; greenhouse; herb; eco-design; agriculture*

Introduction

To fulfil human needs considering the current population prospects (Anon n.d.) and the development of urban areas, the increase in crop production seems inevitable. In 2015, around 10 % of European greenhouse gas (GHG) emissions came from agriculture based on the European Environment Agency. In this context, advanced technologies like vertical farms are being promoted as an option and a complement, to conventional agricultural systems. Vertical farming is considered as an efficient way to reduce the need for arable land and to promote local production. When farming is indoor and in a closed environment, plants are protected from weather, insects and pests. Besides, the amount of used water is minimal in comparison with conventional farming, without leakages of nutrients.

However, vertical farming is capital intensive and requires knowledge to deploy new techniques and equipment. Besides, artificial lighting is needed to cultivate crops. Development of Light-Emitting Diodes (LED), has improved the viability of vertical farming in recent years, allowing cultivation in areas with limited hours of sunlight (Anon 2015).

Vertical farming has benefits and inconveniences compared to other cultivation methods. Vertical farms have more energy-intensive (Graamans et al. 2018) installation compared with conventionally grown vegetables and herbs. However, the yield is better (Molin & Martin 2018), and the use of resources like water, nutrients, arable land and pesticide is lower. Therefore, one may conclude that it is essential to go beyond the assessment of simple global warming potential (GWP) when dealing with vertical farms.

Currently, vertical farming is developed increasingly. Environmental impacts of products from vertical farming can be assessed using life cycle assessment (LCA) approaches. Additionally, LCA can assist or function as a guide for the eco-design process for technical, conceptual, configurational and operational aspects of cultivation systems.

LCA is a tool used by public and private decision-makers in the framework of sustainability. LCA is a versatile and consolidated way to analyse and quantify the potential impacts of a product, a service or a process. It helps to identify and communicate environmental, social and economic hotspots. It can be descriptive or change-oriented, depending on the aim of the study. It is used inside organisations for decision-making to improve competitiveness, or in the design phase. The validity of the results and accuracy and reliability of conclusions lay directly on data quality and relevance of assumptions.

Environmental (social and economic) impacts of projects from vertical farming, such as basil plants, can be addressed using LCA. This study includes the environmental assessment of basil product using the LCA method. The project started from a proof-of-concept (PoC) and evolved to a prototype farm. Basil product issued of the prototype farm is part of this study.

Methods

The goal of the study

The goal of this study is to assess the environmental impacts of the product of prototype vertical farming from Colruyt Group. One of the reasons to carry out this study is to evaluate the potential impact of upscaling vertical farming, by studying current technologies used and by comparing them with potential large-scale production, analysing different sizes and configurations of the farm. The LCA method allows key actors to plan the next steps of their eco-design strategy and to improve environmental impacts while fulfilling future production objectives. This LCA study follows the standard ISO 14040:2006 and ISO 14044:2006 and is in conformance with most of the rules of the

PEF/OEF Guidance of the European Commission (European Commission 2018).

Functional unit and reference flow

The primary function of the studied systems is to produce edible high-quality vertical farming basil pot to be commercialised. The functional unit is defined as '1 pot of high-quality edible basil packed fresh product consumable before its expiry date'. The corresponding reference flow is '27 g (equivalent wet mass with 8% of dry mass) of biomass is one pot with 65% edible mass'.

System boundaries

The system boundary was assigned as 'cradle to grave' considering all life cycle stages of the basil pot from the cultivation stage to End of Life (EoL), as illustrated in Figure 1: System boundaries for cradle to the grave assessment of basil pot.Figure 1.

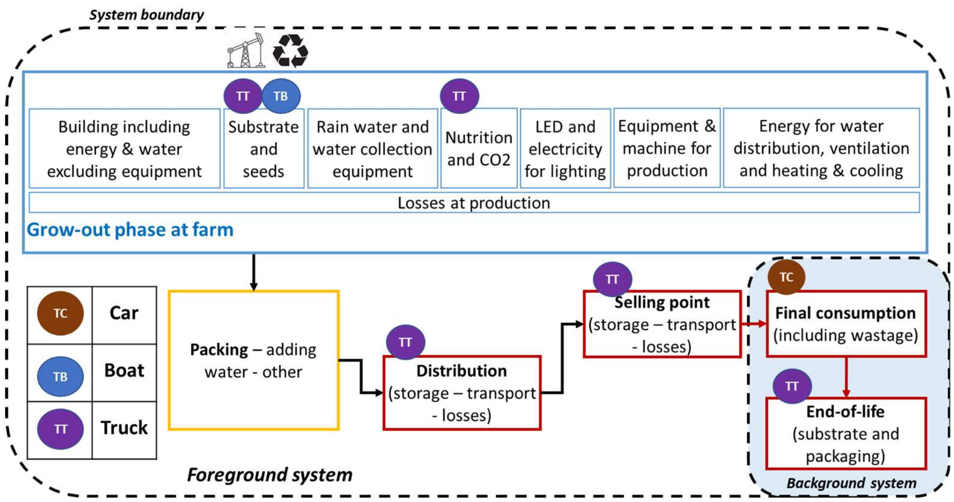

Figure 1: System boundaries for cradle to the grave assessment of basil pot.

General description of the production set-ups

The prototype farm is implemented in a distribution centre (Hellebroek) of Colruyt Group located at Halle, Belgium. The building dates from 1972 and is considered to have an extended 30 years of life for the prototype farm, resulting in an overall 77 years of life span.

Part of this distribution centre was prepared to host the vertical farming prototype. Two types of plants (basil and coriander) are cultivated on the farm. Only a part of the facility used to cultivate basil is included in this study. The cultivation area is isolated with polyisocyanurate (PIR) sandwich panels with 100mm thickness.

The current setting is composed of two layers. Each layer is formed of a gutter with systems of water, nutrition and CO_2 distribution. The facility is designed to include more layers (up to 10) in future. The plants are cultivated in a static way; this means they are not moving after the germination phase. Nutrition, water and CO_2 are provided continuously to the plants in a controlled condition. Once a complete cultivation cycle is finished, plants are packed in pot format at the same location. The EoL is directly considered together with raw materials and the transport to provide an overview of potential impacts to designers in the decision-making context. The EoL of the components also includes the required transportation.

For the modelling of the product, the software package SimaPro, version 8.5.2.0 is used. The list of recommended models at the midpoint, together with indicators, units and source is provided in the

PEFCR Guidance version 6.3 (European Commission 2018).

Results & discussion

The most relevant life cycle stages from highest to lowest contribution to the single score result are (Figure 2): Final consumption, Packaging and its End of Life, Selling point (retail), Building infrastructure, Energy consumption for heating, cooling, ventilation and water distribution (HVAC), LED-materials and electricity for lighting, Losses at production, equipment & machines for production, Substrate and its End of Life, Nutrition and CO_2 consumption, Distribution, Rainwater and water collection equipment, Seeds (minimal contribution 0.2% of normalised and weighted results).

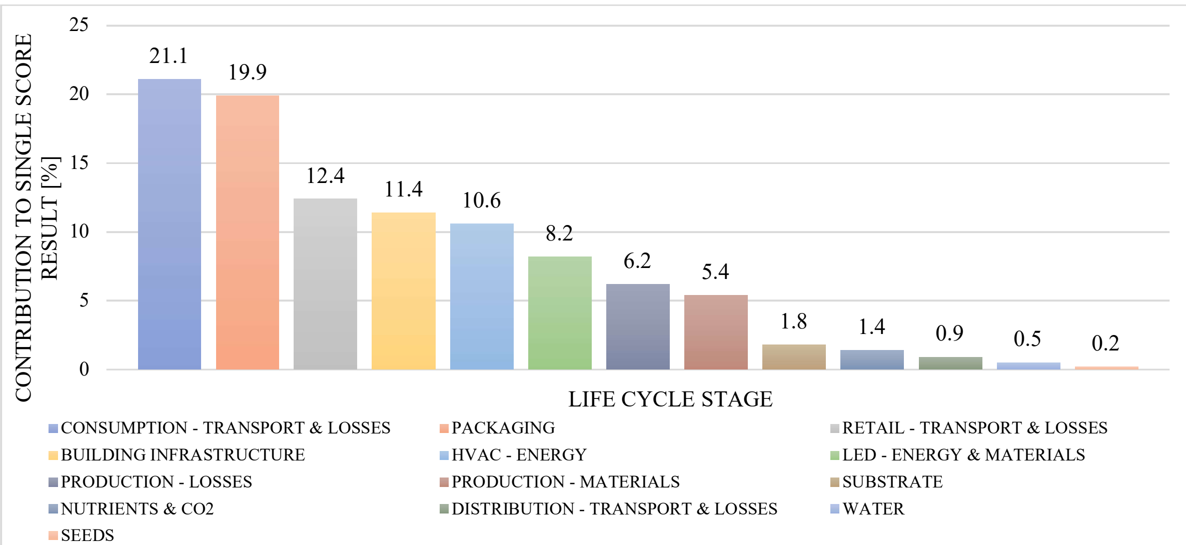

Figure 2: Contribution of the life cycle stages to the single score impact.

To design the farm, Colruyt Group has developed a step-by-step eco-design approach. The approach is part of a continuous improvement process, learning from the past and improving relevant processes for the future. Eco-design choices are made using an internal eco-design tool. The full process comprises three different phases: 1. Proof-of-Concept (PoC) – *past*, 2. Prototype Farm (the subject of the LCA study) – *present* and 3. Full Farm – *future*.

Few examples of Eco-design actions at PoC and prototype farm level are provided below:

- *Waste:* Reduce waste at different levels; reducing overproduction by managing late orders, sowing full trays and losses. Besides, work can be done on reducing waste at selling point and final consumption.
- *Building:* 1) Build sustainable infrastructure, with an extended life span [e.g. the reuse of old infrastructure]. 2) Use alternative insulation for the farm. 3) Explore other building concepts.
- *Packaging:* 1) Use a maximum of reusable and recyclable packaging. 2) Reduce the amount of materials. 3) Use alternative low impact materials.
- *CO_2:* Use CO_2 captured from industrial processes (preferably) around the production plant.
- *Production materials (gutter, etc.):* 1) Optimise and reduce the quantity of material. 2) Extend the life span of equipment and machines.
- *Energy:* Optimise to reduce heating, ventilation, cooling and lighting energy consumption.
- *Transport:* Volume-based transport, therefore reduce the volume by optimising the packaging. 2) Optimise transport and use sustainable transport solutions.
- *Substrate:* Use alternative low impact materials and reduce the substrate use.
- *LED materials:* Reduce/reuse/recycle parts in LED in second life, especially the aluminum.
- *Water:* Reduce water consumption, e.g. through prolonging the number of days the water is recirculated.

The implementation of the actions identified at the PoC level led to a reduction of the environmental impact of 17% (single score) from PoC to prototype farm. The majority of the quantifiable improvements are realised on the packaging (primary and secondary), the nutrients (incl. CO_2) and the substrate mix.

Conclusions

This study allowed Colruyt to identify the most relevant hotspots of their vertical farming under development process using LCA. Several improvements, identified based on the preliminary eco-design study, are implemented as highlighted in this article.

The additional actions identified at the (early) prototype level could potentially reduce the single score with an extra 7% (from prototype to full farm). This reduction will be achieved by minimising the losses at both the production and retail stage, further improvements of LED lighting (materials and energy use) and finally, extending the water cycle.

Some additional improvements are to foresee. As an example, Colruyt Group is convinced that the specificities of its vertical farming concept deliver a basil product with a prolonged and/or more stable shelf life before consumption. Due to missing statistics, average global figures are used to model the losses at final consumption (19% food waste at consumer for fruits and vegetables, FAO) (Gustavsson et al. 2011). The environmental results need to be updated to reflect these quality-related aspects in coming future.

Finally, broadening the involvement of stakeholders (e.g. consumers) in the eco-design process will most definitely generate even more environmental improvements to the basil farm. Involvement of stakeholders is foreseen to be explored by Colruyt Group as a next step.

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Potentials of rooftop greenhouses: Innovative aspects of the water-energy-food nexus for climate change mitigation

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Abstract

Purpose: Urban agriculture (UA) is gaining importance in the light of climate change, its impact on the urban environment and livelihood as well as pressure on land resources. This research investigates the contribution of rooftop greenhouses (RTG) as part of the UA movement to alleviate greenhouse gas emissions (GHG) when compared to conventional production by realizing potentials of the water-energy-food nexus. **Method:** As a case study serves a RTG on top of an office building, which is currently under development to be used for tomato production. The research employs a comparative LCA methodology following ISO 14 040, PAS 2050:1 and IPCC standards supported by Hortex and Umberto software, and literature. It analyses the global warming impacts of four baseline scenarios portraying the variety of North-West-European tomato production, in comparison to the RTG. **Results and discussion:** The symbiosis of RTG and support building can potentially help to abate GHG emissions from tomato production by up to 90% through using waste heat from the support building, recycling and optimizing water use and exploiting fertilization potentials of human urine. Given the importance of energy, the co-digestion of nutrient-rich waste flows of building and RTG can improve the environmental performance furthermore, contributing to an urban circular economy. The comparison to existing literature confirms this study's findings. **Conclusion and recommendations:** To determine the technical and legal feasibility of the proposed measures, applied research is needed. Additionally, potential benefits of UA and RTG other than GHG emission abatement should be analyzed in future investigations to understand their contribution to a (sustainable) urban development.

Keywords: *urban farming; rooftop greenhouse; LCA; global warming; water-energy-food nexus, circular economy.*

Introduction

Cities are facing various challenges due to climate change, population growth, urbanization and increasing resource consumption. Urban agriculture (UA) can offer multiple benefits in the face of these challenges by emphasizing on the reciprocal relationship between the resources water, energy and food following the water-energy-food (WEF) nexus (Lehmann 2018). Benefits are apart from local food production, increased food resilience and enhanced quality of life in cities also the reduction of pressure on intensively used agricultural land and reuse of resources as envisioned by circular economy models. Previous research pointed out that Rooftop Greenhouses (RTG) as an element of UA can potentially contribute to achieving these goals while reducing environmental impacts of food production (Cerón Palma 2012).

This study complements and expands existing studies on urban food production in RTG by emphasizing on a symbiosis of RTG and support building following the WEF nexus. It investigates the opportunities of RTGs in North-West-Europe (NWE) to abate Greenhouse Gas (GHG) emissions when compared to conventional tomato production on the ground using life cycle assessment (LCA). The RTG on top of an office building in Luxemburg serves as a case study to analyze the Global Warming (GW) impact and to investigate the theoretical and technical feasibility of synergy potentials between RTG and the building, on which it is constructed, following the WEF nexus. The practical application of this study is to support the decision-making of various stakeholders of the urban environment on how RTG can contribute to a circular economy and low carbon development of cities.

Material and methods

As functional units (FU) serve both, area related per 1 m^2 greenhouse base area and year, and product related per 1 kg of marketable fresh tomato. The use of multiple FUs can improve the interpretation of environmental results obtained in LCA studies (Ntinas et al. 2017). The average tomato yield is 46,9 kg/m^2*a in a heated greenhouse in NWE and the average greenhouse size for conventional production is 5.000 m^2 with a 90% productive area (Theurl 2008; Montero et al. 2011; Boulard et al. 2011; Müller-Lindenlauf et al. 2013; Dias et al. 2017; Bosona and Gebresenbet 2018). As for the RTG, it is 330 m^2 large with 90% productive area, while the yield is assumed to be the same. The expected lifetime of both is 20 years. The system boundary for tomato production is gate-to-gate for greenhouse production exclusively, and cradle-to-grave for construction of the greenhouse. Since the aim is to compare conventional greenhouses to ones on the rooftop, only impacts that are expected to be influenced by this choice are taken into account. These are construction, heating energy, water, fertilizers, Land Use Change (LUC), organic waste and the transport to the first point of sale.
A **baseline for NWE production** is needed in order to demonstrate GW abatement potentials of RTG. Previous research demonstrated the importance of energy on the GW impact of food production in temperate climate zones (Ntinas et al. 2017). Therefore, four reference scenarios are modelled, which vary according to specifications on heating energy carrier and energy efficiency:

- Best case: High energy efficiency, energy carrier 80% wood chips and 20% natural gas
- Medium plus: Medium energy efficiency, energy carrier 100% natural gas
- Medium minus: Medium energy efficiency, energy carrier 100% heating oil
- Worst case: Low energy efficiency, energy carrier 80% coal and 20% heating oil.

The **inventory data for the reference scenarios** on tomato yield, water, fertilization, organic waste and transport are retrieved from previous studies on LCA of tomato production. IPCC guidelines complemented by data from the European Commission (2010) and PAS 2050:1 provide information to calculate the GW impact from LUC. Construction material quantities are calculated or used from literature according to the Venlo greenhouse design. The heating energy is modelled using Hortex software. The total irrigation water demand is satisfied to a maximum with the available precipitation during cultivation period and the remaining water demand is covered by freshwater. Mineral fertilizers provide the plants' key nutrient demand of nitrogen, phosphorus and potassium (NPK). The organic waste of tomato production is considered for composting.
Inventory data for the RTG and WEF nexus are calculated through combining measured data from the existing support building with literature and modelled data. Waste heat from the support building's canteen and offices will cover the RTG heating demand, which is complemented by the existing heating system (60% biomass, 40% natural gas). A photovoltaic system provides solar electricity for the operation of the heating system. Construction material quantities are calculated according to the design of the RTG, using the material thickness and density of insulating glass covering the three side walls and the roof, and using literature data for the structure materials. Urine can partially satisfy the NPK demand of the tomato plants in the RTG. Potentials are calculated according to the support building's occupation and treatment process (Etter and Udert, 2016). The remaining nutrient demand is covered by mineral fertilizers. The irrigation water demand is covered by distilled water from the

urine treatment and rainwater. Organic waste is valorized according to the WEF nexus in a biogas plant in co-digestion with other nutrient rich waste streams of the support building. The canteen consumes the harvested tomatoes directly.
GHG emissions from LUC result from the change in stored carbon in biomass and soil. The **impact assessment** of other inventory processes uses GHG emission factors from different databases (ecoinvent v3.5, INIES, ProBas, GEMIS, oekobau.dat) and literature. The GHG emission factors of composting and digestion consider material and energy consumption as charges. For the digestion, the substitution of natural gas as a fossil fuel is credited, which leads to an GHG emission abatement potential of 12.6 g CO_2e/kg organic waste when compared to composting. Similarly, the use of urine for fertilization leads to a GHG emission abatement potential of 5.67 g CO_2e/l urine when considering emission credits for the abatement of emissions at the wastewater treatment plant and the substitution of mineral fertilizers and freshwater while using solar energy to operate the urine treatment plant.

Results
The results of the GW impact assessment of the reference scenarios in NWE and the RTG are visible in Figure 1. Overall, the RTG can serve to abate 26% of GHG emissions when compared to the best case, and 90% of GHG emissions when compared to the worst case of conventional production.

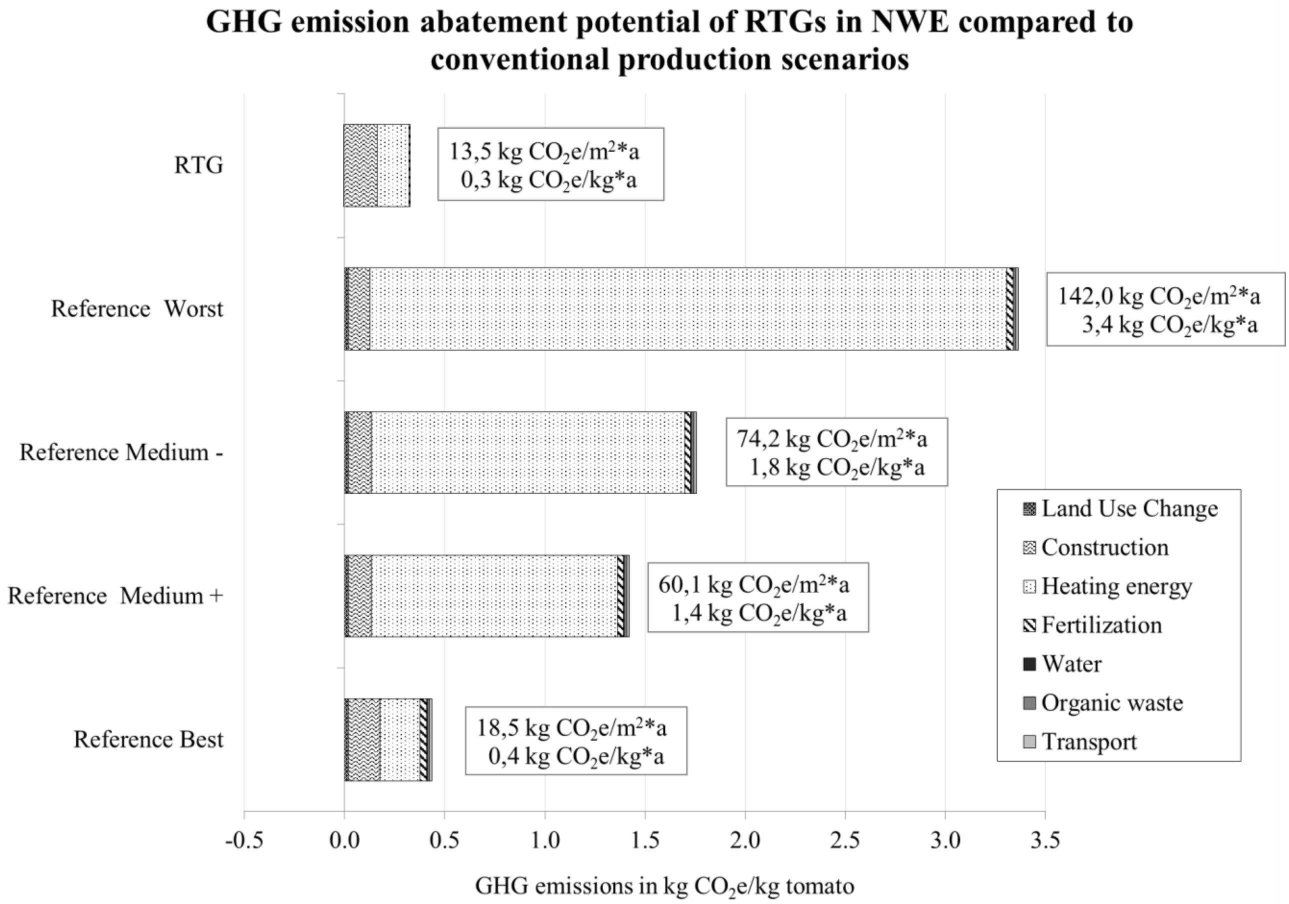
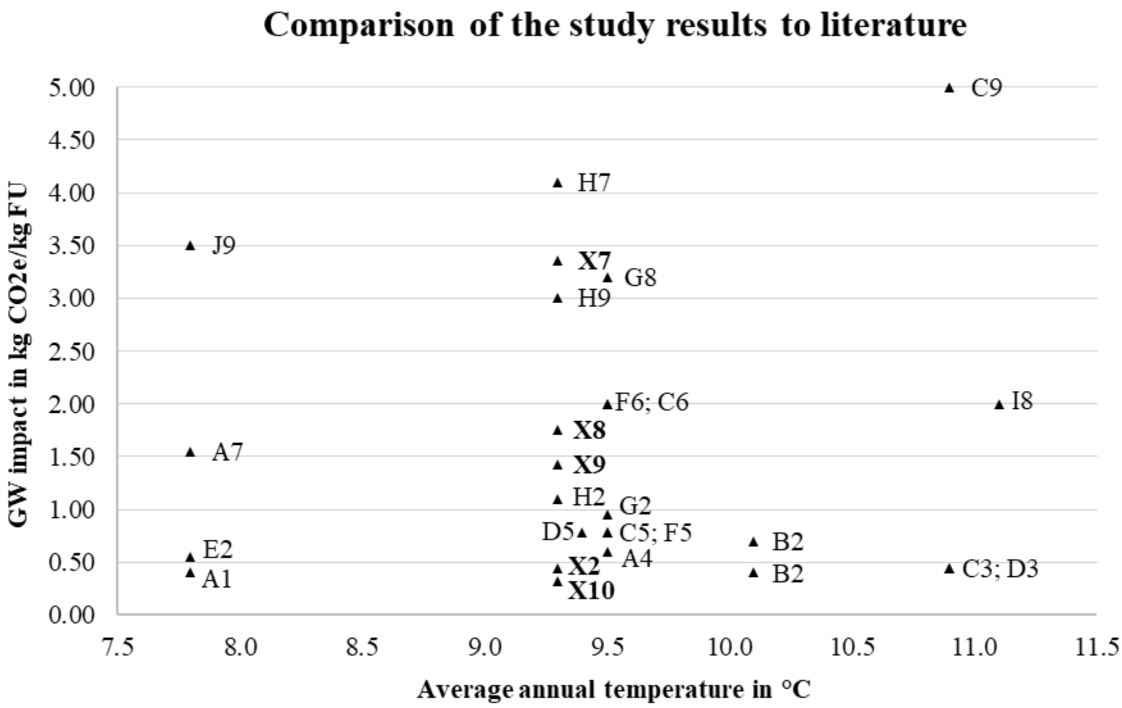


Figure 1: GHG emission abatement of RTG in NWE compared to conventional production

The reciprocal relationship between construction and heating energy emissions is visible in all reference scenarios and the RTG. The construction related emissions for a less energy efficient greenhouse with 4.6 kg CO_2e/m^2*a are less than for the highly energy efficient RTG with 6.9 kg CO_2e/m^2*a. Nevertheless, the disadvantages of higher impact for energy efficient construction are

outweighed by the benefits of thermal energy usage as demonstrates the RTG. Fertilization ranks third in the contribution the overall GW impact of tomato cultivation in all five cases. Exploiting the building's urine potentials to partially cover the tomato nutrient demand leads to an emission abatement of 0.026 kg CO_2e/kg tomato for the RTG when compared to conventional production using mineral fertilizers. The use of urine for plant fertilization is interesting to cover the nitrogen demand of tomato plants, in the given setting it can cover up to 60%. For Potassium and Phosphorus, the nutrient demand coverage by urine is comparatively low, with 7% and 30% respectively. In the RTG model, this delta is satisfied by mineral fertilizers, which leads to an overall GHG emission charge for fertilization in the RTG despite emission credits for fertilizers from urine.
Even though the GW share of LUC in the reference scenarios is comparatively low with 4.1% in the best and 0.5% in the worst case, LUC is of importance to highlight benefits of RTG in terms of resource efficiency and political objectives to decrease land sealing. Similarly, organic waste has a minor contribution to the overall GHG emissions of the reference scenarios, but offers benefits of resource efficiency and the WEF nexus. The credits for biogas production lead to an overall emission credit of 0.005 kg CO_2e/kg tomato for the RTG versus an emission charge of 0.032 kg CO_2e/kg tomato in the reference scenarios. Transport and water usage are negligible in terms of their contribution to the overall GHG emission performance of the respective greenhouses, but contribute to the political and societal benefits of UA by valorizing currently unused resources and producing food locally.

Discussion and conclusions
The comparison of this study's results to previous literature on GW impact of tomato production in similar climates (see Figure 2) shows that the reference scenarios are useful to portray the variety of production in NWE despite limited comparability due to different system boundaries, assumptions, and considered processes and products. It also validates the research hypothesis, that RTG can help to abate GHG emissions of tomato production in NWE by realizing potentials of the WEF nexus. The RTG abates 0.08 kg CO2e/kg tomato when compared to the conventional tomato production with the lowest impact of screened studies in Southern Sweden powered entirely by renewable energy (Högberg, 2010).
Throughout the research and in comparison with literature, it can be noted that the results depend on the emission factor used, which vary depending on the chosen database and source. RTG and conventional production should focus especially on energy efficiency and renewable energy supply to increase the environmental performance of tomato production. GW is not necessarily the only suitable impact category to demonstrate benefits of UA and RTG, such as their contribution to resource efficiency and the preservation of scarce land, water and energy resources. It is important to note that UA and conventional farming can complement each other in their endeavors of food provision, income generation, circular economy and environmental protection rather than competing with each other. The two horticultural forms of production have different motivations and characteristics, such as scale effects of production, knowledge and ambition of the farmer, and mono-specific production in conventional horticulture opposing pluralistic production of many UA projects. Therefore, future research should investigate additional indicators to determine environmental and societal performance as well as benefits of UA and RTG.



Labels indicate source and energy carrier for heating: A= Högberg, 2010; B=Ntinas et al., 2017; C= Torrellas et al., 2012; D= Montero et al., 2011; E= Bosona & Gebresenbet, 2018; F= Antón et al., 2010; G= Dias et al., 2017; H= Müller-Lindenlauf et al., 2013; I= Boulard et al., 2011; J= Mogensen, 2009; X= this study. 1= renewable energy; 2= biomass; 3= geothermal; 4= waste heat, fossil fuels; 5= natural gas CHP with credits for electricity; 6= natural gas CHP without credits for electricity; 7= fossil fuels; 8= natural gas, oil; 9= natural gas; 10= RTG

Figure 2: Comparison of the results to other LCA of tomato cultivation in similar climate conditions

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Evaluating urban heat island mitigation by paddy rice cultivation based on endpoint modeling

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Abstract

Purpose Agriculture and irrigation can ease the urban heat island (UHI) effect, thereby positively impacting the environment. Positive and negative environmental impacts based on life cycle assessment should be considered when researching sustainable agriculture and food consumption. This study focused on the mitigation of the UHI effect by paddy rice cultivation and developed a method for quantifying this function based on endpoint modeling.
Methods We viewed heatstroke, sleep disturbance, and increased energy consumption as impacts of the UHI effect and performed a case study targeting these impacts in the Kinki region, Japan. First, we estimated temperature decreases caused by paddy fields in a 500 m grid cell and defined these decreases as the difference between the current and calculated temperatures when all paddy fields were changed to bare land. The impacts of the UHI effect on human health were estimated via endpoint modeling, using the degree of temperature decrease. The impact of air conditioning on energy consumption was then estimated using the household by cooling degree day model. Subsequently, household expenditure saving and the environmental impact of greenhouse gas emissions could be calculated.
Results and discussion The average benefits of avoiding heatstroke, sleep disturbance, and energy consumption were 17, 60, and 24% of the total benefit, respectively. The estimated total benefit of mitigating the UHI effect via paddy rice cultivation was 73 200 JPY/ha/year. This was significant in comparison to the life cycle environmental impact of rice cultivation. Furthermore, the effects varied by area, e.g., paddy fields near cities provided some benefits to a greater number of residents, but those near suburban areas provided more benefits to fewer people. Approximately 60% of the benefit was derived from paddy fields in grid cells of 100–1000 residents, where 23% of the total population lived.
Conclusions: Paddy rice cultivation can substantially mitigate the UHI effect. Nonetheless, to minimize the environmental load and maximize the environmental benefit, negative and positive impacts should be comprehensively assessed. Regional-level assessment is required for site-specific cases, because the benefits vary considerably by area because of population and field distribution.

Keywords: *urban heat island, paddy field, mitigation, life cycle impact assessment, human health, air conditioning*

Introduction

Agricultural activity may positively affect the environment but negatively affect some impact categories. One positive effect is regional climate mitigation of the urban heat island (UHI) effect. Temperature increases caused by the UHI effect causes health risks, such as heatstroke, increased energy consumption via air conditioning, and risks of local heavy rains and local air pollution in cities. Kumar et al. (2017) reported that agriculture and irrigation can ease the UHI effect. Therefore, agricultural activity near cities play a positive environmental role.

Originally life cycle assessment frameworks intended to evaluate negative environmental impacts, and coverage of positive impacts (e.g. carbon sequestration in soil organic matter) seems still limited. However, positive and negative environmental impacts based on life cycle assessment should be considered totally when discussing sustainable agriculture and food consumption, especially in terms of land use change and biofuel production. This study therefore focused on the mitigation of the UHI effect via paddy rice cultivation and developed a method of quantifying this function via endpoint modeling, which was consistent with life cycle impact assessment modeling.

Material and methods

For quantitative assessment of UHI mitigation, mesoscale analysis using a geographic information system was developed. First, the proposed model evaluated temperature changes caused by paddy fields and estimated the impact on health and energy consumption by area. The mesoscale impact was calculated by multiplying per capita impact and population by area.

This paper reports on a case study in the Kinki region, Japan, located in the central western area of Honshu Island (the Japanese mainland), with a size of 33 000 km^3. Kinki includes big cities, such as Osaka, Kobe, and Kyoto, and two-thirds of the land area is covered by forests with a temperate climate. Figure 1 (left) shows the land use of Kinki using 100 m grid cells. We estimated the benefit of regional climate mitigation of paddy rice cultivation using 500 m grid cells. Yamada et al. (1995) developed equations (1) and (2), a temperature decrease per 10% of land cover of paddy fields within a radius of 250 m of each grid using population of municipalities.

$$\text{4 am: } t = 0.063 \log_{10} p - 0.191 \cdot\cdot\cdot (1)$$

$$\text{2 pm: } t = 0.055 \log_{10} p - 0.051 \cdot\cdot\cdot (2)$$

where t is a temperature decrease (°C) per 10% of land cover of paddy fields within a radius of 250 m of each grid, and p is the population of the municipality to which the target area belongs.

The percentage of paddy fields in the 500 m grid cell was calculated using 100 m-grid land use data, and the temperature change was estimated using the 500 m grid cells. It is assumed the temperature decrease effect as the difference between the current and calculated temperatures when all paddy fields were changed to bare land. We set three target impacts: reduction of heatstroke triggered by high daytime temperatures, mitigation of sleep disturbance caused by high nighttime temperatures, and increased electricity consumption for household air conditioning (cost and environmental load). Ihara et al. (2008) modeled the impact of UHI on heatstroke using the relationship between ambulance transport necessitated by heatstroke and hours of temperatures exceeding 30 °C in a day in the Tokyo metropolitan area. The impact was estimated using equations (3) and (4):

$$D_h = DALY_h * \mathrm{r} * \mathrm{n} \qquad (3)$$

$$\mathrm{n} = 1.52e^{(0.165T_{30})} \qquad (4)$$

where D_h is heatstroke damage (disability-adjusted life year; DALY)/daytime population/day), $DALY_h$ is the average DALY of patients who succumbed to heatstroke (=15.36), r is the death rate of heat-stroke patients transported to hospitals (=1.63%), n is the average number of patients transported to hospitals for heatstroke (persons/daytime population/day), and T_{30} is the hours with temperatures exceeding 30 °C (hour/day).

Okano et al. (2008) evaluated the health impact of sleep disturbance caused by high nighttime temperatures. Sleep disturbance has been reported to increase when nighttime temperatures are above 25.2 °C. According to Okano et al. (2008), this impact was estimated using equation (5).

$$D_s = (T_b - 25.2) * I * f * w \qquad (5)$$

where D_s is the DALY of sleep disturbance (DALY/capita), T_b is the nighttime temperature (°C), I is the increase in sleep disturbance (=3.0%/°C), f is the period of disability (=1 day), and w is the disability weight (=0.05).

The change in household energy consumption was estimated by equations (6) and (7), according to Sawachi et al. (1994).

$$\text{Detached house: } E = 1.12 * 10^{-3} d^2 + 0.621d + 18 \qquad (6)$$

$$\text{Apartment house: } E = 1.91 * 10^{-4} d^2 + 0.798d + 21 \qquad (7)$$

where E is the energy consumption for cooling (Mcal/house/y), d is the cooling degree day (24°C).

The environmental impact of greenhouse gas emissions due to electricity consumption was considered using the emission factor of the largest electricity retailer in Kinki. The impacts of heatstroke, sleep disturbance, and electricity consumption were converted to an integrated impact in terms of monetary value using LIME2 (Itsubo et al. 2012) and Japanese impact assessment methods.

Results and discussion

The average temperature decrease by 500 m grid cells at 2 pm is shown in Figure 1, with 100 m grid land use. Paddy fields were mainly distributed in suburban and agricultural areas. Temperature decreases were not found in large urban centers or forested areas, and no effect was found in 21% of all grid cells, where the population was not zero. The highest temperature decrease was 2.89 °C.

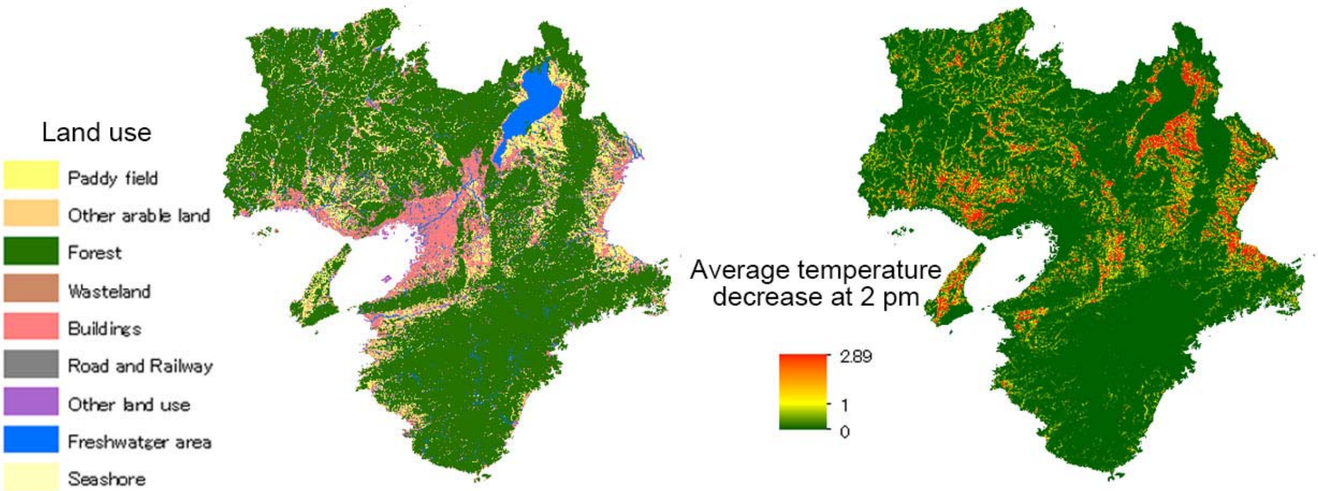

Figure 1: Land use in Kinki region (left) and temperature decrease effect of paddy fields (right)

Table 1 indicates the estimated benefit by the population in grid cells; these without residents were excluded. The average temperature decrease in summer was 0.32 °C, and this effect was highest in moderately dense grid cells (100–1000 residents). The average benefits of decreasing heatstroke, sleep disturbance, and energy consumption accounted for 17, 60, and 24% of the total benefit, respectively. The proportions of the benefits of these three categories were almost the same for all grid cells. No significant difference existed between low-density grid cells (1–100 residents) and moderate-density grid cells in terms of benefit per capita, in contrast to the lower value in high-density grid cells (>1000 residents). The total benefit in Kinki was calculated by summing the multiplied value of benefit per capita and population by grid cells. The total benefit was JPY 15 263 million, which is equivalent to 677 JPY/capita/year. Approximately 60% of the benefit was derived from paddy fields in grid cells with 100–1000 residents, where 23% of the total population lived. Paddy fields near city centers could perform their functions for a greater number of residents, whereas those in suburban areas provided more functions for fewer people.

From these results, the benefit of UHI mitigation by paddy rice cultivation per area was 73 200 JPY/ha/year. This value was comparable to the environmental impacts evaluated by life cycle impact assessments. Yoshikawa et al. (2012) estimated life cycle greenhouse gas emissions and eutrophication impacts related to paddy rice cultivation in Shiga Prefecture, in Kinki. Accordingly, the impact was equivalent to around 42 thousand JPY/ha, suggesting that the benefit of UHI mitigation was considerable compared to the negative environmental impacts of paddy rice cultivation.

Table 1: Estimated benefit of UHI mitigation by population of 500m grid cells

Population	Average population density (persons/km^2)	Average tempe rature decrease in summer (°C)	Average benefit per capita (JPY/capita) Heatstroke	Sleep disturbance	Energy consumption	Population (thousand)	Total benefit (million JPY/year)
1–100	120.9	0.32	309	1090	429	810	1481
100–1000	1379.0	0.43	297	1061	412	5128	9076
>1000	9344.8	0.08	47	168	69	16 606	4706
Total	1848.3	0.32	113	404	160	22 545	15 263

Conclusions

Mitigation of the UHI effect via paddy rice cultivation is considerable when compared to the negative environmental impacts revealed by typical life cycle assessments. Environmental policies should aim to minimize environmental load and maximize the positive environmental effects of human activities. Therefore, negative and positive environmental impacts should be comprehensively assessed. The results of this study also showed that the variation in benefits is high by area due to population differences and paddy field distribution. Regional-level assessment is required if UHI mitigation is evaluated in life cycle assessment applied to site-specific cases.

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Assessing climate change and nutritional trade-offs in substituting animal-based foods with plant-based alternatives – a New Zealand study

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Abstract

Purpose: Food production and consumption have critical effects on environment and human health. Shifting diets (i.e. replacing animal-based foods with plant-based alternatives) is proposed as an effective way to address both environmental and health issues. However, care is needed to avoid unintended consequences such as environmental burden shifting and deficiencies in some micronutrients. This study investigated the product carbon footprint (PCF) and nutritional trade-offs (in terms of five nutrients of health concern and 23 essential nutrients) associated with displacing animal-based foods with plant-based alternatives in a New Zealand (NZ) diet context.
Methods: First, the PCF of peas grown in Canterbury (a major crop and livestock production area in NZ) was calculated using life cycle assessment. Second, per-capita climate change and nutritional targets for NZ were calculated, using the absolute sustainability concept. Third, the typical diet of NZ citizens was identified and an alternative diet partially replacing milk and dairy beef with pea-based food products was proposed. Fourth, the PCFs and nutritional profiles of the typical and alternative NZ diets were evaluated and benchmarked against the defined targets. Finally, the results were scaled to the national level to understand the potential to mitigate NZ's climate change impacts.
Results and discussion: The PCFs of the typical and alternative NZ diets (5.60 and 5.49 kg $CO_2eq \cdot cap^{-1} \cdot day^{-1}$, respectively) exceeded their climate change target by a factor of 3.37 and 3.31, respectively. In terms of nutritional targets, the typical NZ diet met the target for only one of the five nutrients of health concern (cholesterol) but did meet the targets for 20 out of 23 essential nutrients considered. Similar outcomes were observed for the proposed alternative diet. On a national scale, if a 14% displacement of dairy farm land were extended to the whole of NZ, the production-based carbon footprint of NZ's total economy could reduce by roughly 4%.
Conclusions: This study is the first to evaluate the carbon and nutrient profiles of NZ diets in terms of the 1.5°C Paris climate target and a comprehensive list of health-related and essential nutrients. Both the typical and alternative NZ diets failed to meet the climate change target but did meet the targets for many of the essential nutrients. Overall, this research highlights the relevance of considering land use diversification as a key strategy to mitigate NZ's climate change impacts.

Keywords: *Diets, plant-based alternatives, absolute sustainability, climate change, nutrition, peas, protein.*

Introduction

The global demand for food continues to increase due to growing populations, rising incomes, and changing dietary patterns. Food production contributes to environmental degradation and resource depletion, both at global and local levels (Springmann et al. 2018). Furthermore, dietary choices are a major risk factor for human health, leading to obesity and non-communicable diseases like coronary heart disease, type II diabetes and colorectal cancers (Springmann et al. 2018). Hence it is imperative to transform our current food systems into ones that are sustainable and resilient, and able to supply healthy food for everyone. Research shows that shifting diets (i.e. replacing animal-based foods with plant-based alternatives) is an effective way to address many environmental and health issues related to food. However, care is needed to avoid unintended consequences such as deficiencies in some micronutrients (e.g. vitamin B12, selenium, and calcium) that are primarily sourced from animal-based foods in typical omnivorous diets (Springmann et al. 2018). This study, therefore, investigated the climate change and nutritional trade-offs in displacing animal-based foods with plant-based alternatives in a New Zealand (NZ) diet context. Peas were chosen as an exemplar plant-based alternative, given 1) they are a rich source of protein and can be grown widely across NZ and 2) they have potential to be formulated into many foods (e.g. plant-based mince, meat-free burgers and sausages) and beverages (e.g. pea milk and ice creams) due to their functional properties such as water and fat binding, emulsifying, whippability, and foam stability.

Materials and methods

The research method involved the following steps:

i. Calculate the product carbon footprint (PCF) of peas grown in Canterbury using life cycle assessment (LCA) methodology;
ii. Define per-capita climate change and nutritional targets for NZ, using the absolute sustainability concept (Chandrakumar et al. 2020c);
iii. Propose an alternative NZ diet where milk and beef are partially replaced with pea-based foods; and
iv. Evaluate the carbon and nutritional profiles of the typical and alternative NZ diets and benchmark against the defined per-capita climate change and nutritional targets.

LCA of Canterbury peas

An attributional LCA approach was used to calculate the PCF of Canterbury peas. The chosen functional unit was one kilogram of (dehulled) peas at the pea mill gate. The scope of the study was cradle-to-pea mill gate: production of agricultural inputs (pesticides and diesel), transportation, farm activities, and pea mill activities (transport, dehulling and pea hull spreading). The calculated cradle-to-mill gate PCF of Canterbury peas was 0.203 kg $CO_2eq{\cdot}kg\ peas^{-1}$. A full description of the life cycle inventory data and assumptions is available in Chandrakumar et al. (2020c).

Climate change and nutritional targets for food and beverage consumption

Realising the objectives of the Paris agreement, a share of the 1.5°C global carbon budget was first assigned to NZ (=3.19 t $CO_2eq{\cdot}cap^{-1}{\cdot}yr^{-1}$) by sharing the global carbon budget (=24.6 Gt $CO_2eq{\cdot}yr^{-1}$) equally among the global population (7.7 billion in 2020) (Chandrakumar et al. 2020a). Then, a share of the per-capita NZ carbon budget was assigned to food and beverage consumption based on the relative expenditure (19%) of NZ citizens on food and beverage consumption. The proposed climate change target was 1.66 kg $CO_2eq{\cdot}cap^{-1}{\cdot}day^{-1}$. For nutritional targets, this study adopted the nutrient reference values (NRVs) recommended for Australia and New Zealand: one nutrient of health concern (sodium) and 22 essential nutrients (NHMRC 2006). This list was later complemented with four additional nutrients of health concern (sugar, saturated fats, total fats, and cholesterol) and one essential nutrient (see Table 1), as was done in Springmann et al. (2018).

Typical and alternative New Zealand diets

The diet presented in Mackay et al. (2018) was used as the typical NZ diet, due to data accessibility. A hypothetical alternative diet was considered, where 100% of milk and 1.8% of beef intake in the typical NZ diet were replaced with pea-based foods on a protein basis. The milk:beef ratio reflects the relative yields (per hectare) from dairy farms of these two products. Also, no constraint for the serving size of pea-based foods was assumed, given peas can be processed and concentrated for consumption in a range of foods and beverages that use pea-protein extracts as a protein basis.

Carbon and nutrient profiles of New Zealand typical and alternative diets
The PCFs of typical and alternative NZ diets were calculated by multiplying the average daily per capita intake of each food category with its respective PCF. For this analysis, the NZ-specific PCF database developed by Drew et al. (2020) was used, which provides per-kilogram cradle-to-plate PCFs of 346 individual food categories. However, for peas (and pea-based foods) the PCF calculated in this work was used (0.203 vs 0.33 kg $CO_2eq{\cdot}kg\ peas^{-1}$), which is in the lower range of the PCF of peas produced globally (0.15 - 2.56 kg $CO_2eq{\cdot}kg\ peas^{-1}$, Clune et al. (2017)). Similarly, the cradle-to-farm gate PCF values proposed by Ledgard et al. (2020) were used for Canterbury milk (0.76 kg $CO_2eq{\cdot}kg\ FPCM^{-1}$) and dairy beef (17 kg $CO_2eq{\cdot}kg\ beef^{-1}$).
The nutrient profiles of the diets were calculated using the New Zealand Food Composition Database (PFR and MoH 2019). More details of the analysis are available in Chandrakumar et al. (2020b).

Results and Discussion

Carbon footprints of New Zealand typical and alternative diets
The calculated PCFs of the typical and alternative NZ diets were 5.60 and 5.49 kg $CO_2eq{\cdot}cap^{-1}{\cdot}day^{-1}$, respectively. When the PCFs of these two diets were compared with the proposed per-capita climate change target for food and beverage consumption (1.66 kg $CO_2eq{\cdot}cap^{-1}{\cdot}day^{-1}$), the typical and alternative diets exceeded the climate target by a factor of 3.37 and 3.31, respectively.

Nutrient profiles of New Zealand typical and alternative diets
Table 1 presents the nutrient profile of each diet and compares against the proposed targets. According to Table 1, the typical NZ diet met the NRV for only one of the five nutrients of health concern (cholesterol) and 20 out of 23 essential nutrients. The alternative diet showed better outcomes compared with the typical diet for all nutrients of health concern; the quantities of all essential nutrients remained the same or increased in the alternative diet, except for vitamins B12 and D, riboflavin, phosphorus, potassium, calcium, selenium, and pantothenic acid.

Climate change benefits at the national scale
The estimated dairy farm land in Canterbury that is suitable for pea growing is 38,707 ha (Chandrakumar et al. 2020c), which is approximately 14% of the total dairy farm land in Canterbury (LIC and DairyNZ 2019). The associated PCF of these dairy farms is 518 kt $CO_2eq{\cdot}yr^{-1}$, calculated using representative PCF of 13.4 t $CO_2eq{\cdot}ha^{-1}{\cdot}yr^{-1}$. If this land is instead used for pea crop production, the total pea production would be approximately 155 kt $peas{\cdot}yr^{-1}$, with a PCF of 28.4 kt $CO_2eq{\cdot}yr^{-1}$. Likewise, if a 14% displacement were extended to the whole of NZ (the total dairy land in NZ in 2018/19 was 1,743,673 ha (LIC and DairyNZ 2019)), the production-based carbon footprint of NZ's total economy could reduce by 3.1 Mt $CO_2eq{\cdot}yr^{-1}$, which is around 3.9% of the production-based PCF of NZ in 2018 (MfE 2020). Such a change would also be related to decreased milk production and lower protein output (per hectare); the implications of this change, for both NZ and its export markets, need to be considered in future in a more comprehensive analysis.

Conclusions

This study is the first to evaluate the carbon and nutrient profiles of NZ diets in terms of the 1.5°C Paris climate target and a comprehensive list of nutrients (i.e. five nutrients of health concern and 23 essential nutrients). The results indicate that the typical NZ diet was not aligned with the objectives of the 1.5°C Paris climate agreement as it exceeded the climate target by a factor of 3.37. The typical diet met the NRVs for just one of the five nutrients of health concern (cholesterol) but did meet the NRVs for 20 out of 23 of the essential nutrients considered in this study. Similar outcomes were observed for the proposed alternative diet. However, note that the alternative diet moved in the desirable direction to meet the nutritional targets for most nutrients of health concern. Overall, this research highlights the significance of considering land use diversification as a strategy to mitigate NZ's climate change impacts. However, this research involved some limitations and uncertainties, which require further research, as discussed in Chandrakumar et al. (2020c).

Table 1. Nutrient profiles of the typical (Typ) and alternative (Alt) New Zealand diets.

	Nutrient	Nutrient reference value (NRV)	Diet[a] Typ	Diet[a] Alt
Energy		$\geq$ 2499 kcal·cap^{-1}·day^{-1}	2930	2930
Health nutrients	Sugars	$\leq$ 125 g·cap^{-1}·day^{-1}	***149***	***148***
	Saturated fats	$\leq$ 23 g·cap^{-1}·day^{-1}	***35***	***32***
	Total fats	$\leq$ 65 g·cap^{-1}·day^{-1}	***92***	***88***
	Cholesterol	$\leq$300 mg·cap^{-1}·day^{-1}	243	225
	Sodium	$\leq$ 2000 mg·cap^{-1}·day^{-1}	***2941***	***2867***
Essential nutrients	Protein	$\geq$ 52 g·cap^{-1}·day^{-1}	117	117
	Dietary fibre	$\geq$ 27 g·cap^{-1}·day^{-1}	45	52
	Vitamin A	$\geq$ 750 µg·cap^{-1}·day^{-1}	959	1197
	Vitamin B6	$\geq$ 1.4 mg·cap^{-1}·day^{-1}	3.5	3.5
	Vitamin B12	$\geq$ 2.4 µg·cap^{-1}·day^{-1}	3.6	3.4
	Vitamin C	$\geq$ 44 mg·cap^{-1}·day^{-1}	154	178
	Vitamin D	$\geq$ 7.5 µg·cap^{-1}·day^{-1}	***6.3***	***5.5***
	Vitamin E	$\geq$ 8.5 mg·cap^{-1}·day^{-1}	12	14

	Nutrient	NRV	Typ	Alt
Essential nutrients	Thiamine	$\geq$ 1.1 mg·cap^{-1}·day^{-1}	2.7	3.1
	Riboflavin	$\geq$ 1.2 g·cap^{-1}·day^{-1}	2.9	2.7
	Folate	$\geq$ 400 µg·cap^{-1}·day^{-1}	683	770
	Zinc	$\geq$ 11 mg·cap^{-1}·day^{-1}	16	17
	Magnesium	$\geq$ 369 mg·cap^{-1}·day^{-1}	494	512
	Phosphorous	$\geq$ 1037 mg·cap^{-1}·day^{-1}	2083	2043
	Copper	$\geq$ 1.4 mg·cap^{-1}·day^{-1}	1.9	2.0
	Manganese	$\geq$ 4.9 mg·cap^{-1}·day^{-1}	6.7	7.1
	Iron	$\geq$ 11.1 mg·cap^{-1}·day^{-1}	19	21
	Potassium	$\geq$ 3261 mg·cap^{-1}·day^{-1}	4834	4811
	Calcium	$\geq$ 1161 mg·cap^{-1}·day^{-1}	***965***	***774***
	Niacin	$\geq$ 15 mg·cap^{-1}·day^{-1}	51	52
	Selenium	$\geq$ 65 µg·cap^{-1}·day^{-1}	72	70
	Pantothenic acid	$\geq$ 5.0 mg·cap^{-1}·day^{-1}	***2.2***	***1.8***
	PUFA	$\geq$ 14 g·cap^{-1}·day^{-1}	15	16

[a]The numbers in bold, italic, and red indicate that the chosen diet does not meet the NRVs for those nutrients. PUFA = Polyunsaturated fatty acids.

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LCA of an alternative fertigation method with Struvite and Rhizobia inoculation in soilless hydroponic production for *Phaseolus vulgaris*.

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Abstract

Purpose: Soilless agriculture is highly used for urban agriculture, which shows high demands on inorganic fertilization, significantly increasing its environmental footprint. More sustainable ways of production with a reduction of nitrates and phosphates entering the urban water cycle have to be encouraged. The alternative fertilization chosen for the crop *Phaseolus vulgaris* was the slow releasing fertilizer struvite for P, Mg and N, and the soil bacteria rhizobium as additional source of N.
Method: Common bean plants (64 plants) were inoculated with the bacteria rhizobium enabling atmospheric N_2 fixation, 5g of the P fertilizer struvite was applied and placed in perlite bags and irrigated with a P and N deficient nutrient solution (NS)(named treatment SR5). The control was grown with full NS. The yield and content of N and P in the in- and out coming water were assessed. The Simapro software and the EcoInvent 3.5 database were used to perform the LCA where the functional unit (FU) was defined as 1kg of fresh beans. The following impact categories were selected from the ReCiPe (H) Midpoint method: Global warming (GW), Terrestrial acidification (TA), Freshwater eutrophication (FE), Marine Eutrophication (ME), Fossil Resource Scarcity (FRS) and Ecotoxicity (Freshwater, Marine and Terrestrial) (ET).
Results and discussion: The obtained yield for the Control was 4.7kg while the SR5 treatment was 2.3kg. The alternative fertilization implies a reduction of the environmental footprint of the operational part of the system (energy, pesticides, fertilizers, substrate) shifting the weight to the infrastructure (greenhouse structure, rainwater harvesting system, auxiliary equipment). With the alternative fertilization the impact from the operation stays below 10% in most impact categories except for ME (11%) and FE (27%). Considering the FU the environmental footprint of the SR5 is lower in ME and FE and in all impact categories when only operation is accounted. The generation and transport of struvite does not increase emissions in a significant way. While extracting nutrients from the urban environment the equivalent generation and extraction of fertilizers can be avoided.
Conclusion: We conclude that the chosen fertilization with struvite and rhizobium reduces the environmental footprint of the bean production but faces a significant yield reduction. Further research on struvite application and its combination with the Rhizobium has to be considered.

Keywords: Urban Agriculture, Slow-release Fertilizer, Common bean

Introduction:

In recent years Urban Agriculture (UA) has risen as a sustainable alternative for food production in cities, reducing transportation of goods and their packaging as well as the commute to agricultural areas (Sanyé-Mengual *et al.*, 2015). Increasing green spaces on the ground and on rooftops as well as the social and economic benefits are main drivers for the food production in cities (Toboso-Chavero *et al.*, 2019). It can also lessen the pressure on farmers and increase resilience and food security (Sanyé-Mengual *et al.*, 2015).

Urban agriculture has been proved to adapt to the urban outline and has been executed not only on the ground but on roofs, facades and inside buildings (Despommier, 2013; Nadal *et al.*, 2017). Highly used production system for urban agriculture is the soilless agriculture, which has been shown to be highly demanding on inorganic fertilization (Nadal *et al.*, 2017; Sanjuan-Delmás *et al.*, 2018), therefore increasing its environmental footprint significantly (Rufí-Salís *et al.*, 2020). One of the effects of the use and runoff of nitrates and phosphates is water eutrophication which is a great in water bodies close to intensely fertilized agricultural sites. Therefore environmentally friendlier ways of production need to be found to further encourage urban agriculture as a viable option.

To achieve this reduction of nitrates and phosphates loss in the water stream we have reduced and changed the supply for N, P and Mg for the crop *Phaseolus vulgaris* (common bean) for the slow releasing fertilizer struvite, generated by spontaneous precipitation in wastewater treatment plants (WWTP) and the soil bacteria rhizobium as an additional source of nitrogen. The resulting production was then compared to a control treatment with a full nutrient solution (NS). The environmental footprint of these treatments was further assessed using the life cycle assessment (LCA) tool.

Material and methods:

The experiment took place in the integrated rooftop greenhouse (i-RTG) in the ICTA-UAB building (Barcelona). 64 Bean plants were inoculated with the soil bacteria rhizobium to generate a symbiotic interaction enabling atmospheric N_2 fixation. Additionally 5g of the slow releasing P fertilizer struvite were applied irrigated with an N and P deficient NS (named SR5 treatment). A control treatment of also 64 plants with no NS restrictions was also grown to generate baseline results. All plants were transplanted into 40L perlite bags (4 plants per bag in rows of 4 bags). Yields of the treated and control plants were assessed as well as the content of N and P in the drained water. The system was divided into the experiment infrastructure which included the greenhouse structure, the rainwater harvesting system and auxiliary equipment and the experiment operation system which comprised the energy, pesticides, fertilizes and substrates used. To calculate the life cycle environmental impacts of the treatment, we used the Simapro software and the EcoInvent 3.5 database.

The functional unit (FU) was defined as 1kg of fresh beans. The following impact categories were selected, all from the ReCiPe (H) Midpoint method: Global warming (GW), Terrestrial acidification (TA), Freshwater eutrophication (FE), Marine Eutrophication (ME), Fossil Resource Scarcity (FRS) and Ecotoxicity (ET), which is the sum of Freshwater, Marine and Terrestrial ecotoxicities.

Results:

The obtained results when observing the weight of the infrastructure and operation systems in each impact categories show great differences between treatments (Table 1). This Table depicts that a reduction in the inputting fertilization only whith the increase of the resources and energy for the formation of Struvite in the treatment SR5 generates a shift of the impact weight to the Greenhouse infrastructure, reducing the weight of the operation notoriously in all impact categories, specially in TA, FE and ME. Taking in account the FU the following results can be seen in the figure 1. The obtained production of fresh bean for the control was 4.7kg while the SR5 treatment was 2.3kg.

Table 1: The following table depicts the percentages of the origin of the impact in each impact category. Infrastructure being the greenhouse structure, the rainwater harvesting system and auxilary equipment and the operation being the energy, pesticides, fertilizes and substrates used.

TREATMENT	SR5		CONTROL	
IC	Infrastructure	Operation	Infrastructure	Operation
GW	95%	5%	82%	18%
TA	90%	10%	60%	40%
FE	73%	27%	17%	83%
ME	89%	11%	9%	91%
ET	91%	9%	82%	18%
FRS	95%	5%	89%	11%

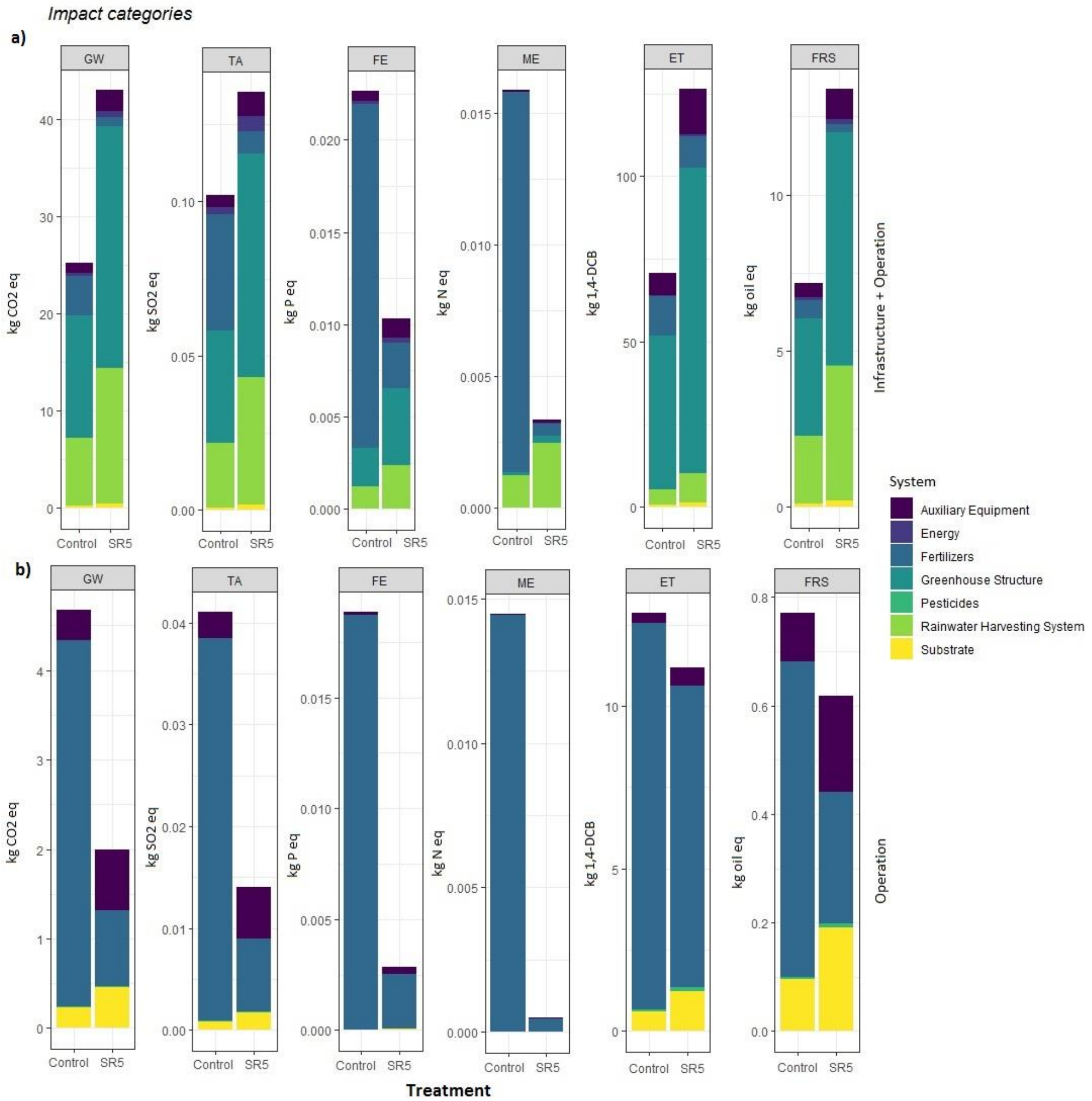

Figure 1: a) Emissions resulting in all impact categories considering infrastructure and operation devided by the FU can be seen b) Emissions resulting in all impact categories considering the operation devided by the FU.

When considering the infrastructure as well as the operation a) shows a better performance in the control treatment in most impact categories except for FE and ME. Only considering the operation of the experiment b) we can see a better environmental performance for the SR5 treatment in all categories despite a reduced production.

Discussion:

The reduced production of the treatment SR5 in comparison to the control can be explained in two ways. Fist the struvite quantity of 5g was chosen in a previous experiment only testing the optimal struvite quantity without a rhizobium inoculation. The rhizobium bacteria requires phosphate from the plant in exchange to the fixed compounds (Allos and Bartholomew, 2010). The given struvite can therefore be insufficient with this higher P demand generated due to the rhizobium inoculation. Another explanation for a reduced production in the SR5 treatment can be an electrochemical imbalance generated in the rhizosphere (Kontopoulou *et al.*, 2015), this can be caused by the reduction of anions given in the NS due to the missing NO_3^- compared to the control treatment. This imbalance can generate a reduced capacity to absorb other cations, diminishing its development and production capacity.

The results also show the importance of the fertilization in the control treatment compared to our treatment. While the operation of the experiment has a high percentage of emissions in TA, FE and ME these percentages quickly fall in the SR5 treatment. This information confirms the statements made by Nadal *et al.* (2017), Sanjuan-Delmás *et al.* (2018) and Rufí-Salís *et al.* (2020) indicating the great importance of fertilization, specially in the case of nitrogen and phosphorous. With the alternative fertilization the impact from the operation stays below 10% in most impact categories except for ME (11%) and FE (27%).

The reduction of N and P in the NS and lecheated water has made echo on the ME and FE categories, being higher in the control treatment even considerin the FU, which was almost duble. These impact categories are directly bount to these nutrient emissions but as we can see in figure 1 b) all categories are affected by the reduction of fertilization, making the total reduction of emission in the operation clear. In this work we have taken in account the production of Struvite in our system (within the fertilization of the SR5 treatment) and its clear that the generation of the struvite as well as it's transport does not increase the emission of the impact categories in a significant way to doubt it's suitability as a more environmentally sound alternative to a full NS.

Keeping in mind that the generation of the struvite derives from the precipitation and extraction of P and N from WWTP (which we have established as environmentally highly impacting nutrients) we can also discuss the additional environmental amendment made during this extraction. While we are recovering nutrients from the urban water cycle we are at the same time preventin the generation of nitrogen fertilizers and extraction of depleting phosphates that can be further used in hydroponic agriculture (Lam, Zlatanović and van der Hoek, 2020).

Conclusion:

With this work we can conclude that the alternative fertilization with struvite and rhizobium has a positive environmental impact while the production of this alternative treatment has been substantially reduced. Therefore we consider it necessary to further explore the application of other quantities of struvite in combination with the rhizobium inoculation. We also conclude that the extraction and use of struvite in hydroponic systems is viable and recommended to reduce the operational footprint in the production system as well as avoiding the extraction and generation of N, P and Mg.

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Topic 12:
Special Products
and Supply Chains

Abstract code: 177

Environmental performance of new processes for the production of fructo- and galacto-oligosaccharides (FOS and GOS)

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Abstract

The prebiotics like FOS and GOS are receiving special attention in the food industry due to their health benefits. They can be produced by enzymatic synthesis by using disaccharides or other substrates as raw materials or by extraction and hydrolysis from different natural sources (roots, legumes). The environmental footprints of these different production schemes are lacking to provide guidance for the ecodesign of such new production processes.

In this work, Life Cycle Assessment (LCA) was undertaken to analyze and compare the production of FOS and GOS by enzymatic synthesis from glucose (to get FOS) or lactose (to get GOS) and hydrolytic production from extraction of yacon potato (to get FOS) or chickpea (to get GOS).

A cradle-to-gate approach was considered in the two scenarios under assessment (the phases of use and/or final disposal of FOS/GOS were not considered). The functional unit was defined as 100 g of FOS/GOS produced. LCAs were performed using data collected at the laboratory scale, supplemented with data from Ecoinvent database. SimaPro was used for the LCA modeling with the midpoint impact EF2.0 characterization method.

Results showed that the main environmental hotspot was the production of yacon potato or chickpea used in the hydrolysis process. For this reason, the hydrolytic process caused higher environmental burdens than the enzymatic synthesis process. Chickpea production causing more impacts than yacon potato production, GOS production generated more environmental impacts than FOS production. When produced by enzymatic synthesis, FOS and GOS were the sources of similar environmental impacts.

From a process point of view, special attention must be paid on three specific stages of production: time of synthesis, freeze-drying and purification of the final product. The environmental load of these stages was associated to high energy consumption and huge amount of ethanol requirement.

The results from this study helped to identify the stages requiring special efforts to ecodesign the production of FOS and GOS at pilot scale in the future. Further research should primarily be focused in the reduction of the biomass used and corresponding solid waste generated during the hydrolytic production. Furthermore, environmental assessment should be included at each development of the process to ensure its efficient eco-design.

Keywords: *prebiotics; innovative production processes; Life Cycle Assessment; food engineering*

1. Introduction

Fructo and galacto-oligosaccharides (FOS and GOS, respectively) are attracting increasing interest as prebiotic functional food ingredients as they may confer health benefits on the host, mainly associated with the modulation of microbiota. However, their benefits go beyond their prebiotic properties, as they are low caloric sweeteners, give a feeling of satiety, contribute to body weight control, relieve constipation, have a low glycemic index and are not cariogenic. Therefore, FOS and GOS are increasingly used in the formulation of dairy products, beverages, bakery products, and some sweets, converting them in functional foods. Moreover, they are extensively employed in infant formula to stimulate the development of newborns microbiota.

As FOS and GOS can be incorporated into many products, their demand has exponentially increased worldwide over time. From a technological point of view, these prebiotics can be produced by enzymatic synthesis (by fructosyltransferase or β-galactosidase enzymes) using disaccharides or other substrates as raw materials or by extraction and hydrolysis (hydrothermal process) from different natural sources mainly from roots (of chicory, artichoke, yacon potato, dahlia or agave) and legume seeds (such as soybean, lupin, lentil, chickpea, pea and cowpea) (Martins et al., 2019).

To the best of our knowledge, no environmental study has been published with special focus on the environmental footprints of different production schemes of FOS and GOS. In this work, the assessment of the environmental impacts associated to the enzymatic synthesis and hydrolytic production of FOS and GOS was performed. To this aim, a Life Cycle Assessment (LCA) was undertaken to analyse two scenarios based on different processes considering sucrose, lactose, yacon potato and chickpea seeds as raw materials. The environmental hotspots were identified on the basis of experimental results carried out at laboratory scale.

2. Material and methods

2.1. Goal and scope definition

The aim of this study was to assess and compare the environmental performance by Life Cycle Assessment of FOS and GOS production by enzymatic synthesis or hydrolysis from different substrates (sucrose and lactose for enzymatic synthesis of FOS and GOS, respectively; hydrolysis of yacon potato and chickpea seeds to obtain FOS and GOS, respectively).

A cradle-to-gate approach was considered in enzymatic and hydrolysis scenarios under assessment, *i.e.*, considering production of sucrose/lactose and yacon potatoe/chickpea seeds, the extraction or substrate preparation to produce the required inputs and the production of FOS/GOS but not the phases of use and/or final disposal of FOS/GOS. This perspective was assumed since FOS and GOS are intermediates and not final products. Among the processes considered throughout the production life cycles, centrifugation, purification, freezing and freeze-drying were performed after the extraction phase. The detailed production processes and the system perimeters are presented on **Figure 1**.

To allow comparisons between the systems under study, the functional unit was defined as 100 g of FOS/GOS produced by enzymatic synthesis or hydrolysis.

2.2. Life Cycle Inventory

Inventory data for the foreground system (direct inputs and outputs for each stage) such as electricity requirements (estimated with power and operational data from the different units: reactors, centrifuges, rotary evaporator, heating plates and freeze-dryers) as well as the use of chemicals, enzymes and water were average data of the laboratory scale.

The background data were taken from Ecoinvent database v3.5 (2018) by using the cut off system model. The laboratory scale process was located at CIDCA-CONICET (La Plata, Argentina) and University of Madeira (Madeira, Portugal), so the average electricity generation and imports/exports from Argentina and Portugal have been considered as GLOBAL in terms of geographical precision in the database.

2.3. Impact characterization

Environmental impacts were quantified with the Environmental Footprint method version 2.0 implemented in Simapro software (v9.0.0.35). This method has been selected as recommended by the EU for product environmental footprint (Fazio et al., 2018). Midpoint impact categories have been considered.

3. Results and Discussion

3.1. Process stages contributions

Enzymatic synthesis. The hotspots associated with enzymatic synthesis were related to the enzymatic synthesis itself and the purification stages, both for FOS and GOS production which presented similar environmental impacts. Enzymatic synthesis was responsible of about 60 ± 15 % of the impacts on all impact categories, while purification was responsible of about 20 ± 15 % of the impacts on all impacts categories. The impact of enzymatic synthesis was mainly due to electricity, requiring a reactor at 50°C during 24 hours and subsequently enzyme inactivation at 95°C. The impact of the purification was mainly due to the use of 1.5 kg of ethanol to obtain the final product rich on FOS or GOS and with low content of monosaccharides. The other steps required the lowest amounts of electricity and no material inputs. Therefore, their contributions to the environmental profile were negligible regardless the impact category.

Hydrolysis. The hotspots associated with hydrolysis were related to the substrate extraction and the freeze-drying although we obtained differences on the relative values and categories. For FOS production, substrate extraction contributed to 39 ± 20 % and freeze-drying to 26 ± 14 % of the impacts. For GOS production, substrate extraction contributed to 57 ± 28 % and freeze-drying to 16 ± 13 % of the impacts. For both FOS and GOS production purification contributed to about 16 ± 12 % of the impacts. Freeze-drying contribution was due to electricity consumption it required, and purification contribution was due to ethanol consumption, as for enzymatic synthesis. The contribution of the substrate extraction step was due to the production process of yacon potato and chickpeas together with solid waste generated after extraction of FOS/GOS from these raw materials. As for enzymatic synthesis, the contributions of the other process steps were negligible.

3.2. Comparisons between the different process scenarios

Figure 2 presents the comparison of the environmental impacts between the processes of enzymatic synthesis and hydrolysis, for both FOS and GOS. A remarkable difference could be noticed between the two processes: enzymatic synthesis caused significantly less environmental damages, both for FOS and GOS and on all impact categories (except for non-cancer human health effects and freshwater ecotoxicity, but the difference in these cases is very low). This should be directly related with differences on the production systems and the substrates used, as detailed above. Although the two processes share a number of stages in common (cleaning, centrifugation, storage and purification), a significant difference between them was observed in the first stage, *i.e.*, the enzymatic synthesis of FOS/GOS from sucrose/lactose or their extraction from biomass (yacon potato/chickpea).

From the energy use point of view, energy consumption were comparable for both enzymatic synthesis and hydrolysis and could not explain the differences observed on **Figure 2**. Enzymatic synthesis implied an enzymatic step based on the use of a cocktail of enzymes with temperatures around 50 °C during 24 hours of reaction and 95 °C for enzyme inactivation. On the other side, hydrolysis included a hydrothermal process under non isothermal conditions, carried out at temperatures between 50 °C and 100 °C but only for 2 hours, requiring rather low energy amount. However, hydrolysis process also involved the additional step of freeze-drying during storage, increasing significantly the electricity requirements of the whole process.

Finally, the total difference on the environmental impacts was mainly due to the huge difference in the amounts of raw materials required for the two scenarios: around 500 g of sucrose / lactose for enzymatic synthesis *vs* more than 5 kg of yacon potato/chickpea for hydrolysis. The interrelated consequence was the high amount of solid wastes generated in hydrolysis processes, also causing an environmental load. Accordingly, hydrolysis reported the worst environmental results.

Among the two hydrolysis processes, the production of FOS caused less impact than the production of GOS, except for water scarcity and mineral and metal use. In accordance of statements above, it was due to the more important environmental impact associated to chickpea production than the environmental impact of yacon potato production.

No literature data are available on these systems for comparison. However, such a study does not claim providing precise environmental impacts of the processes, especially because the study has been conducted at a laboratory scale, which can be far away from an industrial process. Nevertheless, such an approach highlights areas of concern in the further development of the processes, and should be used iteratively at each development stage in order to check if environmental burdens have been decreased by new developments and not transferred to another step of the system. Such an iterative approach could ensure eco-design of the production processes.

4. Conclusions

The production of prebiotics like FOS and GOS is receiving special attention in the food industry due to their health benefits. This study analyzed by LCA two different scenarios at laboratory scale for producing FOS and GOS original mixtures.

Hydrolysis process generated more environmental impacts than enzymatic synthesis. With regards to the production processes themselves, special attention must be paid on three specific stages: time of synthesis, freeze-drying and purification of the final product. The enzymatic based synthesis involved the utilization of enzymes whose production and use require large times of incubation (energy consumption). The hydrolytic production was carried out at high temperatures and lower times than the enzymatic synthesis, requiring less energy. However, the use of freeze-drying in the storage step equaled electricity expenditure for both processes. The environmental load associated to the purification step was due to the huge amount of ethanol used. Nevertheless, the use of huge amount of raw materials in the hydrolysis process induced the highest environmental load which finally widely overcame the environmental burdens associated with energy or ethanol used.

The results from this study helped to identify the stages requiring special efforts to ecodesign the production of FOS and GOS at pilot and industrial scale in the future. Further research should be focused in the reduction of the biomass used and corresponding solid waste generated during the hydrolytic production. Further developments should also include systematically environmental assessment at each development stage to ensure the eco-design of the process, and considering not only the production processes but also their use, and more globally their whole life cycle.

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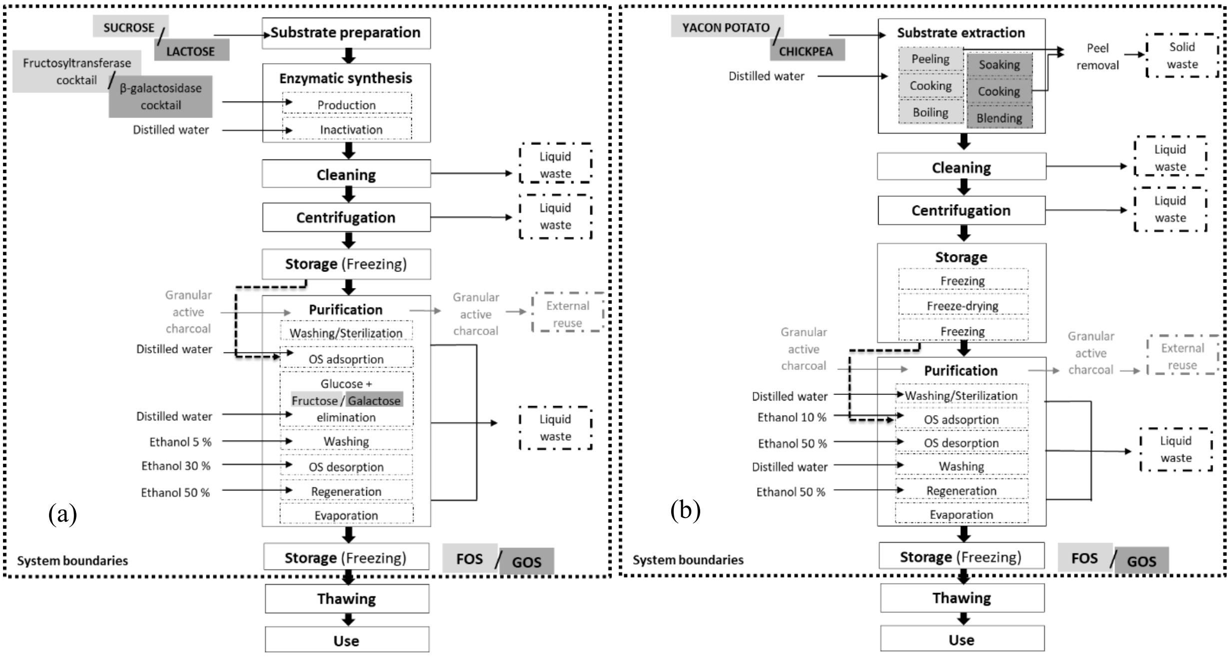

Figure 1. FOS and GOS production processes by enzymatic synthesis (a) or hydrolysis (b).

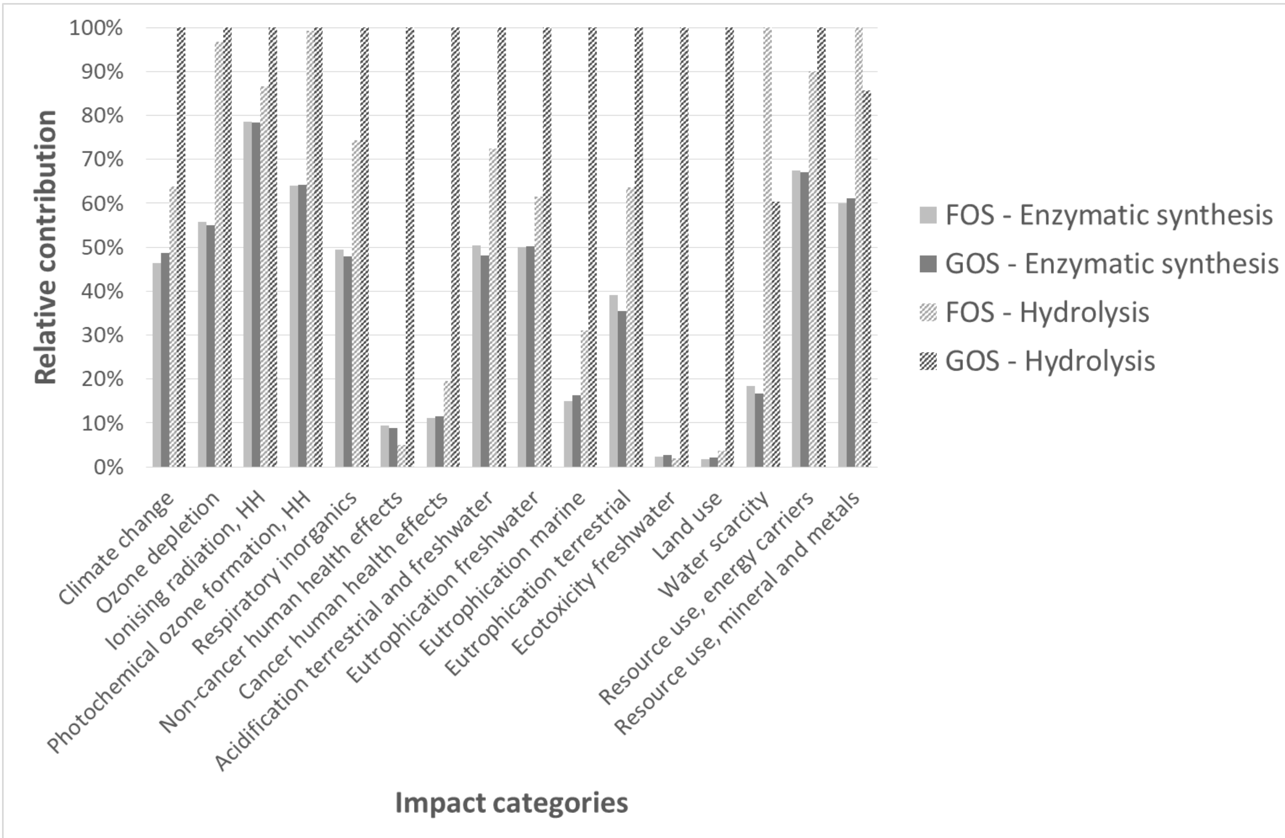

Figure 2. Comparison of the environmental impacts computed by LCA (EF2.0 method) between the processes of enzymatic synthesis and hydrolysis, for both FOS and GOS.

Abstract code: 344

Life cycle assessment (LCA) and economic performance of paddy field-based crop-livestock systems in Southern Brazil

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Abstract

The development of sustainable agri-food systems has emerged as one of the most important goals in the global policy agenda. In Brazil, the improvement of traditional crop-livestock (CL) systems has been supported as a strategy to tackle environmental impacts, avoid the advance of agriculture over native areas, and increase the productivity of the land. However, before new CL systems are brought into practice their environmental and economic performance should be carefully evaluated. In this study we apply attributional life cycle assessment to compare the environmental performance of three CL systems based on paddy fields located in State of Rio Grande do Sul, Brazil. In addition, we calculate the operating profit (OP) as the indicator of economic performance of these systems. We evaluated two experimental systems (BR and BSR) and one modelled baseline system (BL); the production rotations were designed with beef cattle produced in the autumn-winter seasons and grain crops produced in the spring-summer seasons. The BR system was composed of the rotation of beef cattle and rice. The rotation in the BSR system consisted of beef cattle, soybean, and rice; soybean and rice were rotated as the spring-summer crop. In both experimental systems, ryegrass was sown to serve as winter pasture. The BL system was modelled to represent the production of rice in minimal tillage management, with beef cattle grazing rice straw and regrowth after the rice was harvested. Four impact categories have been selected, Global Warming Potential, Acidification Potential, Eutrophication Potential, and Abiotic Depletion. With the boundary from cradle-to-experiment gate, the functional units selected were one kg-liveweight of beef cattle for fattening and one kg of grain. Results show that improving paddy field-based CL systems in RS by reducing tillage, adopting fertilizers to improve production, and adopting sown winter pastures can increase considerably the productivity of land and reduce environmental impacts per unit of product. Besides, the production of ryegrass allowed cattle to stay longer in the systems, avoiding the requirement of other sources of fodder in the winter. Yet, the production of winter pastures has led to a negative operating profit of the cattle enterprises in the experimental systems. However, the rice and soybean crops had positive OP which assured a higher annual OP in both experimental systems. According to the crop-by-crop approach and impact categories adopted in this study, the improved systems presented better performance than the baseline system evaluated.

Keywords: *life cycle analysis; footprint; sustainable intensification; integrated farming; costing; operating profit*

Introduction

The development of sustainable agri-food systems has emerged as one of the most important goals in the global policy agenda. First, because agricultural systems play an indispensable role in providing global food security and livelihoods in rural areas; and second, because several agricultural practices are linked to negative effects on humans, natural resources, and the environment (IPCC, 2019a). In Brazil, the agri-food sector stands out for contributing significantly to the country's economy. Consequently, the Brazilian agri-food sector also contributes to some of the negative effects associated with the activity, such as greenhouse gas (GHG) emissions and depletion of resources. Among the actions set by Brazil to reduce environmental burdens from agriculture is the improvement and adoption of crop-livestock (CL) systems (Bungenstab et al., 2019). CL systems can promote land sparing, reduction of environmental impacts, and increase the productivity of the land. However, before new CL systems are brought into practice their environmental and economic performance should be evaluated. In this study we apply attributional life cycle assessment (LCA) to assess the environmental performance of three cropping livestock systems based on paddy fields; and calculate operating profit as the indicator of the economic performance of these systems.

Material and methods

The paddy field-based CL systems evaluated are located in the Pampa Biome, State of Rio Grande do Sul (RS). Mean values from two treatments of a four-year (eight cropping/livestock seasons) triplicated experimental CL system were evaluated and compared with a Baseline system (BL), which was modeled based on secondary data. Additionally, we also modeled, based on secondary data, a natural pasture-based suckler herd that delivered young stock (190 kg liveweight-LW) to the three systems. In the field experiments, cattle were produced in the autumn-winter seasons while grain crops in the spring-summer seasons. The soil management in the two experimental systems followed the no-till practice. Fertilization was applied according to soil analysis and crop requirement aiming high yields. Agrochemicals application followed best practice management protocols.

In the first treatment, the BR system, the rotation consisted of beef cattle (BR_cattle) and rice (BR_rice); Italian ryegrass was sown straight after harvesting the rice and served as pasture for the cattle. In the BR_cattle, the stocking density was 695 kg LW ha^{-1} with a grazing period of 70 days, which yielded 212 kg LW gain. The BR_rice presented an average yield of 11189 kg ha^{-1}. In the second treatment, the BSR system, the rotation consisted of beef cattle (BSR_cattle), soybean (BSR_soybean), and rice (BSR_rice); soybean and rice were rotated as the spring-summer crop. Italian ryegrass was sown straight after harvesting the crop and served as pasture for the cattle. In the BSR_cattle, the stocking density was 443 kg LW ha^{-1} with a grazing period of 109 days, which yielded 245 kg LW gain. The BSR_rice presented an average yield of 12018 kg ha^{-1}. The BL system was modeled to represent the most common soil management practice in the region; namely, rice in minimal tillage as the spring-summer crop with beef cattle grazing rice straw and regrowth after the harvest. Data for modeling the BL system were retrieved from Balbino et al. (2012) and the *Weighted Rice Budgeting* published by IRGA (2020). In the BL_cattle the stocking density was 437 kg LW ha^{-1} with a grazing period of 53 days, yielding 56 kg LW gain. We assumed that rice yield in the (BL_rice) system was equal to the regional average of 7450 kg ha^{-1}.

We applied a crop-by-crop LCA following a cradle-to-experiment gate approach. The selected production-related functional units were one kg (LW) of beef cattle for fattening and one kg of grain (13% moisture). Emissions to air and water were modeled to complete the life cycle inventory (LCI);

allocation issues were solved using economic allocation. For the production of crop and cattle, GHG emissions to the air and emissions of N-compounds to water were modeled following the IPCC (2019b) guidelines, chapters 3, 5, 10, and 11; the exception was the daily methane emissions factors from paddy fields. These were derived from local studies as 4.06 kg ha^{-1} for the no-till systems (BR, BSR) and 4.50 kg ha^{-1} for minimal-till (BL). P-related emissions were calculated according to Nemecek and Schnetzer (2012), and emissions from diesel burned in agricultural machinery were modeled according to Nemecek and Kagi (2007). Biological nitrogen fixation from soybean was not inventoried as suggested by IPCC (2019b, p. 11.6). Background processes were retrieved from the ecoinvent® v.3.01 database. Four impact categories were selected, Global Warming Potential (GWP_{100a}, kg CO_2 eq.) (Myhre et al., 2013), Acidification Potential (AP, kg SO_2 eq.), Eutrophication Potential (EP, kg PO_4^3 eq.), and Abiotic Depletion (AD, MJ) according to the CML-IA baseline V3.02 / World 2000 method. The SimaPro® v. 8.2.0 software was used to conduct the life cycle impact assessment analysis by running 1000 Monte Carlo iterations with a 95% confidence interval. Infrastructure was excluded from the analysis.

The Operating Profit (OP) was computed as net farm income from operations plus interest expense less opportunity cost of unpaid labor less opportunity cost of management (Kay et al., 2016). Budgets for each CL system and cropping season were constructed following the guidelines from the Brazilian National Food Supply Company (Conab, 2010). The final results were adjusted to inflation and are presented in US dollars to the year 2017.

Results and discussion

Median point value results show that the production of beef and rice in the experimental systems presented lower environmental impacts than the baseline system, except for the AD impact category, Fig. (1). Moreover, the BSR system presented the lowest median values per FU for the production of beef and rice. Further, except for AD, the production of one kg of soybean in the BSR system presented lower impacts than the production of rice Fig. (1h).

As expected, young stock production was the most impacting process for the production of cattle. The suckler herd modeled in this study was assumed to be reared in natural pastures in South Brazil. Suckler herds in these conditions, normally, graze low-quality grasses and have low productivity; consequently, they produce young stock with high environmental burdens. Overall the BSR_cattle system presented the lowest GWP (22 kg CO_2 eq. FU^{-1}), from which 76% came from the young stock production. Similarly, young stock contributed with 84%, and 94% of the GWP for BR_cattle, and BL_cattle, respectively; 86%, 79%, and 97% of the AP for BR_cattle, BSR_cattle, and BL_cattle, respectively; and 82%, 75%, and 95% of the EP for BR_cattle, BSR_cattle, and BL_cattle, respectively. The use of fertilizers and lime to produce ryegrass in the experimental systems increased emissions at the experimental stage, which partially explains the lower contribution from young stock in these systems. This effect was more evident in the AD impact category, Fig. (1d). For beef production, methane derived from enteric fermentation and manure deposited onto pastures was the most important source of GHG emissions and dominated GWP results.

The BR_rice and BSR_rice systems presented lower emissions per FU than the BL_rice in all four impact categories, Fig. (1e to 1h). Once again, the outputs from the BSR system presented the lowest impacts. This superior performance of the BSR system may be partially explained by the higher productivity in this system. The higher yields in the BSR system could have been a positive influence of the soybean crop in the rotation, however, the LCA model adopted in this study cannot confirm this hypothesis. Methane emissions originated by the decomposition of organic matter under anaerobic conditions was the main contributor to GWP for rice production, 80%, 78%, and 83% for

BR_rice, BSR_rice, and BL_rice, respectively. The experimental systems were managed under no-till and thus emitted less methane per day when compared to the minimal tillage adopted in the BL system. Furthermore, direct and induced field emissions of N_2O generated by the application of N-fertilizers also contributed considerably to GWP. The production of soybean required neither flooded irrigation nor N-fertilization explaining the considerably lower GWP, and AP in the BSR_soybean system. Therefore, the use of soybean can reduce considerably the impacts of the CL system. Soybean GWP in this study was slightly lower than the values found by other regional studies. This lower impact may be a consequence of the higher yields reached in the BSR_soybean system (~ 3700 kg ha^{-1}), which were ~37% higher than regional averages.

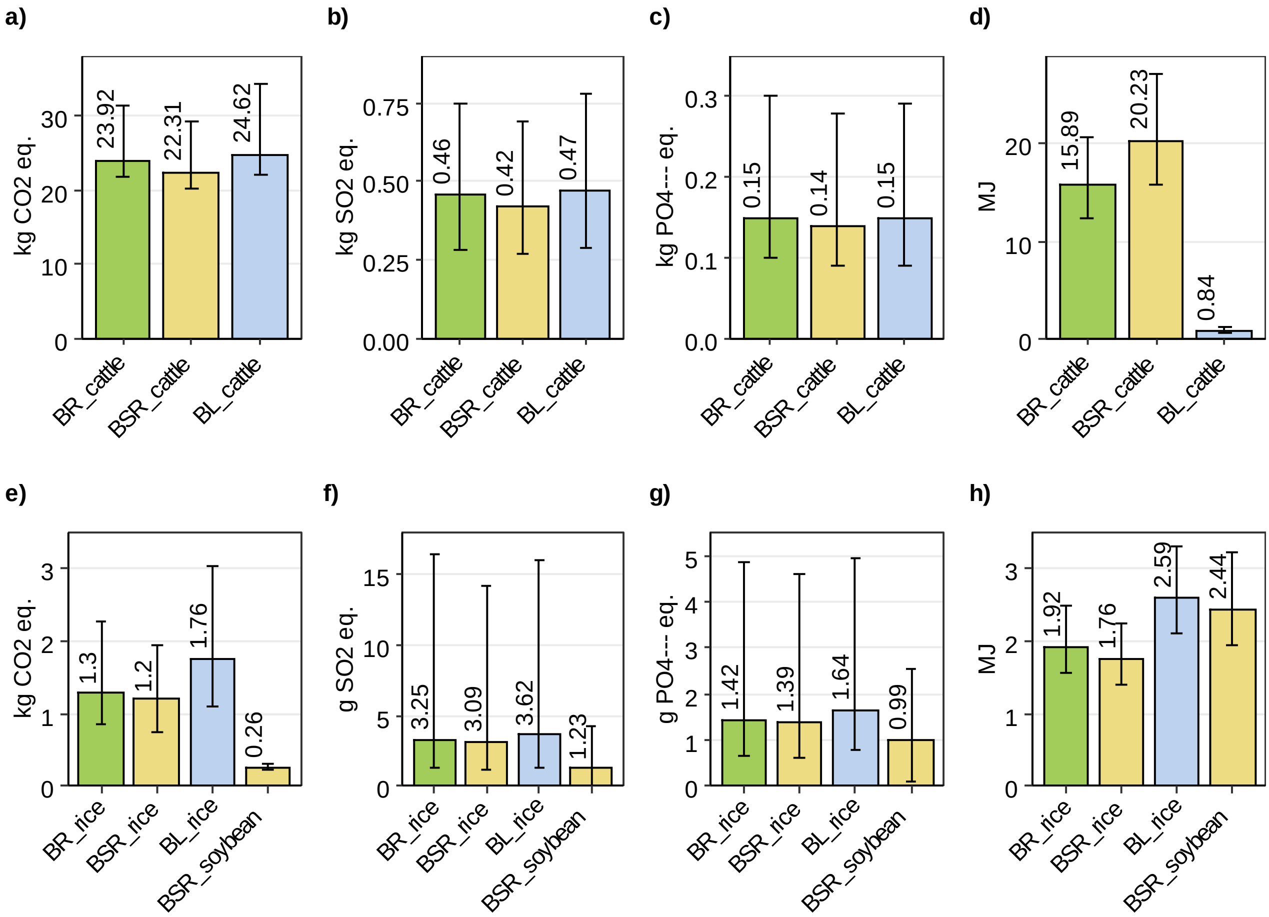

Fig.1. Median values of the life cycle impact assessment for the production of one kg (LW) of beef cattle for fattening and one kg of grain (13% moisture) in the three crop-livestock systems studied (Beef cattle and Rice (BR), Beef cattle Soybean and Rice (BSR), and Baseline (BL)).

Results of the economic analysis show that the BR_cattle and BSR_cattle presented negative OP, however, the annual results for the experimental systems were higher than the BL system, Fig. (2). Annual OP was on average higher in the BR system (\$1117.11 $(ha{\cdot}a)^{-1}$), followed by the BSR system (\$749.85 $(ha{\cdot}a)^{-1}$) and BL system (\$585.19 $(ha{\cdot}a)^{-1}$). Despite the higher daily LW gain in the experimental systems, returns were not sufficient to reach the break-even point. These results were driven by the costs of producing the ryegrass pasture. Nevertheless, in the experimental systems, cattle had access to good quality forage for a longer period during the cold months. Thus, cattle exiting the experimental systems were heavier and fitter, this may bring advantages in the fattening phase by, for example, reducing the production cycle. Consequently, the negative results of the backgrounding phase may be recovered at the end of the cycle. Operating expenses to produce rice were high but always surpassed by the gross revenue, assuring positive OP for all three systems. Soybean also presented positive OP, yet, it was lower than rice, Fig. (2).

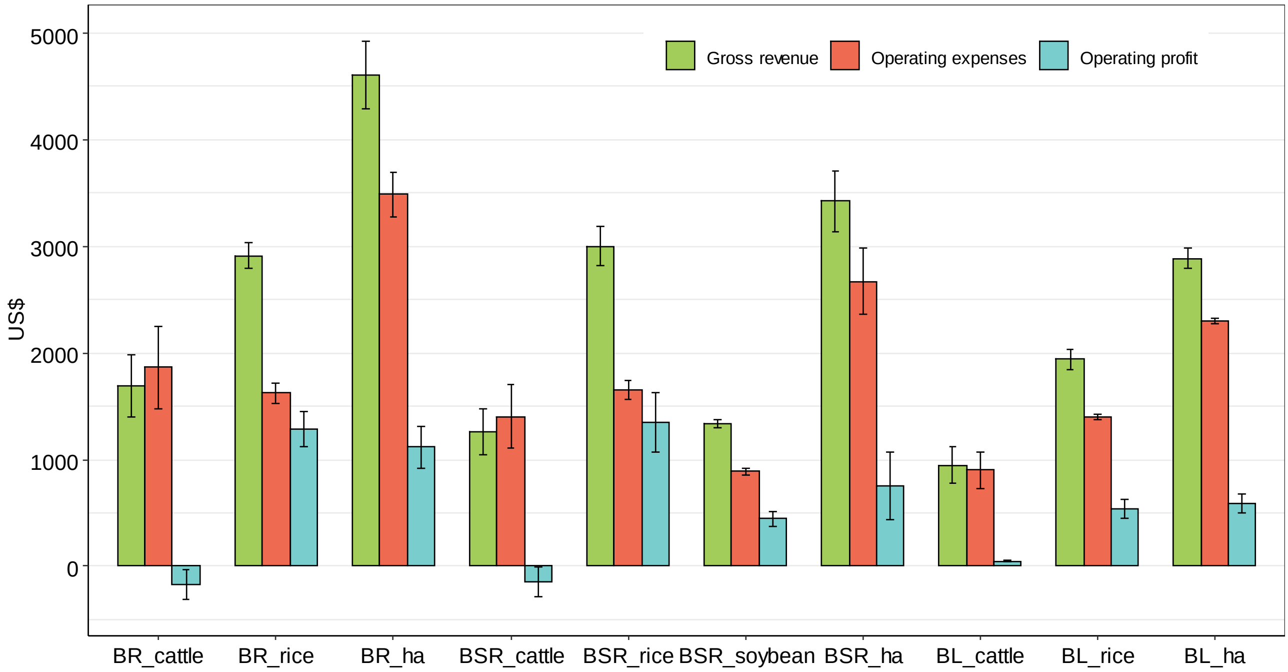

Fig. 2. Mean (± standard deviation) gross revenue, operating expenses and operating profit of the three crop-livestock systems and individual enterprises.

Conclusions

Our study showed that improving paddy field-based CL systems in RS by adopting no-till practices, fertilizers to improve production, and adopting sown winter pastures can increase considerably the productivity of land and reduce environmental impacts per unit of product. Besides, the production of winter pastures allows cattle to stay longer in the improved systems, avoiding pressure over natural pastures in the winter. Yet, the production of pastures led to negative operating profit in the experimental beef cattle enterprises. However, the rice and soybean crops had positive OP which assured a higher annual OP in the experimental systems. Generally, the improved systems evaluated this study can be considered more sustainable than the baseline system evaluated, i.e., they reduced environmental impacts per unit of product, increased production without advancing over new areas, and presented positive economic returns. However, increasing the use of synthetic fertilizers, as adopted in the experimental systems in our study, has been condemned as an unsustainable practice in agriculture and desire further consideration. The 95% confidence interval error bars presented in Figure 1 show that the uncertainty generated by the Monte Carlo analysis is large and right-skewed. The propagation of the uncertainties across our LCI model, including those related to the emission factors, could have influenced the results significantly. Moreover, the multiplicative characteristic of LCA models and the lognormal distribution assumed to most processes explain the right skewness of the results. Finally, we believe that future research towards more sustainable paddy field-based farming systems should strive to find leverage points between resource use, environmental impacts, and economic returns. Expanding the selection of impacts and adopting different LCA approaches, including hypothesis tests, could provide more information about the performance of CL systems.

Acknowledgments

The first author would like to thank the National Council for the Development of Science and Technology (CNPq) for the Ph.D. scholarship 290048/2017-6. The authors also thank the *Grupo de Pesquisa em Sistemas Integrados de Produção Agropecuária* - GPSIPA/UFRGS for providing the experimental data for this study, as well as the anonymous reviewers for their constructive comments.

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Mapping South America's soybean supply chain for regionalized life cycle assessments

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Abstract

Purpose: Including land use in the life cycle assessments (LCAs) of agri-food products demands detailed knowledge about regions of agricultural production to accurately estimate potential damage to biodiversity and ecosystem services. In this study, we mapped the supply chain of soybean sourced from South America to (1) spatialize land occupation life cycle inventory (LCI) information for soybean production to match existing biodiversity characterization factors, and (2) allocate resulting biodiversity damage to importing countries.
Methods: Supply chains were mapped using a combination of data sources (e.g. tax information, bills of lading, logistics, trade data, etc.) to link a jurisdiction of production in Brazil, Argentina, and Paraguay to countries of import. This information was used to derive a commodity 'supply mix' representing the average tonne of soybean sourced from jurisdictions in South America and exported to China, the EU and France in 2017. From this supply mix, we then derived a spatially-explicit LCI from which we obtained potential biodiversity damage of soybean production in each continental ecoregion and allocated to each import country.
Results and discussion: Our results show that the average tonne of soybean produced in South America and destined for France had the lowest potential biodiversity damage compared to China and the EU. While all importing countries sourced soybean mainly from the Brazilian Cerrado, the larger biodiversity damage occurred in other ecoregions such as the Araucaria Moist Forests or the Parana-Paraiba Interior Forests (both in Southern Brazil), with France showing the lowest total potential damage compared to China and the EU.
Conclusions: While supply chain mapping can improve the spatial relevance of regionalized LCAs, the information they reveal also allows for more targeted supply chain interventions without, however, requiring full traceability of commodities from "farm to fork".

Keywords: *Land use, regionalization, biodiversity, soybean, logistics.*

Introduction

Land occupation (or land use) has only recently been included as a key component of the life cycle inventory (LCI) to estimate potential damage to biodiversity and ecosystem services in life cycle assessments (LCAs). Characterization factors (CFs) are based on biophysical boundaries (e.g. soil, biomass) or species richness that vary widely in space and are often available at a resolution that does not match information on the land use of a given product. Damage to biodiversity and ecosystem services can be particularly challenging to estimate for agricultural commodities because (1) commodities are often aggregated in bulk storage or processing facilities, thereby obscuring the location of commodity production, and (2) supply chains vary based on logistics which can change according to consumption centres.

One option to overcome these challenges is to improve commodity supply chain mapping so as to improve LCI spatialization and match land use information with the resolution of regionalized CFs, while linking impact assessment results to specific international markets. In this study, we mapped the supply chain of soybean from South America with the goal of improving the spatialization of the LCI so as to derive potential biodiversity impacts of land occupation as they relate to exports to China, the EU and France.

Material and methods

We mapped the supply chain of soybean (as whole bean) from Brazil, Argentina and Paraguay through to importing countries by combining tax information, bills of lading, infrastructure type and ownership, and detailed trade data. First, we linked the origin of individual soybean shipments to 'logistics hubs' representing jurisdictions containing silos. These links were drawn following detailed information on trader and infrastructure ownership (Brazil), databases that track national soybean movement (Argentina), and/or a combination of infrastructure capacity and optimization of distances through linear programming (Brazil, Paraguay). Then, the jurisdictions likely supplying soybean to each logistics hub were identified by a linear programming-based minimization of transport distances using soybean production and demand in each jurisdiction. The result is a soybean supply chain linking the jurisdictions of soybean production to logistics hub (containing silos), port, exporter, and import country for each individual and international shipment. Soybean supply chains are available online (trase.earth), with further methodological details available for Brazil (v.2.5.0), Argentina (v.1.0.1) and Paraguay (v.1.1.1.) (Trase 2020).

We performed a LCA of one tonne of soybean produced in South America and exported to China, the EU and France in 2017 with a focus on biodiversity damage from land occupation as shown in Eq. (1) (Yang 2016; Koellner et al. 2013),

$$I_{occ} = \sum_j \mathrm{LCI}_{occ,j}\mathrm{CF}_{occ,j} = \sum_j A_{occ,j} t_{occ}\mathrm{CF}_{occ,j}, \qquad \text{Eq. (1)}$$

where I_{occ} (PDF y) is the biodiversity damage of land occupation, $\mathrm{LCI}_{occ,j}$ (m^2 y) is the life cycle inventory obtained by multiplying the land occupation area ($A_{occ,j}$, m^2) in jurisdiction j by the occupation time t_{occ} (assumed 0.30 y), and $\mathrm{CF}_{occ,j}$ (PDF m^{-2}) is the ecoregion-specific CFs from Chaudhary and Brooks (2018) (crop intensive). Country-specific values of $A_{occ,j}$ were derived from a commodity 'supply mix' representing a combination of ecoregions making up an average tonne of soybean exported to each country. This mix was obtained using the jurisdictions identified in the soybean supply chain maps that were classified into ecoregions based on the location of the majority of soybean area within each jurisdiction as identified by remote sensing (GLAD, unpublished).

Results and Discussion

Close to 70% of soybean exported in 2017 from South America to China, the EU and France (59 Mtonnes) were linked to a jurisdiction in Brazil, Argentina or Paraguay. The remaining 30% of trade could not be mapped due to missing information (e.g. state of origin, exporter, etc.). China's soybean imports from South America in 2017 spanned 26 different ecoregions, while the EU's sourcing originated from 18 ecoregions, and France 7 (Figure 1) for a total respective trade volume of 52.5 Mtonnes, 6.4 Mtonnes and 0.2 Mtonnes. The majority of soybean exported to the three countries came from the Brazilian Cerrado. Land occupation for this ecoregion was 381 m^2 y $tonne^{-1}$ for soybean exported to China, 430 m^2 y $tonne^{-1}$ for the EU, and 494 m^2 y $tonne^{-1}$ for France (Figure 2). Supply chain mapping to jurisdictions in South America allowed for a supply mix to be derived in order to calculate LCI_{occ} that is both spatially-explicit (at the same resolution as the CFs) and country-specific.

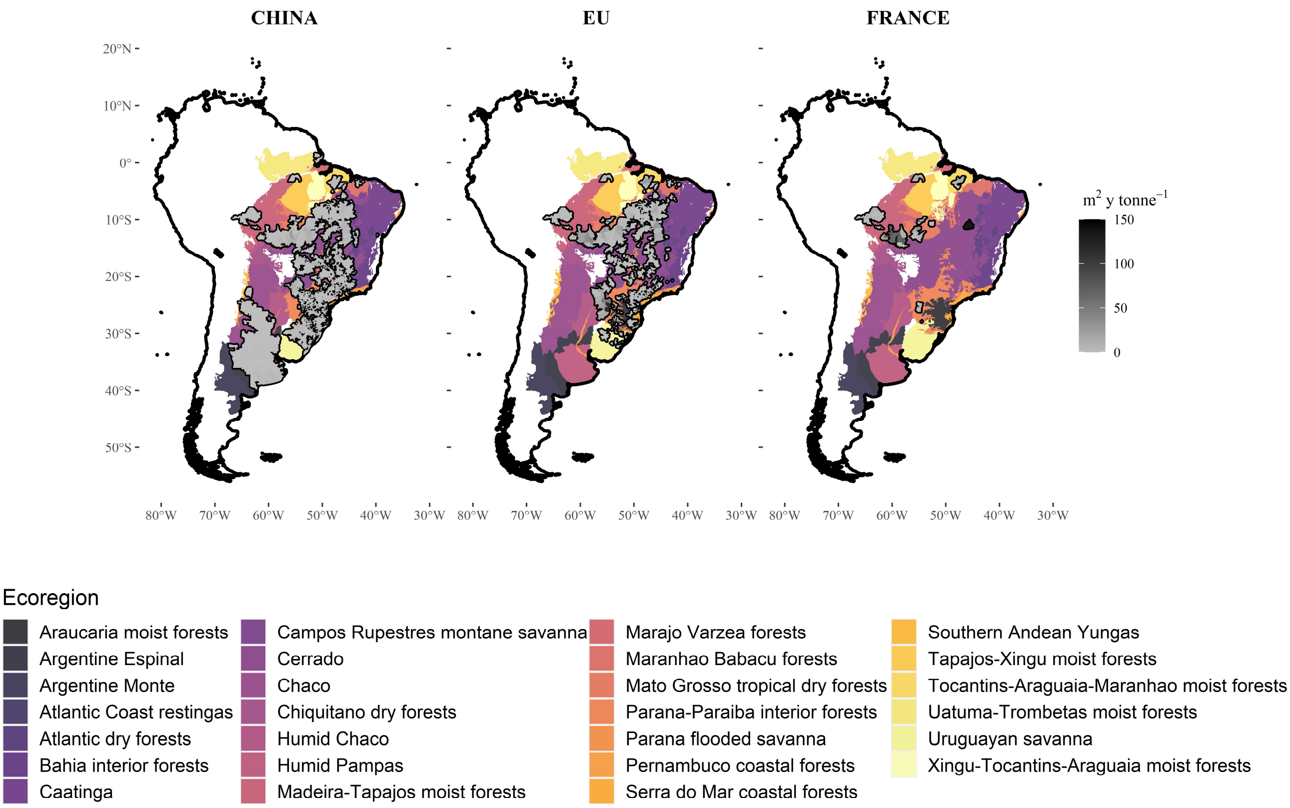

Figure 1: Life cycle inventory for the average tonne of soybean exported to China, the EU and France in 2017 from the ecoregions of South America (representing 70% of total soybean trade).

The ecoregions where soybean sourcing had the largest potential damage to biodiversity were the Araucaria Moist Forests (China), Parana-Paraiba Interior Forests (China, EU) and the Cerrado (China, EU, France), all of which are in Brazil (Figure 2). These impacts were lower for the average tonne of soybean destined to France compared to China and the EU. These impacts were also lower than those estimated using an average LCI_{occ} obtained from average land use and CFs available at the country level, thereby highlighting the importance in sub-national regionalization in LCA (Figure 2). Our regionalization of impacts also highlighted biodiversity hotspots for each export destination following the ecoregion from which soybean was sourced. As such, these countries, group of countries or actors (e.g. companies, consumers) could consider more targeted supply chain interventions in regions of production to improve the environmental performance of the commodities they use as input into their agri-food products. We also note that the results were obtained without requiring farm-level supply chain mapping, but rather mapping to a jurisdictional level which constitutes an appropriate and meaningful spatial resolution to improve regionalization in LCA.

Conclusions

We mapped the soybean supply chain of South America to provide a spatially-explicit and import country-specific LCI for more regionalized LCAs. Supply chain maps linking jurisdictions of production to country of import can help increase the regional significance of LCAs. Our results also showed that additional regionalization can be achieved without requiring commodity traceability from "farm to fork" with results pointing to regional hotspots where additional supply chain management and actions may take place.

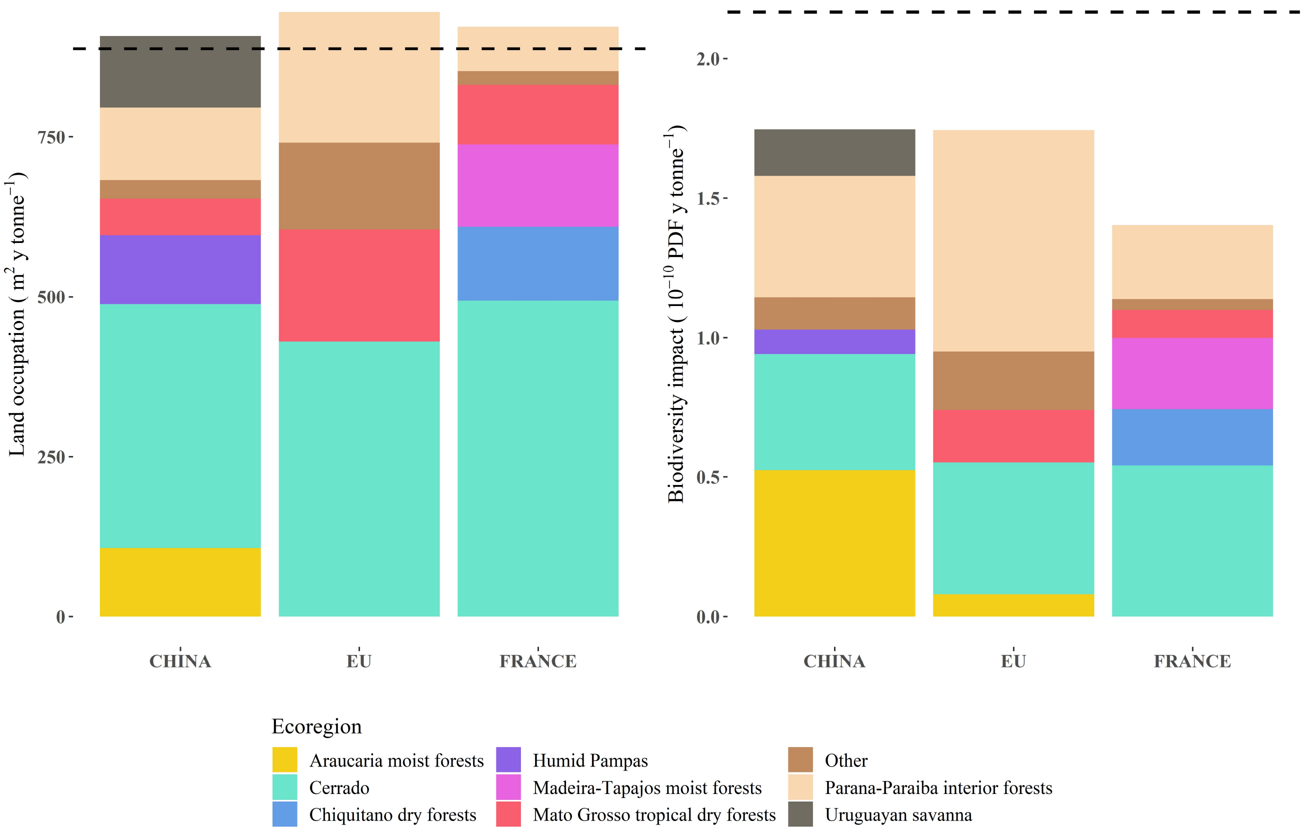

Figure 2: Land occupation (left) and potential damage to biodiversity (right) for the average tonne of soybean sourced in ecoregions of South America and destined to China, the EU and France in 2017. Results are compared to average conditions (dashed line) obtained from national average land use and characterization factors from Chaudhary and Brooks (2018) aggregated nationally.

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Abstract code: 49

Social impact of meat extended shelf-life solutions – a learning journey

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Abstract

Purpose
Companies want to understand their social impacts along the value chain. Still, metrics for social sustainability, at product level, are relatively new and not yet widely applied. The aim of this study was to gain practical experience on applying the methodology of the Product Social Impact Assessment (PSIA) Handbook and to explore different data collection tools. The methodology was applied for two Corbion ingredients for meat, offering protection against *Listeria* growth and shelf-life extension.

Methods
The assessment followed the stages described in the Handbook: Materiality assessment, Goal and Scope definition, Hotspot assessment and Impact assessment using the 5-point reference scales. The PSIA Framework defines 4 stakeholder groups, with 5-8 social topics per group. The materiality assessment led to the determination of relevant social topics. Secondary data sources, including desk research, RepRisk ESG platform and SHDB v4 (social hotspots database), were used for the hotspot analysis. Primary data collection focused on using data sources that were readily available such as SEDEX Members Ethical Trade Audit reports and company reports (e.g. from suppliers). The materiality and hotspot analysis helped limiting the number of social topics and stakeholders covered in the PSIA by identifying relevant topics and risk areas.

Results and Discussion
The PSIA of Opti.Form Ace 37 and Verdad N15 supply chain, based on primary data, confirmed that all topics examined scored "compliance with applicable standards or laws" or "progress beyond compliance", further substantiating the products' value propositions for safety and beyond by ruling out negative social impacts. The absence of negative social impact in the supply chain strengthens the credibility of the positive social impact from product use. Yet, effective communication of the results is still seen as a challenge.

Conclusions
The Handbook provided a structured approach to identify the positive and negative social impacts of products, covering both the supply chain and the use phase. The combination of the different data collection tools is necessary to obtain reliable results and to cover data gaps.

Keywords: *Product social metrics, sLCA, Food safety, meat preservation*

Introduction
Corbion wants to better understand how its business activities have a social impact throughout the supply chain and how they affect stakeholders along the value chain. To assess the social impacts of individual products or services, companies are faced with the challenge that a number of capabilities

and procedures need to be developed. Although social and environmental LCAs are based on the same concept of life-cycle thinking and share many common concepts, there are several key differences when implementing these in organizations (Saling et al 2019). In 2017, Corbion joined the Roundtable for Product Social Metrics (PSM), a cross-sector initiative to give guidance on how to measure social impacts of products and services, in a way that is recognized for its high quality, credibility and business viability.

The aim of this study was to gain knowledge and practical experience in applying the Product Social Impact Assessment (PSIA) Handbook (Goedkoop et al. 2018) and explore different data collection tools, through a case study. This study addresses the data collection challenges of PSIA by testing a wide range of primary and secondary data sources (Morão et al. 2019).

The Handbook methodology was applied to Corbion meat safety solutions offering protection against *Listeria* growth and extended shelf life. The two products analyzed, Opti.Form Ace P37 and Verdad N15, have similar functionality in terms of safety and shelf life but address different markets. Opti.Form Ace P37 is a low cost product while Verdad N15 is suitable for consumer-friendly labeling. Both products are applied by manufacturers of cooked meat products in the US.

Material and methods

The case study follows the stages described in the Handbook for PSIA (Goedkoop et al. 2018).

The scope of the PSIA covered the supply chain, manufacturing, and use of Opti.Form Ace P37 and Verdad N15, as shown in Figure 1. These products are manufactured at Corbion Blair in the US. The assessment covers two stakeholder groups: workers and users.

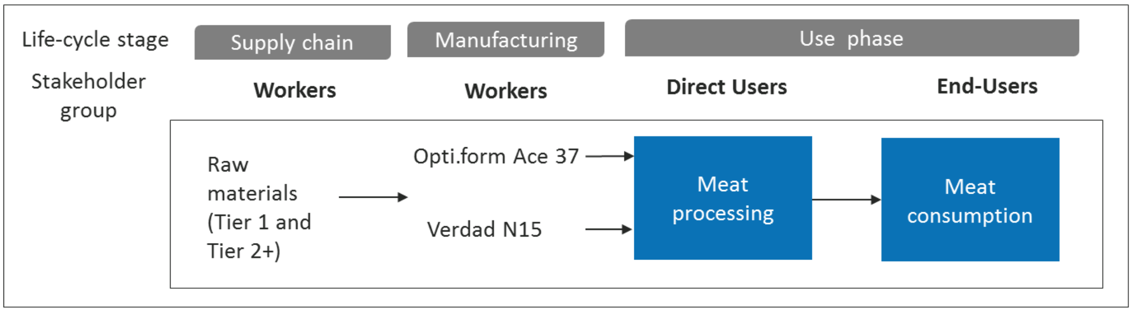

Figure 1 – System boundaries and stakeholder groups.

The relevant social topics analyzed in this study were derived from Corbion's materiality matrix, which was developed to set priorities for the company sustainability strategy. The materiality matrix visualizes the relevant social, environmental, governance, and economic issues as a function of their importance to stakeholders and companies' strategy. The Corbion materiality matrix, generated in 2017 resulted in the identification of nine material themes which have a high impact on the company strategy and were considered important by most of the stakeholders (Corbion, 2017).

Secondary data sources were used for the hotspot analysis, including desk research, RepRisk ESG platform[1] and SHDB v4 (social hotspots database)[2]. Primary data collection focused on using data sources readily available internally such as SMETA (SEDEX Members Ethical Trade Audit)[3] reports

[1] https://www.reprisk.com/
[2] http://www.socialhotspot.org/
[3] https://www.sedex.com/

and company reports (e.g. from suppliers). To interpret the collected data, the Handbook 5-point reference scale is applied to assess social performance of the different stakeholders and social topics. This scoring step is designed to consider both positive and negative impacts of products or services, as described in Figure 2. The scoring is based as much as possible on primary data and uses the Performance Indicators described in the Handbook.

Results

Five topics from the Corbion materiality matrix were linked to social topics from the PSIA Handbook, resulting in the selection of the following social topics per stakeholder group:

- Workers: Health and safety, Renumeration, Child labour, Forced labour, Discrimination Freedom of association and collective bargaining;
- Users: Health, Inclusiveness, Product safety and Responsible communication.

The hotspot assessment, a quick screening step, was used to identify the most relevant social topics. Table 1 provides a comparison of the several tools explored for this step. We found different risk areas using the different tools. The social topic child labour appeared to have a low risk regardless of the data source. The results from this step were used to give direction on the data collection requirements to conduct the scoring in the full PSIA assessment.

Table 1 – Comparison of the data collection tools for hotspot analysis.

Tool /criteria	Country-Sector specific data	Company specific data	Covers upstream value chain	Real-time data updates	Web-based	PSM topics covered
Input/output databases (SHBD and PSILCA)	+	-	+	-	-/+	+
RepRisk	+	+	+/-	+	+	+
Desk Research	+	+	+/-	+	+	+/-

For the PSIA, potential risk areas and benefits were scored using the 5-point reference scale and were based on supplier specific data sources. For the stakeholder group workers, the main primary data source for the PSIA were the SMETA reports. The data included in the SMETA reports corresponds to each of the social topics outlined in the Handbook, is validated through an independent audit process and is specific to each manufacturing site. In addition to identifying non-compliances, the reports also identify positive actions as a "good example" which were used as positive evidence for the PSIA scoring. Obtaining primary data for Tier 2 or Tier 3 suppliers was more challenging and not always possible as it requires in depth knowledge of the value chain. When SMETA reports were not available, several additional data sources from company reports & documents (i.e. annual reports, CSR reports, policy documents, code of conducts and press releases) were consulted.

The scoring of workers in the supply chain showed that most areas score in compliance or progress beyond compliance, despite the findings in the hotspot analysis. The high-risk topics identified in the hotspots assessment were not confirmed by the scoring results/more detailed company specific analysis. Actually, the primary data showed the score can even be positive for some suppliers. This example confirmed the importance of checking issues flagged during the hotspot analysis.

Discussion

The materiality and hotspot analysis proved to be useful in reducing the amount of primary data required to conduct the scoring by limiting the number of social topics and stakeholder groups that are relevant and need to be covered. Our experience showed that RepRisk and SHDB can be very useful for a quick hotspot analysis for workers but need to be complemented with primary data or by desk. However, primary data for Tier 2 or Tier 3 suppliers remains challenging. The two supply chains analyzed in the study were similar resulting in very small differences in the PSIA. This also means that, for future cases, the scoring of the value chain may be re-used, reducing the effort required in terms of data collection and interpretation.

The PSIA provides a structured approach to identify the social impacts of a product on users. However, unlike for the workers group secondary data tools could not be applied. Additionally, for a company that deals mostly in the B2B segment, some of the Performance Indicators (PIs) for users were hard to apply. Currently, the Roundtable members are using this experience to improve the practical applicability and robustness of the PIs.

The assessment of Opti.Form Ace 37 and Verdad N15 supply chain confirmed that all topics examined scored "compliance with applicable standards or laws", or "progress beyond compliance", further substantiating the products' value propositions for safety and beyond by ruling out negative social impact. The absence of negative social impact in the supply chain strengthens the credibility of the positive social impact from product use. For example:

- The positive impact of the products Opti.Form Ace 37 and Verdad N15 in terms of food safety, were justified by the performance of the products against *Listeria*.
- Verdad N15 contributes to consumer health as it enables low sodium meat products.

The value of the PSM studies will benefit from showing the results from the scoring using the 5-point reference scale. However, communication of results in an effective and transparent way, yet protecting the companies data remains challenging. More cases are needed to further explore and develop suitable approaches.

Conclusions

The Handbook provided a structured approach to identify the positive and negative social impacts of products, covering both the supply chain and use phase. The combination of the different data collection tools is necessary to obtain reliable results and to cover data gaps.

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Abstract code: 97

geoFootprint: the interactive web-application for modelling spatially explicit agricultural footprints

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Abstract

Purpose: Agriculture is a major contributor to greenhouse gas emissions and impacts on soils and ecosystems. Inventory data, the data foundation used to quantify agricultural impacts in Life Cycle Assessment, are however generic and incomplete, i.e., are typically defined at country level and limited to a few countries. We present geoFootprint, a regionalization platform which facilitates exploration, manipulation and assessment of spatially explicit life cycle inventories of 15 key crops on a global scale.

Method: Deployed around a spatial database, a regionalization engine and a web-based platform, geoFootprint integrates publicly available geospatial data into LCA calculations. The regionalization engine combines various spatially-explicit attributes, LCI datasets provided by the World Food LCA Database (WFLDB) and different agricultural emission models to compute regionalized inventories and corresponding footprints of 15 crops and their co-products for any location in the world, and across various geographical scales (10x10 km grid-cells up to country level). The web-based platform allows the interactive, crop-specific exploration and manipulation of key information (related to management, context and footprint) at various spatial scales of interest (grid-cell-, jurisdictional-, and country level), facilitates the simultaneous re-calculation of hundreds of footprints, and provides direct link to farm level modelling through the Cool Farm Tool.

Results and discussion: geoFootprint calculates regionalized crop inventories for each 10x10 km grid-cell where crop production takes place. To date, it comprises about 4 million regionalized crop inventories. We assess these inventories according to 12 environmental metrics, covering impact categories such as climate, water, ecosystems and biodiversity. We leverage this data foundation in our interactive web-based platform. This facilitates an unprecedented support for different key actors in the agricultural domain: private companies are able to understand, assess and manipulate the potential environmental benefits for specific cultivation practices simulated though large-scale scenarios; (non-)governmental organizations can identify pockets of environmental risk and underlying drivers on a global scale; the research community receives access to a test environment to test and improve LCA-based models in the agricultural domain.

Conclusions: geoFootprint pushes the boundaries of LCA to a new level and will trigger new opportunities for research in the fields of remote data generation and harmonization, spatially explicit emission modelling and regionalized impact assessment. It aims to be the first step toward an enhanced capacity to assess, measure and monitor how different agricultural practices can drive society to more sustainable food production systems at regional and global scale.

Keywords: *Agriculture; footprint; regionalization; LCA; agriculture footprint; geofootprint*

Introduction

Agriculture is a major contributor to greenhouse gas emissions and impacts on soils and ecosystems. In an effort to align with sustainability goals, many companies have committed to reduce their footprint through their agricultural practices. To assess improvement potential and track progress, life cycle assessment (LCA) is used as a reliable and comprehensive tool. Today, however, life cycle inventory (LCI) data for agricultural production systems remain generic and incomplete. Datasets are typically defined at country level and limited to a few countries per crop. This is a significant limitation considering the spatial variability inherent to cultivation systems (Reinhard et al. 2017).

The geoFootprint tool (www.geofootprint.com) presented in this work represents a new frontier in environmental footprint modelling of crops. Deployed around a regionalization engine and a web-based platform, geoFootprint combines publicly available geospatial data with LCI datasets provided by the World Food LCA Database (WFLDB) (Nemecek et al. 2019) as well as the needed agricultural emission models and thereafter characterisation factors to compute and display regionalized footprints of 15 crops (incl. maize, rice, wheat, oil palm, soy, cotton, sugarcane etc.) and their co-products (e.g. maize stover, wheat straw) for any location in the world, and across various geographical scales (10x10 km grid-cells to country level). This effort is made possible through a unique partnership between Quantis (www.quantis-intl.com) the Cool Farm Alliance (www.coolfarmtool.org) and arxiT (www.arxit.com), with the support of a global network of private agri-food companies and public organizations such as FAO, UNEP, SAI Platform, Word Resources Institute and the Swiss Federal Office for Agriculture.

Material and methods

The geoFootprint architectural structure and methods are developed around three key components (Reinhard et al. 2020):

1) a spatial database providing instant access to harmonized spatial data as well as default agricultural inventory data from WFLDB and ecoinvent (www.ecoinvent.org) (e.g. crop maps, yields, fertilizer inputs, irrigation intensity, etc.),
2) a regionalization engine operationalizing the modeling guidelines of the WFLDB (Nemecek et al. 2019) and the Cool Farm Tool (CFT) (Kayatz et al. 2020) to generate spatially explicit crop model inventories and footprints at a resolution of 10x10 km,
3) a web-based platform which facilitates the interactive navigation, exploration and manipulation of environmental key characteristics (e.g. temperature, soil properties), management practices (e.g. fertilizer application rate, tillage practices), and corresponding footprint results (e.g. climate change, soil erosion, water scarcity, eutrophication) associated with the cultivation of a given crop for any location globally.

We use (1) and (2) to compute regionalized crop inventory datasets. We perform this regionalization by combining spatially-explicit attributes on crop-characteristics (harvested area, yield, fertilizer application rates, irrigation requirement) and on environmental conditions (precipitation, tree cover area loss, soil properties and terrain) with the most representative (WFLDB) default crop inventory dataset on the country-level. For each specific 10 x 10 km grid-cell where cultivation of a particular crop takes place, we retrieve the corresponding crop-characteristics and environmental conditions and feed them into an array of inventory and emission models which produce and overwrite all flows of relevance in the default crop inventory datasets template (e.g. land occupation and transformation, irrigation, NPK & organic fertilizer types and application rates, carbon dioxide from land use and land use change, dinitrogen monoxide and methane from various sources, ammonia, nitrate and phosphate leaching, etc.). That is, we generate comprehensive regionalized agricultural unit process datasets on the grid-cell level under full consideration of various spatial input parameters (Reinhard et al. 2020).

Different Application Programming Interfaces (API) allow interactions between the regionalization engine, the web-based platform and the CFT as an external module. Users can thus re-compute

specific scenarios and address farm-level and large-scale assessments via one platform. Developed in a flexible way, the geoFootprint computational framework enables to process regionalized inventory information and corresponding footprints in a comprehensive way opening possibilities for additional crops and impact indicators integration.
Importantly, developing a spatially-explicit tool unlocks novel possibilities to Land Use (LU) and Land Use Change (LUC) inventory modeling – two key drivers of environmental impacts. Combining spatially explicit data from the Global Forest Watch platform (www.globalforestwatch.org) and from EarthStat (www.earthstat.org), geoFootprint applies a shared-responsibility approach to allocate LUC to individual crops. The carbon fluxes associated with LU and LUC are integrated as part of the inventory modeling and directly considered in the final footprint of the crop of interest.

Results

geoFootprint calculates regionalized crop inventories for each 10x10 km grid-cell where crop production takes place. To date, it comprises about 4 million regionalized crop inventories. Per crop, the number of regionalized inventories varies between 104’000 (oil palm) and 521’000 (maize). Operating on the technical foundation and naming convention of existing inventory databases, we can characterize the flows in the regionalized crop inventory table according to their environmental importance. To date, we calculate 12 environmental metrics. We compute crop-specific soil erosion, changes in soil organic carbon and nitrogen use efficiency to approximate environmental impact on soil quality. Further, we calculate climate change, eutrophication and acidification impacts. We also apply recently developed regionalized impact assessment methods for water and biodiversity (Chaudhary et al. 2015; Boulay et al. 2018).
We leverage this data foundation through an interactive web-based platform that offers a series of functionalities such as a) environmental footprint and contribution analysis per main stages for every grid cell, sub-national jurisdiction and country, b) weighted average environmental footprint for any aggregation of grid cells or jurisdictions, c) footprint per hectare or per ton of harvested crop and co-product, d) customizable map views and color scales, e) change of system of units from metric to imperial, f) import and export of data, g) modification of cultivation inputs and practices for recomputation of customized footprints. The web-based platform was designed after capturing, in one-to-one interviews, the functional and non-functional needs from 15 major public and private stakeholders in the agri-food sector. Feedback from these potential users was also captured after testing beta versions of the platform.
Figure 1 and Figure 2 show the potential of the tool to provide global maps of climate change impact, crop-specific management practices and other contextual information at the grid-cell level. Figure 1 illustrates the climate change impact of oil palm production displayed at the grid-cell level (10 x 10 km) for Indonesia. Impacts are displayed in kg CO_2-eq per hectare. Only grid-cells with oil palm production show impacts, i.e., are colored in red. The darker the color, the larger the impact.
When selecting a specific area, the user receives access to a wide array of information (Figure 2). (1) shows the toolbar where the user can select the aggregation level (grid-cell, sub-national level 2, sub-national level 1, country), crop, metrics and legend. (2) shows the benchmark section, where the production-volume weighted impact of the selected area is compared to the average crop impact of the corresponding sub-national level 1 jurisdiction (Kalimantan Timur) and country (Indonesia). (3) shows the contribution associated with the various man-made input and output of the agricultural crop production. (4) shows the tabs which allows to navigate between regionalized key information of the crop, the management practices and local context. (5) shows a map highlighting the user selection (note that sub-national Level 2 is selected). (6) indicates global key information regarding the selected crop. (7) shows the scenario navigation bar which facilitates, in the licensed version of geoFootprint, the definition and execution of advanced scenarios. Note that because of the static property of the print-screen, these only outline very few of all geoFootprint functionalities.

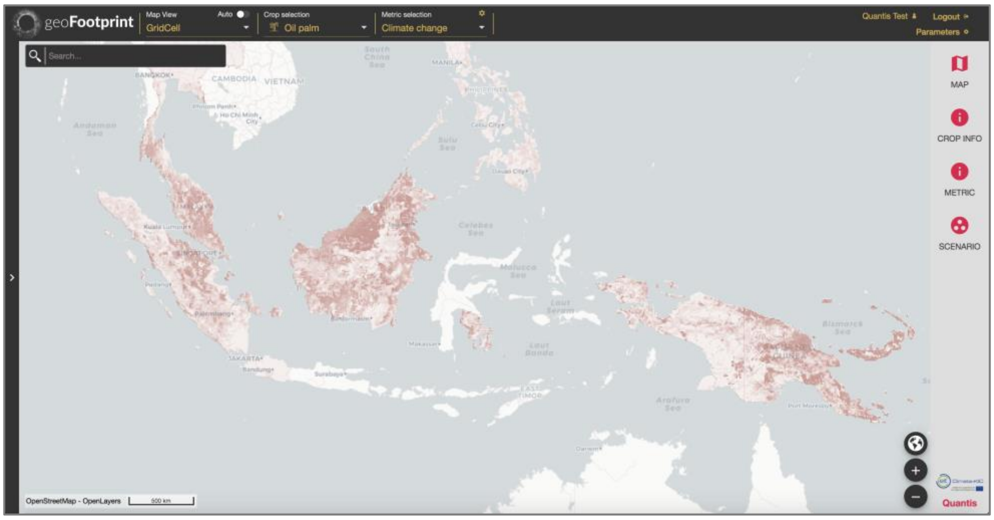

Figure 1: Print-screen preview of the geoFootprint web platform (at current status of development) with climate change impact related to oil palm production in Indonesia displayed at the grid-cell level (10 x 10 km).

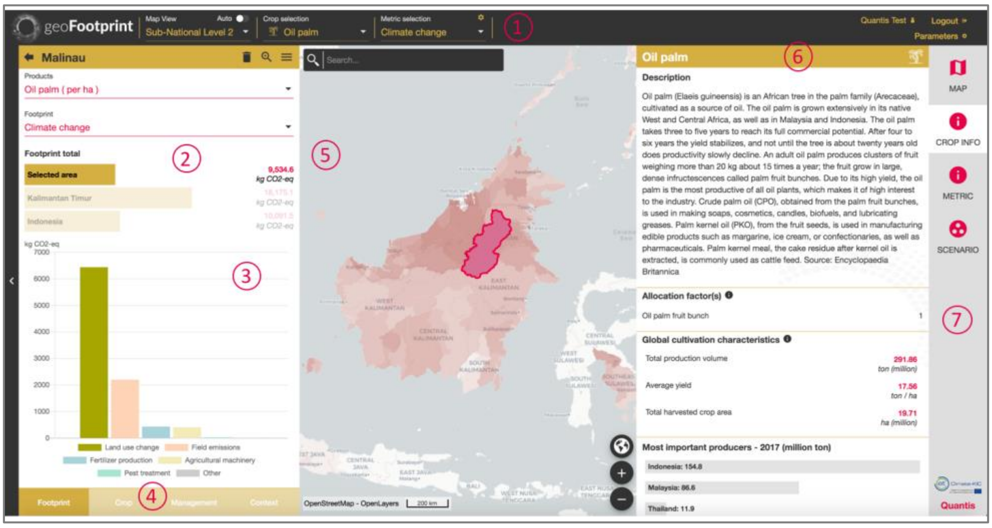

Figure 2: Print-screen preview of the geoFootprint web platform (at current status of development) with climate change impact related to oil palm production at sub-national level in the Malinau regency, Kalimantan Timur, Indonesia.

Discussion

geoFootprint generates regionalized agricultural inventories and thereafter footprints of agricultural key commodities in a user-friendly web platform at an unprecedent spatial resolution of ~10x10 km, on a global scale. Intuitive and easy to use, geoFootprint allows to prioritize action where it matters most and better measure, monitor and manage sustainable agricultural crop production. Its unique top-down modelling approach brings a long-awaited complement to bottom-up, farm-level assessment tools and methods. Doing so, it also opens the door to highly regionalized land use and land use change assessment and monitoring. Continuous improvement of the spatial and temporal representativeness of input data will be key to ensure the validity of the calculated footprints and their relevance in supporting decision-making for a more sustainable agriculture. Transparency of data and methods and multi-stakeholders' collaboration are seen as a key success factors and are central to the initiative.

Launched in the end of 2020 as an open-access (read-only) and as a licensed version (enabling custom scenario simulations), geoFootprint aims to support a variety of different actors: private companies with agricultural supply chains, by providing highly granular data and assessing the potential environmental benefits for specific cultivation practices simulated though large-scale scenarios; (non-)governmental organizations, by highlighting pockets of environmental risk and underlying drivers globally; the research community, by providing a test environment for improving LCA-based models in the agricultural domain and access to regionalized agricultural LCI and footprint data across different scales.

Conclusions

geoFootprint pushes the boundaries of LCA to a new level and will trigger opportunities for research in the fields of remote data generation and harmonization, spatially explicit emission modelling and regionalized impact assessment. It aims to be the first step toward an enhanced capacity to assess, measure and monitor how different agricultural practices can drive society to more sustainable food production systems at regional and global scale, leveraging the massive amount of spatial data collected daily through remote sensing. With the involvement of the community, private, public and non-profit, and driven by a common objective, geoFootprint will keep on evolving and will support all actors in the value chain in making a positive, transformative change.

Acknowledgements

We are grateful for the financial support from EIT-Climate KIC (www.climate-kic.org) as main co-funder, and all private companies who have supported the project since 2018.

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Abstract code: 446

Process Model and Life Cycle Assessment of Irish Demineralized Whey Powder

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Abstract

Life cycle assessment (LCA) is a mature tool to quantify the environmental impact of a product, process or service. In Irish dairy plants, activity data are usually only available collectively across multiple processes. For example, electrical and thermal energy are monitored collectively for unit processes such as the evaporation and spray drying, rather than for each process separately. This creates a problem for creating activity data for each unit process. The objective of this study was to use a process model to calculate activity data for different processes with its operating conditions to allow greater insight into the mass and energy balance. The activity data from the validated process model were used to conduct a LCA. SuperPro Designer software was used to develop the process model and GaBi software was used to conduct a gate-to-gate LCA. Process data were collected primarily from the dairy factory and secondary data from the literature. Carbon footprint calculated for demineralized whey powder (D90) was about 0.904 kg CO_2eq./kg and the relative contribution from the thermal energy, electrical energy, transport, packaging, and chemical agents were about 0.674, 0.144, 0.010, 0.030 and 0.046, respectively. Thermal energy (steam) was generated onsite using natural gas in a CHP plant & boilers and using onsite biogas generated from anaerobic digestion plant in a dual fuel boiler. Using nanofiltration (NF) which increased whey solid content from 6.4% to 23% before evaporation and drying operation reduced the thermal energy consumption to evaporate the water per unit output, thereby reduced the carbon footprint of demineralized whey powder. This Irish dairy processing plant is an example of circular bio-economy applied in practice to produce Irish D90 in a sustainable manner after using a dairy wastewater as a feedstock for the biogas generation in an onsite anaerobic digestion (AD) plant and used as fuel for steam production.

Keywords: *Life Cycle Assessment (LCA); 90% Demineralized Whey powder (D90); Anaerobic digestion (AD); TVR – Thermal Vapor Recompression*

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1. Introduction

Sustainable production of dairy products is a major challenge. The predominant method to quantify environmental impacts is Life Cycle Assessment (LCA). Demineralized whey powder (D90) is used as an ingredient for the manufacture of infant formula, but has not been the focus of LCA studies found in the literature. For the dairy sector, most of the LCA studies published in the report and scientific publications have focused on milk production, which accounted for almost 90% of the carbon footprint of dairy products (Nutter et al. 2013). However, we cannot neglect to quantify the environmental impacts of dairy processing stage. It is important to quantify the carbon footprint associated with the dairy product from farm gate to dairy factory gate including all the upstream activities to find the hotspot in the demineralized powder production process to explore the possibility in reducing the energy consumption. Moreover, It is often the case when a gate-to-gate LCA is conducted that the inventory data for utilities and resources used represent several products collectively. To solve this problem, allocation based on solid content was used in most of the LCA studies on dairy products in the literature to partition the utility and resources consumption at each unit process. Feitz et al. (2007) proposed an allocation method based on solid content and stated that using allocation based on solid content revealed the underlying causality especially for the powder production where water evaporation was the main operation and this method was also recommended by IDF (2015). However, in this study, the approach taken was bottom-up (process-based) where processes are divided into a common and unique process similar to a study by Aguirre-Villegas et al. (2012) and allocation based on solid content was only used for the supporting processes such as dairy wastewater treatment plant and packaging. For the rest of unit operations, the activity data were generated using a process simulation model (SuperPro Designer).

Process modelling is extensively used in the petrochemical industry, however, the dairy sector lags behind the chemical industry because of the complexity involved in the biochemical transformation taking place while the product undergoes temperature variation in each unit process along the production line (Madoumier et al. 2015). Furthermore, since the process data are often only available in aggregate form, in this study, the process model was used to simulate the unit process for the mass and energy balance at each key unit process. Therefore, the objective of this study was to develop and validate a process model using predefined unit process modules and conduct LCA for the Irish demineralized whey powder.

2. Material and methods

2.1 Facility details

The facility of the analyzed dairy processing plant consists of a 10 MW_e combined heat and power (CHP) providing 84 % of thermal energy and 94 % of electricity demand. The remaining 16 % of thermal energy was supplied equally by natural gas and biogas. The biogas was generated onsite in an anaerobic digestion (AD) plant by using dairy wastewater as its feedstock. The plant imported 6% of its electricity from the national electricity grid mix.

2.2 Description of process model for D90 production process

In this study, sweet whey (6.4% total solid) processed for the manufacturing of demineralized whey powder had three sources one within the plant and two from other factories. A transport distance of 30 km was included from one of the source of sweet whey representing about 18% and the transport of remaining whey was not included as cheese factory is located near the dairy powder processing plant. Whey from different sources was collected in a storage tank and then undergone through a membrane filtration process to preconcentrate the whey to a 23% dry matter. Electrodialysis and ion exchange process reduced the mineral content of the whey to a 90% before passing it to a multi-effect evaporator with a Thermal vapor recompression (TVR). Since the whey from cheese plant and casein production within the plant passed through two different multi-effect evaporators and some demineralized whey concentrate was sold to a third party, thus, to simplify, whey separated from the casein production was not included for this LCA study. Eventually, the demineralized whey powder with a 97.5% solid content was produced in a spray drying unit operation.

2.3 LCA methodology

The LCA was limited to evaluate the GHG emissions for the production of Demineralized Whey Powder and this gate-to-gate LCA was analyzed by following the ISO 14040 and ISO 14044 standards (ISO 2006a; 2006b). The system boundary consisted of all the upstream activities, for example, different fuels used to generate the electricity, onsite burning of natural gas fuel for the steam production in the CHP plant, production of packaging material, chemical agents used in the cleaning-in-place (CIP) and transport of whey to the processing plant as shown in the Figure 1. GaBi software was used as a modeling tool to model the Irish D90 production process and the GaBi database was used for all the upstream activities. The functional unit was 1 kg of D90 produced and life cycle inventory was based on the primary data collected from the dairy factory. The primary data such as electricity and steam consumption at each unit process were in a collective form and to include more details regarding mass and energy balance at each key unit process with operating condition, a process flowsheet model was developed using a SuperPro Designer software.

The approach taken was to model the key unit processes such as separation, pasteurization, membrane filtration, evaporation and spray drying by considering the operating conditions at each unit process in order to compute the mass and energy balance using pre-existed generic models available in a SuperPro Designer software. Then, each key unit process model was parameterized and calibrated with the aggregated electrical and steam consumption data collected from the dairy processing factory. The model was validated for a different time period and then used to calculate the unit process activity data required for the life cycle inventory.

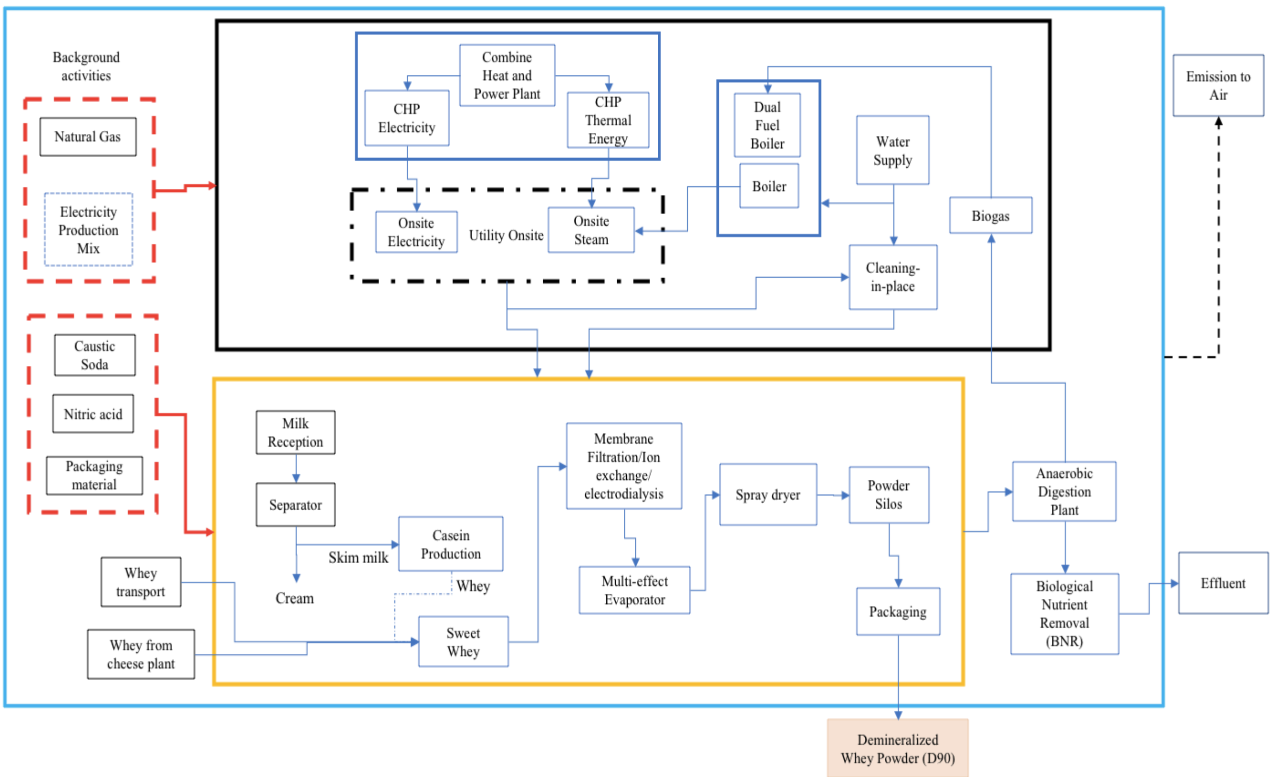

Figure 1. System boundary diagram (blue box) for the analyzed gate to gate LCA of 90% Demineralized Whey Powder (D90). Black border represents utilities (electrical and thermal), Red dashed line border represents background activities and orange border represents unit processes at the dairy processing plant.

3. Result and Discussion

The climate change impact was calculated to be 0.904 kg CO_2 eq. per kg of D90. The relative contribution from the thermal energy, electrical energy, transport, packaging, and chemical agents were about 0.674, 0.144, 0.010, 0.030 and 0.046, respectively. The climate change impact is shown in Figure 2. for the production of one kg of 90% demineralized whey powder.

Transport contributed relatively small amount because only 18% of whey was transported from another dairy plant located 30 km from the existing plant and the remaining 82% of whey was supplied from a cheese plant located near the dairy processing plant. The evaporator (i.e. 5 effects Thermal Vapour Recompression (TVR)) consumed electrical energy and thermal energy of around 0.03 and 1.25 kwh/ kg D90, respectively. The total electrical energy and total thermal energy consumption was low due to using nanofiltration (NF) which concentrated sweet whey from 6% to 23% total solid, thus, reduced the amount of water content of whey for further evaporation in the subsequent evaporation processes such as in the evaporator and drying unit operation. Moreover, the spray drying unit operation was the most energy intensive process represented about 60% of total thermal energy consumption and total thermal energy consumed contributed about 70% of the total global warming potential (GWP).

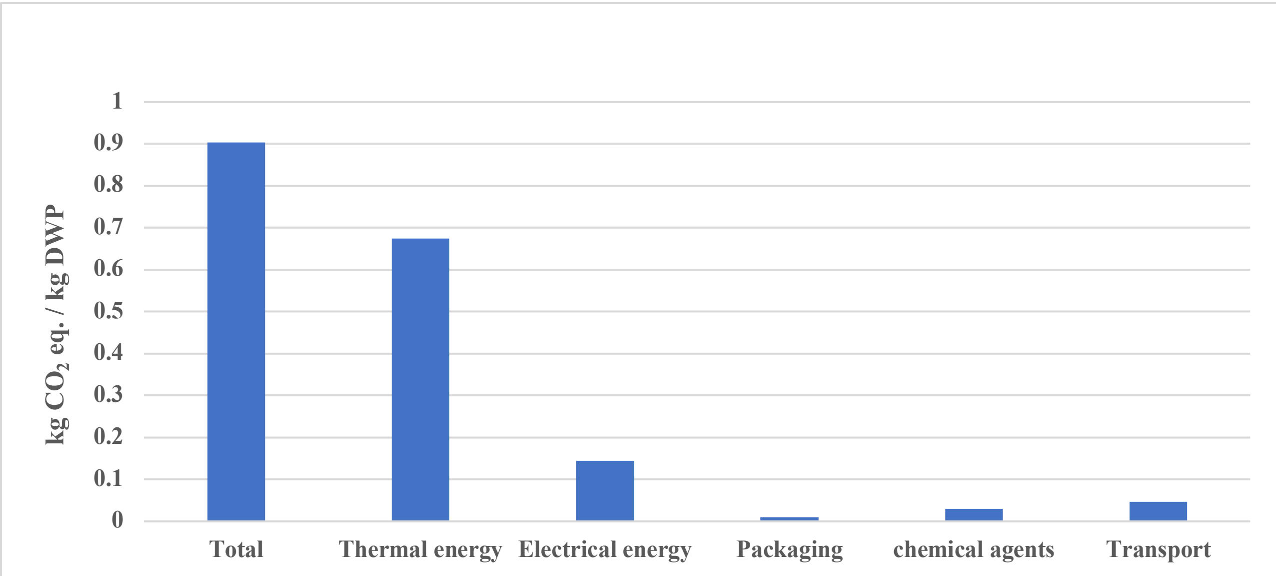

Figure 2. Greenhouse gas (GHG) emissions result per one kg of the Irish Demineralized Whey Powder (D90).

The total climate change impact calculated for D90 manufactured in this Irish dairy processing plant was highly influenced by the choice of fuel for the steam production onsite, for example, natural gas used as a fuel for the CHP plant to produce both electricity and steam, onsite biogas produced from the anaerobic digestion (AD) plant as a fuel for boiler to produce steam and using natural gas for other two steam boilers. Moreover, using Nano-filtration (NF) in combination with Electrodialysis (ED) and Ion Exchange (IE) to reduce 90% minerals content of the sweet whey before evaporation and drying unit process had reduced the overall steam usage for producing a 90% demineralized whey powder. The main application of 90% demineralized whey powder is in the infant milk formula (IMF) where mineral content of whey must be reduced to match with the mineral content of the human milk.

4. Conclusion

In this research work, the carbon footprint calculated was about 0.904 kg CO_2eq. for one kg of 90% demineralized whey powder. This study was the first Irish study on combining the process model with LCA to evaluate the carbon footprint of an Irish demineralized whey powder. Since there was no other studies in the literature for the LCA on demineralized whey powder, no comparison was possible. The use of the simulation model allowed greater technical insight and certainty than would be possible using a top-down approach where environmental burden are allocated among products passing through shared equipment.

5. Acknowledgement

I would like to acknowledge the Dairy Processing Technology Center (DPTC) for providing research fund (Grant Number TC/2014/0016) to conduct this research work and DPTC industry partner for providing the industry data of the plant to make it possible to conduct this research work.

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Life cycle assessment of pets and companion animals in Switzerland

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Abstract

Purpose: Pets are an important leisure activity in industrialised countries. From the point of view of ecological consumption, the question arises whether this is relevant from an environmental point of view. For the first time a full life cycle assessment study was carried out to examine the environmental impact of Swiss pet ownership.
Methods: The study was carried out as part of an internship and examined six animal species frequently kept in Switzerland: horses, dogs, cats, rabbits, ornamental birds, and ornamental fishes. All relevant influences on the environment are recorded in the life cycle inventory analysis. This includes feeding, housing, feces, car journeys and other purchases caused by the pet. The relevant environmental aspects were evaluated using two impact methods: the global warming potential and the method of ecological scarcity (eco-points) as a measure for total environmental pollution or impact. The decisional unit for analyzing and comparing the alternatives is one year of keeping one or group of animals.
Results and Discussion: It was found that the impact increases with the size of the pet (and thus the feed requirement). The larger and heavier the animal, the higher the environmental impact. Other aspects, such as housing, can vary greatly depending on the species. The analysis shows that specific decisions regarding the keeping of a pet can have a considerable influence on the environmental impact. A key factor here is the feeding of the pet. Compared to the average consumption of a person living in Switzerland, the keeping of a horse used by one single person would increase the related environmental impacts by one third. For the keeping of a dog it would be around six percent, for smaller animals the increase in pollution would be three percent or less.
Conclusion: The average Swiss consumption of products (food, textiles, equipment, etc.) and services (travel, events, public utilities, etc.) is a burden on the environment. The keeping of an animal can have a relevant influence on this individually caused environmental pollution, especially in the case of large animals such as horses. However, with a view on Switzerland as a whole, the keeping of pets is of secondary importance. In 2015, it accounts only for about 1.2 % of the total environmental pollution caused by the Swiss consumption.

Keywords: *pet food, companion animal, decisional unit, dog, horse, cat.*

Introduction

Animals have been loyal companions throughout human development for thousands of years. In the beginning, the purpose of animal husbandry was almost exclusively the supply of products such as meat, milk, eggs, leather and wool or even protection from wild animals. Thus, the animals kept by humans were almost exclusively farm animals. Today, animals are often kept as pets. As such they are part of the personal lifestyle of the owner.

Purchasing and keeping pets trigger a certain environmental impact. Depending on the animal species and husbandry, these impacts on the environment and the consumption of resources vary in magnitude. They must be added to the personal environmental footprint of the animal owners. To date, there are no detailed and public life cycle assessment studies on the environmental impact of keeping pets known to us. Therefore, this life cycle assessment examines the environmental impact of keeping different common species of animals as pets in Switzerland. This paper presents the summary version of the full German report on the study from Annaheim et al. (2019). It addresses the following research questions:

- How large is the potential contribution of a pet to a person's personal environmental balance over one year?
- How do the environmental impacts of distinct types of pets differ?
- Which influencing factors are relevant and how?
- How large is the contribution of pets to the overall burden of Swiss final consumption?
- What possibilities are there for reducing environmental impact, or how does the impact change if there is a change in attitude?

Methods

The studied species of animals are horse, dog, cat, rabbit, ornamental fish and ornamental bird. All these animals are mainly kept as pets. In this study, considered as not yielding any material benefit to its owner as it would for example be the case for police dogs, draught horses, or fishes in public aquariums. Certain animals, like the ornamental fish, the ornamental bird and the rabbits, should not be kept alone. Therefore, for these animals, the evaluations refer to an animal-friendly number of individuals.

The scope of the life cycle inventory (LCI) includes the breeding, feeding, housing, energy consumption, transport, disposal of urine, faeces, dung, and purchases of other necessary objects like toys. For certain feeding products like straw or slaughterhouse waste, which are side products of processes, their environmental impact is allocated due to their economic value. Complete statistical data on average pet ownership in Switzerland is not available. Therefore, realistic basic scenarios for different animal species are calculated based on own assumptions. These reflect a typical type of husbandry. Data on feed quantities, required equipment and the resulting expenditure are taken from Internet sources, with the assumed quantities being validated by various sources.

Background data are taken from data packages included in the SimaPro 9.1 software and the data available in the ESU service's company internal database (ESU 2020, Jungbluth et al. 2020a, b). The full LCI documentation is available in the digital EcoSpold format for sale.

The impact assessment methods used to assess the environmental impact are the Global Warming Potential 100a (GWP, IPCC 2013) including the full effects of aviation (Jungbluth & Meili 2019) and the Ecological Scarcity 2013 Method (Frischknecht et al. 2013).

The results are calculated and presented for the unit "keeping an animal as a pet in a Swiss household or farm for one year". This allows an evaluation in terms of the research-questions mentioned in the chapter above. However, this unit does not match with the definition of the "functional unit" according to the ISO 114040/44 standard (International Organization for Standardization (ISO) 2006). Strictly speaking, different pets are hardly comparable in the sense of the ISO standard. Too different are the needs that different animals can meet and too individual are the reasons to buy a pet (leisure, education, social contact, health etc.).

The approach is justified by the practical questions' consumers have. If, for example, the purchase of a pet is considered in principle, then various aspects are discussed in a family before a decision is taken. Environmental aspects may be one of the criteria to make such a decision. In this sense, we think LCA should also be used to guide them from an environmental point of view.

Other examples on consumer questions have been elaborated in the past (e.g. for drinking typical beverages Jungbluth & König 2014). In such studies there is no strict comparability as in product LCA, but they can certainly help to compare personal lifestyle decisions and present them from the perspective of the entire life cycle. These studies thus contribute to making personal lifestyles more environmentally friendly and to supporting decisions in this regard.

To make the difference compared to a comparative product life cycle assessment clear, we speak in this study of a "decisional unit" and not of a functional unit.

Results

The total average consumption of a person living in Switzerland causes about 23 million Swiss eco-points (or short UBP for Umweltbelastungspunkte) or 14 tons of CO_2 equivalents in one year (Frischknecht et al. 2018, climate change potential without RFI). This already includes the average number of animals kept.

However, depending on the choice of the pet, its keeping can more or less influence the environmental impact of a single person. To calculate the impact of pets per person, the number of people living in the household and who can benefit from the animal must also be considered.

Figure 1 shows the results for different animals. It highlights that keeping a horse has the largest environmental impact. It is by far the largest and heaviest animal of the species studied and therefore has the highest need for feed. This accounts for a substantial proportion of the impact. Keeping a horse leads to 8.5 million UBP per year, which corresponds to 37 % of the average yearly environmental impact from consumption of a person living in Switzerland. The smaller the animals and their feed requirements, the lower their environmental impact. For a dog with a burden of 1.4 million UBP per year, it is in the range of about 6 % of the burden of the average Swiss consumption of a person. A cat leads to 537'000 UBP per year and thus to 2 % of the pollution caused by consumption. The exposure from keeping two rabbits is similar, a group of fifty ornamental fish in an aquarium account for just over 1%, and four ornamental birds for less than 1 %.

For aspects other than feeding, their influence on the environmental impact varies depending on the species. Therefore, different scenarios regarding the keeping of the different pet species were estimated. For horses, as stated before, the feeding has the highest influence, followed by the shelter and the bedding. The scenario of keeping a tournament horse slightly increases the overall impact, measured with UBP (+7 %), while changing the bedding from straw to woodchips may lower it (-20 %). Alternative feeding of only grass, hay, straw and concentrate can lower the impact about another 21 %.

Changes in feeding can also lead to the opposite effects as seen drastically for cats and dogs. BARF ("Biologically Appropriate Raw Food") is the practice of feeding a high concentration of raw meat and bones to dogs or cats. Therefore, within the BARF scenario, the overall environmental impact triples compared to the standard nutrition of cats and dogs. More detailed insight on the different scenarios of pet husbandry can be found in the full report on the study.

For calculating the overall environmental burden of pets in Switzerland these results have been multiplied with the number of pets kept. Cats contribute the most to it as seen in Figure 2. They generate over 879 billion UBP annually and are responsible for 655 million kg of CO_2 equivalents. Horses and dogs are also truly relevant to the overall balance (658 billion UBP and 244 million kg CO_2 equivalents, 706 billion UBP and 506 million kg CO_2 equivalents respectively). A comparison with the total environmental impact (from final consumption) of the Swiss population over one year (Frischknecht et al. 2018) shows, that the environmental impact from pets only contributes about 1.2% to it, either measured with UBP or kg CO_2 equivalents. Horses and dogs account for a similar proportion of the UBP (0.34 % and 0.37 %), while cats are slightly higher, at 0.46 %. In terms of global warming potential, cats dominate more clearly with 0.57 %, followed by dogs with 0.44 % and then horses with 0.21 %.

Discussion and Conclusion

For the first time, an LCA study provides a comprehensive and good insight into the environmental impact caused by keeping pets. It shows that, depending on their size, pets can account for a sizeable proportion of the pollution caused by a person living in Switzerland each year. According to Dao et al. (2015), the limit for a planet-compatible level of greenhouse gas emissions is 0.6 tonnes of CO_2 equivalents per person and year. This value is already significantly exceeded by keeping a horse, without the person who owns the animal having consumed yet in any other way. This shows that the individual burden can be strongly influenced by pets.

However, it is not only the type of pet animal that is decisive, but also specific decisions concerning its keeping. It is not to be expected that a horse will reach the level of a dog, but it is possible to reduce impact for example by choosing an environmentally friendly cat litter. Environmentally friendly means here that the litter bought should have a short transport route. Litter made from vegetable by-products will probably perform better than mineral litter in most cases. However, additional factors such as user-friendliness, cleaning habits, odour pollution, etc. should be considered when deciding. Often the diet of the pet accounts for a substantial proportion of the resulting stress. It is therefore worthwhile to look for optimisation potential here. For example, rabbits can also be fed with scraps that are not dangerous for them. This reduces the overall burden, since the part caused by the production of fresh fodder is completely or partially eliminated.

Regarding the overall impact of pets, it can be seen that over the entire Swiss population, it is not the extent of the exposure of an individual animal that is particularly relevant, but an interaction between the number of animal species and their exposure. However, the impact of pet husbandry is rather small concerning the overall impact from consumption. Nevertheless, this study shows potential improvement possibilities for keeping pets.

Some aspects of keeping pets can even be achieved alternatively. For example, the protection or observation of native wild animals (beaver watching, birdwatching, river watching, etc.) can also fulfil similar functions. This type of leisure activities could also be included in an extended study in a comparison.

Conceivable extensions of this study are manifold. One possibility would be the embedding of these results in different lifestyles and nutritional styles. Those interested in such an in-depth study are welcome to contact us.

The study has been referenced in several German speaking and in some other European media like newspapers, online media, TV, radio, or journals. The reactions are manifold and show that talking about pet in such analytical way can lead to very emotional comments. Pets are often considered as an individuum on its own and not as part of the personal lifestyle. These harsh reactions might be the reason that former studies were not available on the internet anymore or that it was impossible to reach the authors (Vale & Vale 2009). They also lead to a revised version of our study better explaining the rationale behind such analysis and the importance of reducing unnecessary environmental impacts associated with the keeping of pets. Direct discussions with pet owners and stakeholders helped to address such issues and direct the discussion in a meaningful discussion.[1]

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Figures

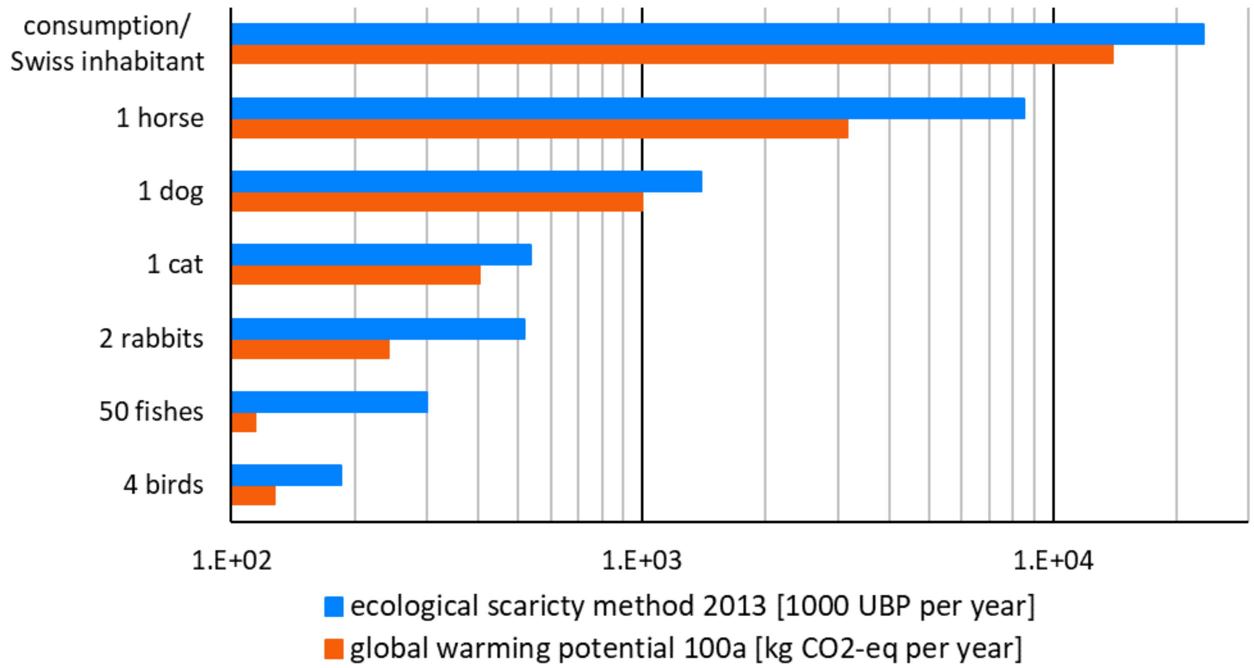

Figure 1: Comparison of the environmental impact (left scale) and greenhouse gas emissions (right scale) of a human and all pets over one year. The table below shows the relative environmental and climate impacts in relation to the average annual consumption of a person in Switzerland in 2015 in a logarithmic scale

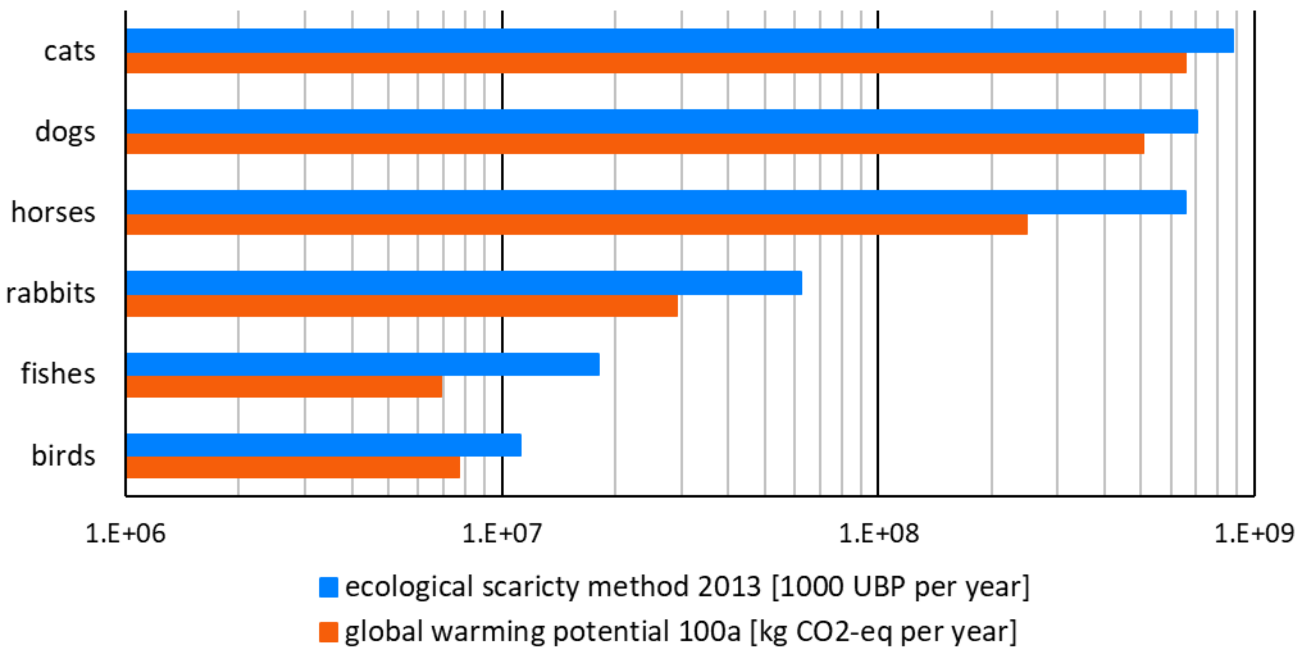

Figure 2: Total environmental impact and greenhouse gas emissions due to the keeping of all pets in Switzerland per year in a logarithmic scale

Topic 13:
Sustainability, Eco-Efficiency, Ecodesign and Circularity

Abstract code: 54

Circular economy in agri-food sector: under what conditions is wastewater reuse eco-efficient?

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Abstract

Wastewater reuse is a non-conventional water resource that could answer present and future water-scarcity issues, supplying diverse water users: agricultural, industrial or even domestic. The aim of this study is to focus on the environmental efficiency of urban wastewater reuse for agricultural irrigation, at global scale. To this end, various parameters are analysed to identify situations where the wastewater reuse is better or worse than the local water supply mix. Two wastewater regeneration treatment alternatives with contrasting energy content (mild treatment versus membrane treatment) are considered in order to represent the range of reclaimed water quality that could be requested by local water policies. Four main parameters are adjusted so as to compare the scenarios on a panel of contrasting situations: the geographical situation (coastal or continental), the level of water stress, the origin of local water resource and the electric mix. Overall results show no significant environmental benefit for the urban wastewater reuse for continental location, especially in the case of energy-intensive regeneration treatment. However, water savings in littoral water-scarce situations by wastewater reuse can compensate environmental burdens of reclaimed water treatment and benefit reuse scenarios. When compared to desalinated water, urban wastewater reuse is always more environmentally efficient, independently of the reclaimed water treatment technology. The low nutrient level or treated urban wastewater provides negligible environmental benefit (avoided fertilizer production) to the reuse scenarios.

Keywords: Wastewater reuse, Water supply mix (WSmix), Life cycle assessment, Water footprint, Water scarcity, Agricultural irrigation.

Introduction

In the context of climate change, the evolution of the state of water resources is an issue of worldwide importance. Unconventional water resources must be identified and securely deployed to meet future water demands. Wastewater reuse (WW-reuse) is considered as a promising response to water scarcity issues (WWAP 2017) for various application fields. Agriculture, whose water supply accounts for more than 70% of the world's water withdrawals (FAO 2016), is the first WW-reuse market (Lautze et al. 2014). In agricultural irrigation, wastewater can also provide nutrients for fertigation (Sala and Serra 2004) and its nitrogen or phosphorus contents largely depend on wastewater treatments (Iannelli and Giraldi 2011). The environmental efficiency of WW-reuse rely heavily on the "fit to purpose" water regeneration treatment, required to meet water quality policies of the reclaimed water use sectors in question (agriculture, industry or domestic). Wastewater regeneration environmental impacts are strongly related to the nature of the treatment technology (usually tertiary treatment) and its electric consumption appears to be a major contributor (Lane et al. 2015; Pintilie et al. 2016). When WW-reuse allows water resource savings (as in coastal situations), then local water scarcity is also a key parameter for assessing the environmental impact of avoided local water deprivation. Thus, the environmental assessment of WW-reuse as a non-conventional water resource depends on a water-energy nexus, which links the local water availability with the environmental impacts of wastewater treatment. Water resource choice decision making requires to determine under what conditions the environmental impacts of the implementation of WW-reuse (energy, infrastructure, etc.) are lower than the expected benefits (water resource and nutrients saving). Life cycle assessment (LCA), as a holistic tool, can assess the global environmental effectiveness of WW-reuse, including impacts of water deprivation or savings, treatment technologies infrastructures, consumables/maintenance and energy consumption. Several studies of environmental assessment of WW-reuse have been carried out (Arzate et al. 2019; Hsien et al. 2019). However, as most of them are case studies for specific conditions and locations (more or less arid), it is difficult to draw general conclusions on the environmental efficiency of reclaimed water when compared to conventional water supply.

Material and methods

The goal of this study is to achieve a generic evaluation of the environmental efficiency of WW-reuse through life cycle assessment (LCA) for virtual scenarios of the most common reuse application: urban WW-reuse for agricultural irrigation. By comparing the environmental burdens of reclaimed urban wastewater with those of a local irrigation conventional water supply (baseline scenario), the objective of the study is to identify situations where WW-reuse is of environmental interest. The baseline scenario corresponds to a world average local water supply mix for agricultural irrigation, based on the water supply mix (WSmix) concept (Leão et al. 2018). The functional unit is the supply of 1 m3 of water at the user gate (irrigated plot). In order to avoid masking effects, all other things being equal between WW-reuse versus WSmix scenarios, are removed from LCA calculations (ceteris paribus). The urban wastewater treatment plant (WWTP) effluent discharge to local water body is included in the system boundary (Figure 1) as an avoided impact in the WW-reuse scenario. Of course, the nutrient content of reclaimed water for irrigation generates an environmental benefit as it avoids fertilizers production.

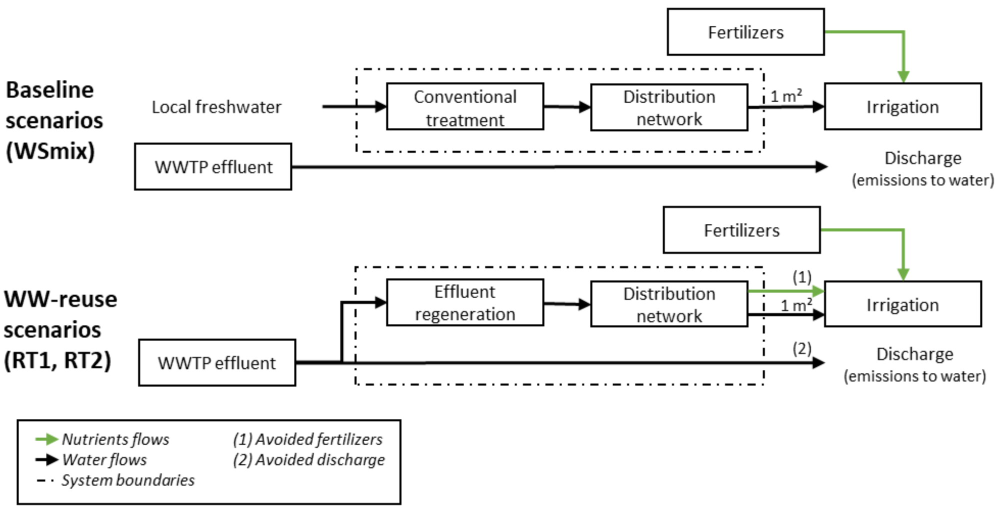

Figure 1 - System boundaries for both WW-reuse and Baseline scenarios.

For each of the two virtual systems studied (agricultural WSmix and WW-reuse), the main key parameters are identified in order to build a versatile experimental protocol, representative of the different WW-reuse situations. First of all, a clear distinction must be made between continental and littoral locations for which the water balance of the studied systems differs.

In a continental water basin, the amount of water consumed, defined as the difference between withdrawal and discharge (ISO 14046), is the same for both scenarios. Indeed, in WSmix scenario, water withdrawal for irrigation is balanced by WWTP effluent discharge reloading the local water bodies while in WW-reuse scenario, there is no water withdrawal but WWTP effluent discharge is avoided. This balance is valid assuming a renewable use of groundwater resources and considering the recharge of the local water basin through the discharge of treated wastewater. In this case, WW-reuse does not lead to water savings. However, when wastewater is discharged into the sea (littoral locations), all water withdrawals from the catchment area constitute water consumption. Thus, as long as these assumptions are made, WW-reuse only leads to water savings in coastal areas. Then, in addition to geographic location (continental or littoral), water scarcity level and electric mix are the two other main parameters that affect the environmental efficiency of WW-reuse compared to WSmix. Regarding the baseline scenario, two WSmix are also considered by varying water source origin: a world average conventional WSmix and a desalinated WSmix. As the regeneration technology train (RT, combination of treatment units) mainly defines the WW-reuse scenario (irrigation water provided by regenerated urban WWTP effluent), two representative RT based on bibliography are studied: a mild-treatment RT1 (sand filtration, coagulation-flocculation, ultra-violet disinfection) and an intensive treatment RT2 (RT1 + microfiltration + reverse osmosis). In order to account both the impacts related to water deprivation and those related to energy consumption (water-energy nexus); results are displayed with endpoint indicators, which are also easier to interpret for decision-making purposes. Calculations are made using the ReCiPe 2016 method (Huijbregts et al. 2016) as it includes recent water deprivation indicators for two of the three protection areas. A supplementary endpoint impact on resources is implemented in order to include water stock exhaustion impacts due to extraction of fossil groundwater or overuse of water bodies (Pfister et al. 2011).

Results

In this study, the environmental impacts of the three scenarios studied (Baseline, WW-reuse RT1 and WW-reuse RT2) are calculated for 17 contrasted situations in order to evaluate water scarcity effect at continental and littoral location with groundwater overuse or renewable use, water source origin effect and electric mix effect. Figure 2 shows LCA endpoint results for 3 of the 17 situations studied: the water scarcity effect at littoral location with groundwater renewable use. All detailed results of the entire experimental protocol will be detailed in a forthcoming paper. In continental locations, as the water balance remains equal for both baseline (WSmix) and WW-reuse scenarios, water deprivation effects at user gate are equals. However, when located in a coastal region, water savings, which can be reflected in the three final impacts (human health in the case of a location with a low human development index, ecosystems and resources when groundwater is overexploited), benefit WW-reuse scenarios. In most cases, water treatment (including extraction energy consumption for WSmix) is the major contributor that distinguish the three scenarios. Therefore, in the case where water distribution to user is equal for WSmix and reclaimed water, the difference between continental scenarios only depends on water treatment efficiency and local energy mix. The environmental impacts of the intensive regeneration treatment RT2 scenario are always much higher than the baseline scenario, except when it corresponds to a desalinated water supply. In this case, the water-distribution distance becomes an essential parameter in order to differentiate an intensive regeneration treatment WW-reuse solution from an unconventional WSmix based on desalination. Energy mix effect in urban WW-reuse environmental efficiency evaluation is limited as it affects freshwater treatment as well as regeneration water treatment. A more renewable energy mix will tend to favor WW-reuse scenarios in coastal situations, as the extra cost of treatment can be offset by the water savings achieved. Avoided fertilizers (wastewater nutrient content) and emissions to local waterbody (avoided wastewater discharge) due to WW-reuse have a low contribution to WW-reuse scenarios endpoint impacts.

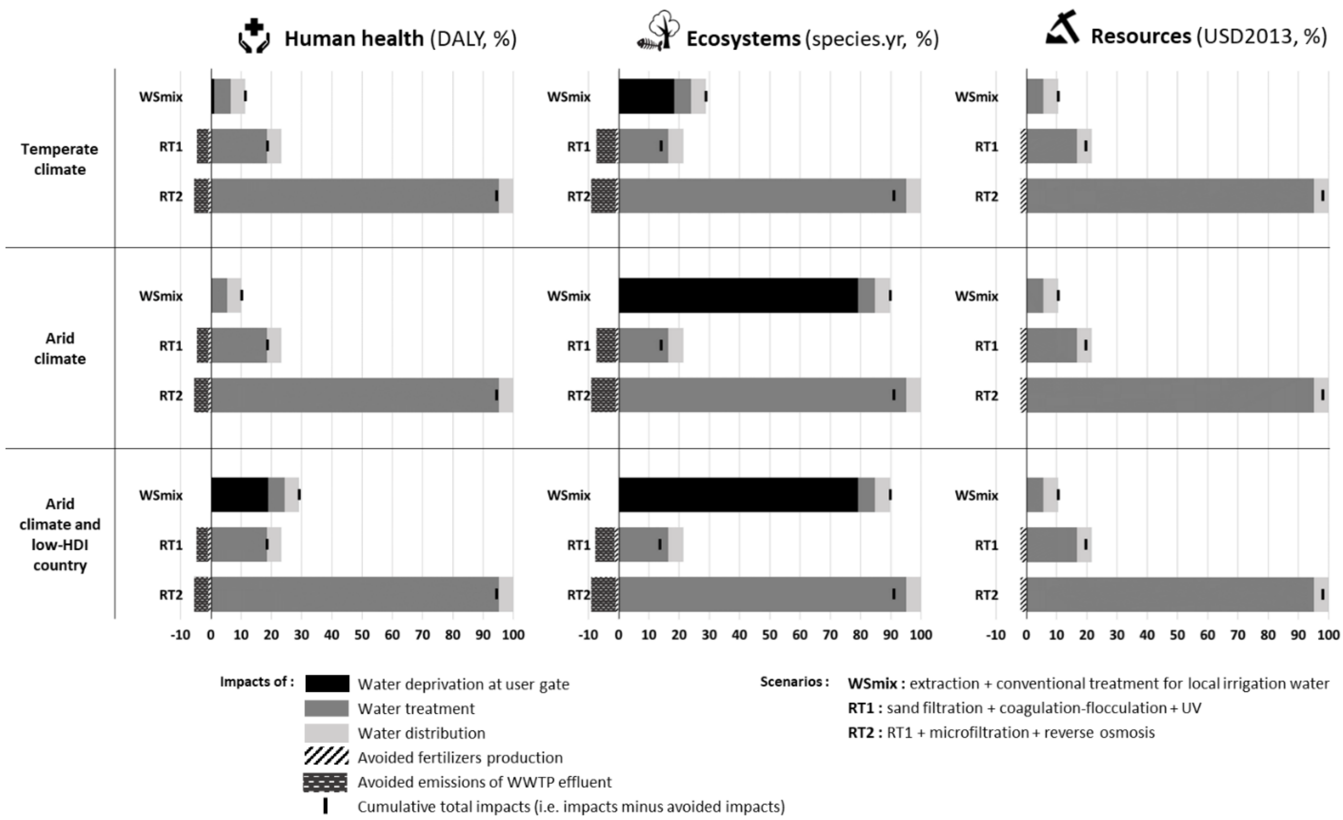

Figure 2 - Water scarcity effect on environmental impacts (LCA) for 1m^{3}of irrigation water at user gate: urban WW-reuse for irrigation vs. WSmix, in a littoral location. Water origin for WSmix: surface water and renewable use of groundwater.

Discussion

For every situation studied (according to the experimental protocol), a stochastisation method is used to determine if the WW-reuse scenarios are more efficient than the baseline ones. For all continental situations, no clear environmental benefit is obtained from WW-reuse. In coastal situations savings on water resource are obvious and can compensate a mild wastewater treatment as the RT1 scenario. RT2 scenario comparison with Baseline is more contrasted: in more than half of the situations the world average WSmix is more environmentally efficient. The comparison with a baseline water supply scenario is essential and should be as local as possible in a site-specific study. The lack of country-specific water extraction and treatment inventory data (water treatment technologies used are those currently available in LCI databases) affects the accuracy of the results. The large range of RT for wastewater regeneration create a large variability in WW-reuse scenarios that can be studied, depending on the wastewater quality and reclaimed water user policies for treated water quality. The case of raw WW-reuse is not studied here (no regeneration treatment) although it corresponds to current common practices for irrigation in developing countries. All our conclusions can be affected by local situations as a high difference of distribution network or different energy mix between baseline and WW-reuse scenarios.

Conclusions

For most continental situations, urban WW-reuse for agricultural irrigation does not provide environmental benefit when compared to a worldwide average local WSmix, independently of the chosen regeneration treatment and of the local water scarcity. However, in coastal situations, water resource savings can compensate wastewater treatment impacts if it is not too energy-intensive, especially in water scarce areas. When compared to an unconventional water supply from desalination, urban WW-reuse is always of environmental interest. In water scarce littoral locations as well as in water scarce continental locations with groundwater overuse, no generic conclusion can be made regarding to the intensive regeneration treatment WW-reuse scenario and a specific study should be conducted with site-specific data. The agricultural benefit of water nutrient content appears to be low in current WW-reuse due to relatively low nitrogen and phosphorus concentrations in the outlet of regeneration treatment. Therefore, only a complete redesign of treatment plants that would better preserve nutrients (less denitrification) would be able to improve the environmental efficiency of urban WW-reuse for agricultural irrigation regardless of the site considered. This nutrient-related benefit of WW-reuse is indeed present in developing countries that allow direct reuse of wastewater, but at the cost of high pathogen-related risks to human health.

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Abstract code 280

Development of a serious game using LCA for ecodesign in viticulture: Vitipoly®

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Abstract

Problem and aim: There are an increasing number of serious games with an environmental management theme, but few combine agriculture and environment, and none relate to environmental life cycle assessment (LCA) or ecodesign. A serious game called Vitipoly® came out of a process of creating participative ecodesign methods and tools for winegrowers. It is designed for training students of viticulture and for participative ecodesign by extension officers and viticulturists. This paper describes our experiences from testing and developing the game with viticulture students, and identifies the opportunities and challenges for this game-based medium.
Methods: The Vitipoly® game aims to raise player awareness of the environmental impacts of vineyard management and to develop skills in ecodesign. The game comprises a playing board, information cards, and a streamlined LCA tool for live calculations of LCIA results during the game. The task for the players is to improve the environmental performance of a vineyard case study. The game was tested with five groups of eight viticulture students over two 2-hour sessions. Feedback from the session participants and an advisory panel (extension officers and viticulture teachers) has guided the evolution of the game. The opportunities and challenges for this game-based medium for ecodesign were observed and described during the development process.
Results and discussion: The students devised viticulture scenarios that reduced environmental impacts by 20% on average (over multiple impact categories), which was similar to that obtained by groups of winegrowers in more traditional participatory ecodesign workshops. All groups were enthusiastic about the game, having discovered LCA and the variety of environmental impacts for viticulture. Their feedback enabled improvements to several aspects of the game and the VitLCA© calculator. It was observed to be a useful teaching aid as it helped to consolidate their vineyard management knowledge. Live LCA calculations proved to be necessary for the players to see the consequences of their decisions. Designing a streamlined LCA tool to quickly generate live LCA results during the game, in a way that informs the decisions of players, was found to be a challenge.
Conclusion: Designing a game-based medium for ecodesign was a long process that required considerable interaction with users. The testing showed this medium to be an effective teaching aide to help students discover LCA, and for prompting their future engagement with better environmental management of vineyards.

Key words: *engagement, hotspots, education, impacts, VitLCA tool*

Introduction

Serious games provide educational and engagement functions while diverting the players (Wu and Lee, 2015). There are an increasing number of games with environmental management themes (Madani *et al.*, 2017), but few combine agriculture and environment, and none relate to environmental life cycle assessment (LCA) or ecodesign. In France, winegrowers are challenged by the media, consumers and the public to reduce impacts, and they are keen to receive guidance on how to do this. Growers also need to be educated on this during their viticulture studies. In response, a serious game called Vitipoly® came out of a three-year process of creating participative ecodesign methods for viticulturists (Rouault *et al.*, 2019). Tools developed for traditional participatory ecodesign processes with viticulturists were adapted into a 'game box', for training students of viticulture and for ecodesign workshops with groups of viticulturists, facilitated by extension officers. This paper describes our experiences from testing and developing the game with viticulture students, and identifies the opportunities and challenges for this game-based medium.

Material and methods

The Vitipoly® serious game aims at raise player awareness of the environmental impacts of vineyard management and develop skills in ecodesign. The game is played by groups of four to eight players, under the direction of a game master. The aim of the game is to improve the environmental performance of a vineyard case study.

The game box contains (Figure 1) i) a playing board, ii) eight pages of information describing eight different Loire Valley vineyards cases (two of which are organic) and their life cycle environmental impacts (LCIA), iii) two packs of cards describing various viticulture management practices, and climate conditions (and their associated disease pressures), iv) two booklets containing background information about environmental hotpots for vineyards, the management practice options available, and the pesticides that can be used and their ecotoxicity impacts (freshwater); v) a streamlined LCA tool for live LCA calculation during the game, and vi) the guidelines for the game master.

The game session starts with a half-hour introduction to LCA for grape production and an explanation of how to play the game. The game itself lasts two hours and involves an approximate one-hour exchange between the players and the game master about the viticulture management practices that were chosen by the players, and the consequential environmental impact, calculated during the game with the LCA tool.

The game was tested in 2019 with a total of five different groups of players, each with eight viticulture students and their teachers, over two separate 2-hour game sessions (groups 1,2 in the first session, and groups 3,4,5 in the second session). Each group was assisted by a member of the research team. The live LCA calculations were performed during the game sessions using two different streamlined LCA tools, which generated the life cycle inventory (LCI) in different ways, but which both generated life cycle impact assessment (LCIA) results using the Recipe Midpoint (H) V1.12 method (Goedkoop *et al.*, 2009).

Figure 1: elements of the Vitipoly® prototype

In the first session (groups 1,2), both tools were tested in parallel, with each group using a different tool to observe the role of the tool. After each game session, feedback was collected from the participants through free discussion and for the first session through a world café some days later with four focus questions to prompt brainstorming of possible improvements of the game. An advisory panel of two viticulture extension officers and three viticulture teachers also guided the evolution of the game. Two more sessions were planned for March and June 2020, but were to be postponed due to the Corona Virus outbreak.

Results and discussion

LCIA results generated in the Vitipoly® game sessions: The students devised viticulture scenarios that reduced annual environmental impacts for the case study vineyard (Table 1) by 20% on average (over multiple impact categories), which is similar to that performed by groups of winegrowers in more traditional participatory workshops. The improvements were variable depending on the impact categories, and the strategies chosen by the groups. For example, for groups 3 and 5, introduction of copper-based fungicides instead of synthetic pesticides increased terrestrial ecotoxicity and metal depletion impacts, while partly replacing tractors with electric robots reduced climate change, particulate formation, terrestrial acidification and fossil depletion.

Table 1: Percentage improvements in the LCIA results (Recipe Midpoint (H) v1.12) for the eco-designed scenarios developed by four of the groups [1] during the Vitipoly® game.

Impact category	**Group number**			
	1	2	3	5
Climate change	22%	21%	33%	29%
Particulate matter formation	17%	32%	51%	46%
Ozone depletion	32%	50%	70%	55%
Photochemical oxidant formation	15%	31%	49%	45%
Freshwater ecotoxicity	27%	70%	65%	65%
Marine ecotoxicity	30%	47%	39%	37%
Freshwater eutrophication	26%	35%	13%	- 19%
Marine eutrophication	28%	1%	1%	1%
Terrestrial ecotoxicity	34%	- 3%	- 135%	- 116%
Terrestrial acidification	19%	30%	48%	41%
Fossil depletion	22%	34%	53%	47%
Metal depletion	0%	8%	- 47%	- 65%
Water depletion	0%	26%	46%	24%
Agricultural land occupation	15%	0%	0%	0%
Mean improvement	**20%**	**27%**	**20%**	**14%**

[1] Group 4 results are not reported due to a disfunction of the computer during the session for this group.

<u>Feedback:</u> Student players were all enthusiastic about the game. This was due to them discovering LCA and the range of environmental impacts for viticulture practices including impacts that they didn't consider before. The participant's suggestions for improving included: i) improving the dynamics of the game by assigning different roles to players to encourage more participation, ii) providing clearer information about the disease pressures and weather forecast and about pesticide characteristics; iii) introducing risk alerts about yield when the players make wrong choices; iv) including information about the impacts of the operations on the cards; v) improving the design of the board to clarify the periods of vine development; v) receiving simultaneous comparison of initial and ecodesigned scenarios; and vi) adding economic aspects. The feedback from the advisory panel validated the suggestions of the students, and also identified the game to be a useful teaching aid as it helped to consolidate the student's vineyard management knowledge Furthermore, they suggested to i) add more organic viticulture cases; ii) change the temporal sequencing of the game to be in half weeks so it reflect how wine growers make decisions (based on twice a week weather forecasts), and ii) add biodiversity implications. Most of the feedback has been taken onboard to improve player participation, and to clarify and document the role of the game master (ideally a teacher or extension advisor), which was found to be crucial.

<u>Role of the streamlined tool for generating live LCIA results</u>: One of the tools, referred to as the "workshop tool", includes pre-calculated LCA results of practices (using Simapro software) and makes possible adjustments of the results in function of the practice parameters changed by the participants (Rouault *et al.*, 2019). It generated the LCA results in a way that showed the contributions of each viticulture operation., which was found to greatly facilitate exploration of

ecodesign opportunities, but which needed long calculations for each new case explored and gave less flexibility in designing alternative practices. The other tool, referred to as the VitLCA® tool (Renouf *et al.*, 2018), generated the LCA results in a more conventional way showing the contributions of the input and output substances and processes, which was less useful for exploring ecodesign opportunities during the game, but which was much quicker. It was found that this did not limit the eco-design process, and that VitLCA® proved to be suitable in the role. The need to perform analyses using the tools meant that, ideally, an extra person in addition to the game master of game may be needed. However, an experienced game master may be able to manage both tasks at the same time. Live calculation of LCIA results proved to be necessary so the players can see the implications of their choices and learn, and. The operationality of this calculation was improved from session to session.

Conclusion

Designing a game-based medium for ecodesign is a long process, and required considerable interaction with users. The testing showed the medium is an effective teaching aid for helping students discover LCA, and for prompting their future engagement with in the environmental management of vineyards through ecodesign. It is also a useful teaching aid for consolidating student's vineyard management knowledge.

Aknowledgements

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From Circular to Linear? Assessing the Environmental Performance of Steel and Plastic Kegs in the Brewing Industry

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Abstract

Purpose: In the brewing industry, conventional steel kegs have seen competition from single-use (also referred to as one-way) plastic kegs increase due to their lower cost, lighter weight, and ease of use. This study aims to assess the environmental performance associated with these kegging solutions for the brewing industry. The results of this study can assist brewers that aim to lower their environmental impacts in making more sustainable choices.

Methods: Life cycle assessment (LCA) was employed to evaluate and compare steel and plastic kegs from a cradle-to-grave perspective, including their production, use, and final waste treatment. The functional unit for the assessment was 1 liter of kegged beer. Different kegging solutions (30L) are compared, which include 1) a steel keg, 2) a plastic single-use keg, and 3) closed-loop plastic kegs scenarios, where the PET is recycled (in the Netherland and Sweden). Each of the kegging solutions is assumed to be transported between the brewery and bar, a distance of 100 km. While the plastic kegs are used only one time, the steel kegs are used up to 80 times, including cleaning and refilling.

Results and discussion: Results suggest that both kegs are useful in certain situations. The steel keg was found to have lower GHG emissions and fossil resource depletion, while the plastic keg performed better for water depletion and metal depletion. A closed-loop PET recycling scenario was illustrated to significantly reduce the environmental impacts, primarily by recycling the PET. Furthermore, the lower weight of the plastic keg proved to be an important factor for the impact as well. The transportation distance from the brewery to the bar was found to be a sensitive assumption. From further analysis, it was found that if the transportation from the brewery is increased, the plastic keg may become a better option, with a break-even point of roughly 250 km.

Conclusions: In conclusion, it was found that steel kegs were better for the local market, while plastic performed better outside the local market, which is especially important in a large country such as Sweden. Furthermore, the environmental performance of the single-use plastic kegs could improve through a closed-loop process similar to those available in other countries. The results can be useful in the brewing industry to provide insights of the environmental impacts of kegging solutions.

Keywords: beer, LCA, keg, packaging, brewing

Introduction

The food and beverage sector has received significant focus in recent years to mitigate the negative environmental impacts. The brewing industry has also ramped up efforts to improve the environmental performance of their operations and products, developing collaborative approaches (BIER, 2015; EC, 2018). As Hallström et al. (2018) suggest, there may be significant potential to improve, as the alcoholic beverage industry alone was found to represent between 3-11% of all dietary GHG emissions in Sweden.

The literature available for improving brewing industry environmental impacts is limited, with most studies focusing on country-wide consumption assessments or specific beers and packaging (Hallström et al., 2018; Amienyo and Azapagic 2016; Cimini and Moresi 2016; Shin and Searcy 2018; Niero et al. 2017). Packaging has been a crucial subject of inquiry in the field. As Niero et al. (2017) suggest, the beverage packaging sector has been pioneers in sustainability, with the first life cycle-based environmental impacts studies conducted on beverage containers. The business sector has also highlighted the importance of packaging in promoting a transition towards a circular economy (CE), see e.g., Ellen McCarthur Foundation (2015) and EC (2015).

Interestingly, the packaging landscape for beer has also changed in recent years in Sweden. In the retail market, bottles have received increased competition from cans and for kegged beer, steel kegs have seen increasing competition from plastic kegs (SBA, 2020). The craft brewing industry, which often struggles with limited labor and capacity, has been keen to reduce costs and time for their production and distribution processes while improving their sustainability. However, the shift toward plastic kegs, often promoted as one-way' solutions marks an important and shift to inquire, as it may mark the transition from a circular system to a linear system. Additionally, there is very little scientific inquiry on the environmental performance of these kegging solutions, necessitating support for more informed decisions for the packaging of beer. The overall aim is to assess the environmental performance associated with these kegging solutions to provide input to the craft brewing industry to support their sustainable production efforts.

Material and methods

To assess the environmental performance of the steel and plastic kegging solutions, life cycle assessment (LCA) was employed. The ReCiPe Midpoint (H) life cycle impact assessment (LCIA) method was used. However, four of the available impact categories, namely greenhouse gas emissions (GWP) and Material Depletion (Water, Fossil, and Metal) are outlined in this paper. All life cycle inventory data for modeling the steel and plastic kegs and associated processes were obtained from LCI databases such as Ecoinvent v. 3.5 (2018). The functional unit of this study is the transportation of 1 liter of beer by keg. The system boundaries include all cradle-to-grave processes associated with the different kegging solutions, i.e., production of the kegs, their transportation, use, and the final disposal. The production of beer and all associated processes with serving are not included as it was assumed to be similar in all kegging options and therefore excluded from the study.

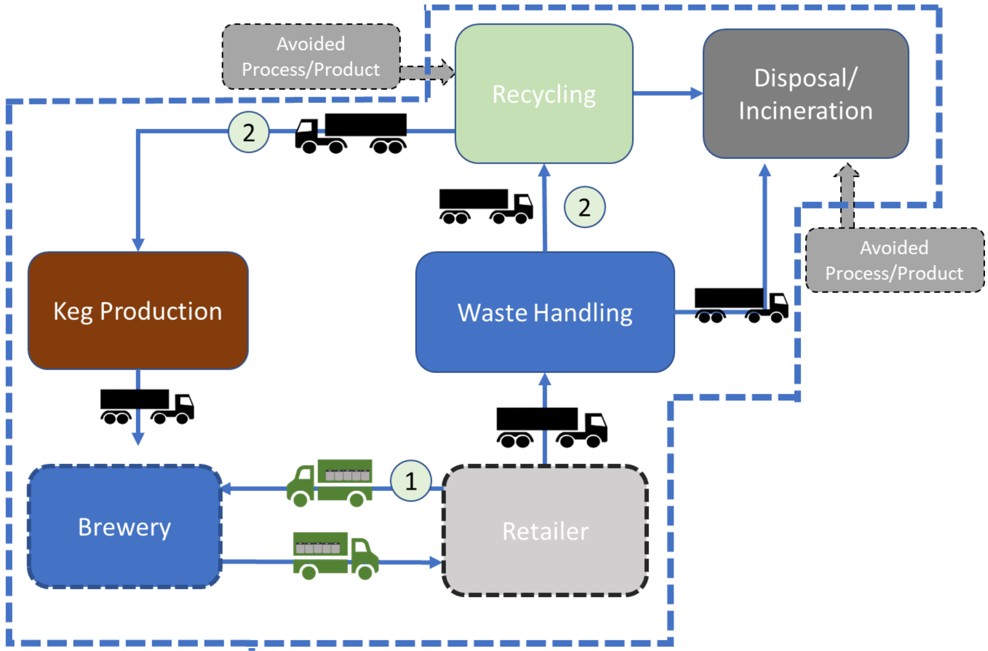

Figure 1: Depiction of the system boundaries of study. Dashed lines around the brewery and Retailer highlight that internal processes are not included in the study.

For the assessment, it is assumed that the beer is produced and filled by a brewery in the Stockholm area, and that the beer is shipped to an end-user (i.e. a bar), roughly 100 km away. Plastic kegs are sourced from the Netherlands, while the steel kegs are sourced from Italy. The steel kegs, as illustrated in Figure 1, recirculate (including washing) before entering the waste management system in Sweden to be recycled. The kegs are assumed to recirculate 80 times based on findings in Cimini and Moresi (2016). The plastic kegs are used only once and enter the waste management system in Sweden after being emptied. All transportation for the kegs to Sweden, in addition to their transportation to the waste handling and recycling systems, are assumed to be conducted by semi-truck. Transportation of the kegs from the breweries to the bars, and back for the steel kegs, is assumed to be conducted by light commercial vehicle. Two further scenarios are also included, where the PET of the plastic kegs is also recycled using a similar system as OneCircle (2018), i.e., a closed-loop system. In these scenarios, it is assumed that the kegs will be crushed, and the PET sorted and sent to the Netherlands to be used for producing new kegs (denoted *Plastic Keg Closed Loop-NL*). Given that the same sorting process can be done in Sweden, the *Plastic Keg Closed Loop-SE* scenario is also included to add the sorting of recyclable PET, which is then sent to the Netherlands. All other sorted plastics are assumed to be treated in municipal incineration plants in the Netherland and Sweden, respectively, with credits for the energy recovery (i.e., electricity).

Results and Discussion

The results illustrate that the steel keg has significantly lower GHG emissions and fossil resource depletion compared to the plastic keg. In contrast, the plastic keg has lower water and metal resource use. Further analysis showed that the increased water resource depletion for the steel keg was primarily due to cleaning the keg for reuse. The plastic keg illustrated more considerable fossil resource use, arising from the manufacturing of the plastic components. Roughly 50% of the total GHG emissions for the plastic kegs originate from the manufacturing of the kegs, with the remaining 50% a result of transportation and disposal, see Table 1. Furthermore, the overall life cycle impacts of the plastic keg are illustrated to have a net positive effect on water depletion. This is due to the fact that the Swedish energy mix has a considerable water footprint, and the benefits of energy recovery from the incineration of the plastic keg may offset enough water use from the Swedish energy mix for it to result in a positive effect. The closed-loop scenarios show that plastic reuse can significantly lower three of the four impact categories featured in this LCA. The extra impacts deriving from transport to a collection point, and transportation to a recycling plant are outweighed by the avoided impact of using virgin material, see e.g. the lower impacts for the closed-loop impact. Similar findings have been asserted in Eriksen et al. (2018) and Chilton et al. (2010) for recycling PET bottles.

Table 1 - Results per Impact Category, shown in respective impacts per liter of kegged beer.

Impact Category	Plastic Keg	Steel Keg	Plastic Keg-Closed Loop NL	Plastic Keg-Closed Loop SE
Water Depletion (m^3)	-7.12E-06	8.68E-04	1.22E-04	2.34E-04
GHG Emissions (kg CO_2-eq)	3.00E-01	1.49E-01	9.91E-02	2.18E-01
Metal Depletion (kg Fe-eq)	6.53E-03	4.06E-02	4.62E-03	4.77E-03
Fossil Depletion (kg oil-eq)	1.02E-01	5.31E-02	3.80E-02	7.67E-02

Further analysis of the results suggests that the plastic keg becomes the better choice when the transportation to the retailer (again assumed to be a bar) is more than 250 km away from the brewery for the GHG emissions. This is slightly higher than results found in a study by Carbon Trust (2011) which suggests the break-even point to be roughly 150 km. As such, it is important to note that in a country such as Sweden, shipments outside of Stockholm, to larger cities in the south and north of Sweden would be more beneficial to ship by plastic keg than steel kegs. This also provides insights into packaging for the craft beer industry, which has been shown to be a large contributor to brewing industry impacts (Shin and Searcy, 2018; Cimini and Moresi, 2016).

Conclusions

This study aimed to assess the environmental performance associated with steel and plastic kegging solutions. It was found that steel kegs were better for the local market, while plastic performed better outside the local market, which is especially important in a large country such as Sweden. Furthermore, the results also highlight the potential for improving the performance of plastic kegs by implementing local recycling strategies through a closed-loop process to recycle the PET similar to those available in other countries. The kegging solutions were also found to be sensitive to the transportation distance, with the plastic kegs to have lower GHG emissions if the distance from the brewery to a bar is greater than 250 km from the brewery. As such, the results provide the brewing industry with insights into the environmental impacts of kegging solutions to promote better decisions and more sustainable production methods.

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Aggregating midpoint indicators for eco-efficiency using data envelopment analysis

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Abstract

Purpose: For future sustainable agricultural systems, we need to reduce the negative environmental impacts of agricultural production while maintaining productivity, food security and viable income for the producers. In order to assess such multi objective systems, we can use the concept of eco-efficiency, where we relate one or multiple outputs to one or multiple inputs or (undesirable) impacts.
Methods: The environmental impacts are calculated using Swiss Agricultural LCA tool SALCAfarm and SimaPro (ecoinvent3 database). Using correlation analysis to reduce the number of dimensions, the nine resulting impact categories are then related to the output in order to calculate eco-efficiency scores. Here we implement a method from the field of productive efficiency analysis in order to aggregate the environmental impacts for agricultural production. Data Envelopment Analysis (DEA) is used to elicit a best practice frontier using 251 farm-year combinations, utilizing observed best practice actors as benchmarks for less efficient actors. Therefore, the resulting efficiency score denotes the potential for improvement, if best (observed) practice was adopted.
Results and Discussion: The eco-efficiency scores show high variability (coefficient of variation = 53%) with regard to the farming system (organic, proof of ecological performance (PEP)) and production region (plains, hills, mountains) and farm size (6-64ha utilized agricultural area). Notably, depending on production region, organic farming systems show higher as well as lower eco-efficiency than their PEP counterparts.
Conclusions: The combination of life cycle impacts and DEA methodology in order to calculate eco-efficiency is a promising technique to estimate eco-efficiency scores without having to rely on normative information. The results are easy to interpret and communicate. While the method has high demands regarding sample size and homogeneity it offers an alternative to more normative methods like endpoints or weighted midpoints.

Keywords: *LCA, agriculture, eco-efficiency, Data Envelopment Analysis DEA, normativity*

Introduction

Farmers and policy makers alike are under increasing pressure to foster sustainability of food production (FAO 2014). This forms a multi-objective problem, where the environmental impact, economic performance and social equity should be improved simultaneously. In order to transition to a sustainable food production system, we need methodologies that allow for simultaneous assessment of multiple dimensions that have no easily deductible common unit. The concept of eco-efficiency relates one or multiple outputs (i.e. produced goods) to one or multiple inputs (resources, undesirable environmental impacts). There exist many concepts and framework for eco-efficiency, we relate here to the definition of environmental productivity as defined by Huppes and Ishikawa (2005): Production value per unit of environmental impact.

Eco-efficiency requires that the outputs as well as the inputs can be aggregated to a single value, and while the outputs are often in monetary units, the inputs, or in case of eco-efficiency, the environmental impacts come with many different units and order of magnitudes. While there exist methods to aggregate LCA midpoints using pathways and areas of protection, they rely heavily on normative information and value choices. Data Envelopment Analysis (DEA) offers a tool to elicit implicit weightings and use them to aggregate elements with different units and magnitudes. As proposed by Kuosmanen and Kortelainen (2005), DEA methodology has been extended to the environmental field, where it is used for the measurement of eco-efficiency.

A systematic literature review on the application of LCA+DEA methodology by Vásquez-Ibarra et al. (2020) found a recent increase in number of publications. Using 64 articles retrieved for 2008 – 2019 they identified classical DEA formulation (BBC) with constant return to scale as the predominant implementation of LCA+DEA methodology.

The following study aims to show how LCA, the concept of eco-efficiency and DEA methodology can be combined to assess the sustainability of agricultural products.

Material and methods

The data for this study encompasses 251 farm-year observations of 113 individual Swiss farms. The farms cover the three main production regions in Switzerland: plain region, pre-alpine hills, and mountains region. 20% of the observed farms practice organic farming. The farms produce milk, cereals, beets and potatoes, beef, pig fattening, and vegetables. On average, a farm produces three product groups, reflecting the high grade of diversification of Swiss agriculture.

The raw data consists of detailed production inventories and accountancy data. The inventory data was used to calculate on farm emissions using Swiss Agricultural LCA tool SALCAfarm. Finally, SimaPro (version 9.0.0.47) was used to calculate the life cycle impacts. The resulting impact categories were further analyzed using correlation analysis to identify impacts with high correlations and reduce the dimensions. The decision which environmental impacts to consider in the final analysis was made using the results from correlation analysis as well as (normative) conceptual considerations. The latter step was included to make sure all domains of interest (energy demand, land use, toxicity, GWP) are represented with at least one impact category.

The data envelopment analysis was conducted using the R package rDEA (Simm and Besstremyannaya 2016). In order to be able to analyze the effects of farm size on eco-efficiency, a constant return to scale assumption was used for the DEA. The resulting eco-efficiency scores are values between 0 and 1, with 0 meaning 0% efficiency and 1 meaning 100% efficiency (relative to the best performing benchmark farms). The eco-efficiency scores were tested for robustness using bootstrapping. Additionally, sensitivity to selection of environmental impacts was tested.

Results

Correlation analysis resulted in a selection of nine midpoint indicators covering energy demand, land use, deforestation, water use, global warming potential, acidification, eutrophication and toxicity. These midpoint indicators were used as inputs in the DEA analysis. As outputs, we used gross farm receipts [CHF]. Here we chose the gross farm receipt as output to reflect the farmer's point of view, which is the need to achieve livable wages.

While, on average, organic farms display higher eco-efficiency, they also display a higher variability than proof of ecological performance (PEP) farms (Figure 1). The eco-efficiency is particularly low for PEP farms in the mountains region.

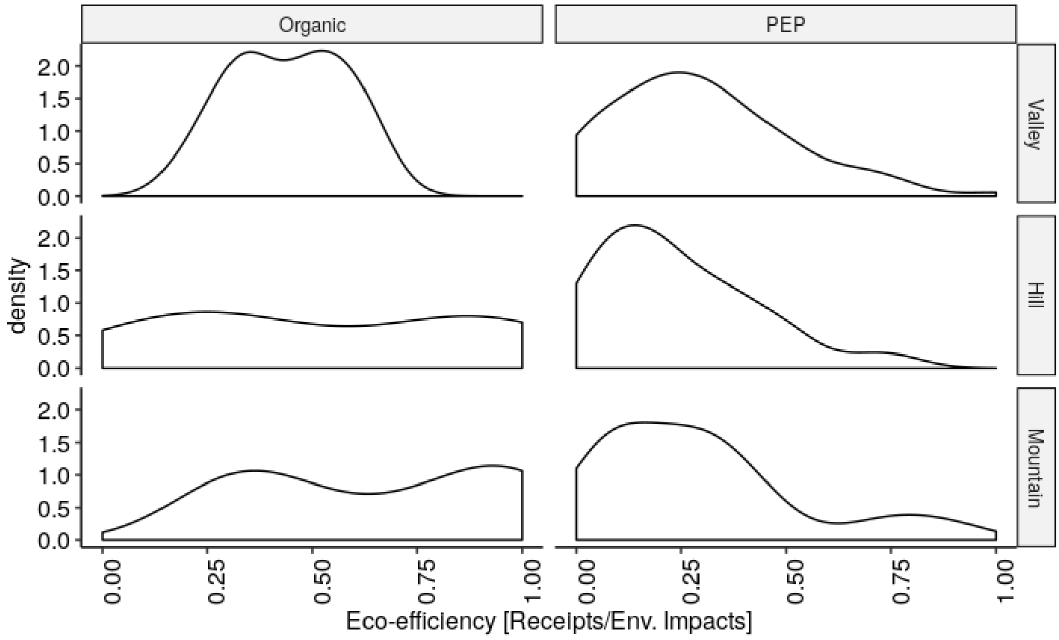

Figure 1: Eco-efficiency scores for farming system and region. PEP = Proof of Ecological Performance (preliminary results)

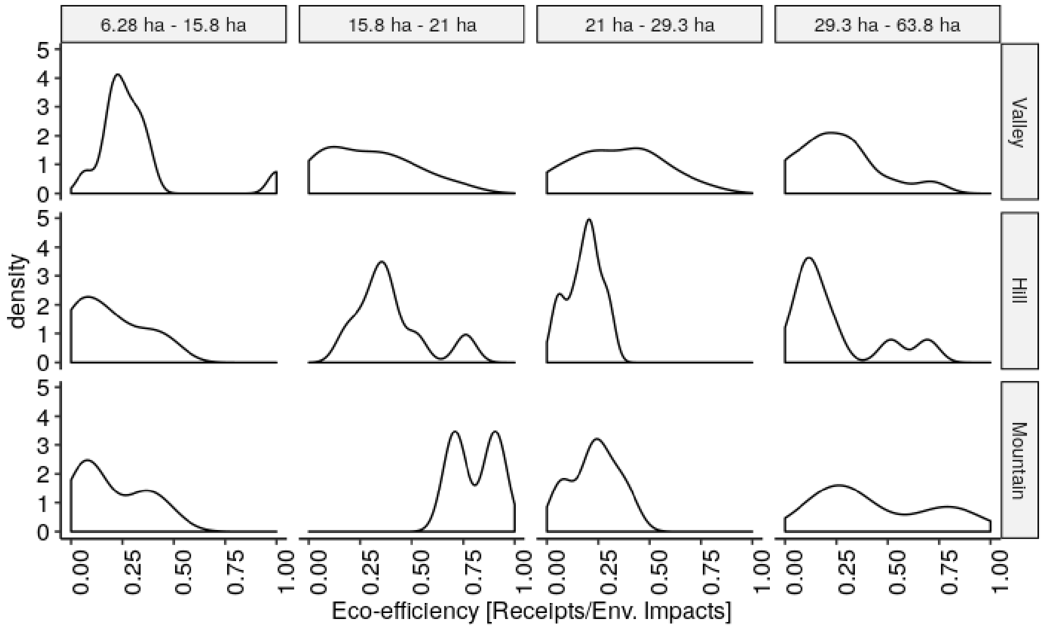

Figure 2: Eco-efficiency scores for farm size and region (PEP Farming systems only) (preliminary results)

Using only the PEP farms, figure 2 shows the effect of farm size on eco-efficiency. The farms are grouped in four equally sized groups, according to the farm size (utilized agricultural area). The smallest farms show lower eco-efficiency for all production regions. The three groups from medium to large farms show varying effects of farm size on eco-efficiency, depending on the production region.

Discussion

The analysis of the eco-efficiency scores shows that the production region (i.e. abiotic and biotic

factors resulting from climate, soil and vegetation period length) have a limiting effect on eco-efficiency. Farming system and farm size on the other hand show a complex interaction and bigger is not always better (or organic is not always more eco-efficient than PEP).
The quality of the DEA results themselves depends heavily on the included variables (i.e. environmental impacts'). Omitting an important impact category can result in a strong bias. This can be alleviated by careful selection of environmental impacts to be used in the assessment. The result also depends on the used set of 'similar producers', since, in the context of DEA, efficiency is relative to its peers.
The resulting efficiency is therefore not in relation to a theoretical efficient technology but to observed technologies in the sample. If prior information about the relative importance of the different environmental impacts is available, it can be implemented using constraints to the linear programming optimization problem. Since DEA is a benchmarking technique it is not possible to evaluate against a better than observed performance. In addition, with increasing number of inputs, substitution effects become dominant and more and more peers are considered efficient. Sensitivity analysis (e.g. bootstrapping) can be used to judge the robustness of the results. By calculating eco-efficiency scores under assumption of both, constant return to scale and variable return to scale, we can estimate the effect of sub-optimal farm size on eco-efficiency.

Conclusions

Using DEA, one can account for different implicit weightings of environmental impacts without having to resort to normative judgements, but still allowing prior information to be transparently implemented. Additionally, by benchmarking against best observed practice one can avoid having to specify a theoretical best case scenario.

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Organic and conventional citrus production. An eco-efficiency analysis

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Abstract

Purpose: Choosing the best production techniques for agricultural systems, in sustainability terms, is not an easy task. Despite the increasing importance of the environmental aspects, economic results are also of capital importance, and a sustainable food system must encompass a strong food supply chain in terms of jobs and growth. The main goal of this study is determine whether citrus organic and conventional production systems are comparable in terms of eco-efficiency. To achieve this goal, the economic result (as good output) and the environmental impacts (as bad outputs) will be integrated for a sample of citrus farms in Spain.

Methods: A survey was carried out on citrus farmers, 145 corresponding to organic production and 122 to conventional. Life cycle assessment was used to estimate the environmental impacts of farms whereas the net income of each farm was measured by means of life cycle costing. Two functional units, mass and area-based, were chosen. As for the system boundaries, a cradle-to-farm-gate boundary was defined. Nine impact categories have been studied. All of the impacts, except those related to toxicity, were characterised by using the CML-2001. Ecotoxicity and human toxicity were calculated according to USEtox 2.0 methodology. The results of the environmental and economic assessment of each farm were integrated by means of Data Envelopment Analysis (DEA) in a unique measure of eco-efficiency for each farm.

Results and discussion:
Eco-efficiency serves as a basis to compare the farms in both environmental and economic terms. When integrating those terms, a key point is that the environmental ones encompass several impact categories expressed with different measurement units and DEA design allows this integration to be carried out. All the farms found as eco-efficient produced organic oranges, the average eco-efficiency ratio is higher for organic farms although the eco-efficiency ratio shows higher variability for organic farms. By using bootstrap with DEA significant difference was found in the average eco-efficiency of both production systems for the whole sample and also for a selected sample of the farms with lower environmental impacts. As regards to the correlation between variables, citrus farms eco-efficiency is not directly related with area, profits or cost levels. Correlation analyses neither show any strong relation between eco-efficiency and any given impact category.

Conclusions:
The choice of the function unit (ha or kg) affected the measurement of the economic and environmental performance but its effect is extremely mitigated in the eco-efficiency index. Hence, farm eco-efficiency was found to be closely related with agricultural practices and techniques and also with the balance between economic and environmental performance.

Keywords: agri-food; citrus; LCA; LCC; DEA; bootstrap

Introduction

Choosing the best production techniques in agricultural systems is not an easy task, as both economic and environmental criteria should be taken into account. Agricultural systems show a high degree of variability due not only to their dependence on farm features, such as soil type, water and nutrients availability or climate conditions, but also to the numerous management decisions and variety of agricultural practices (Notarnicola et al. 2017). Ribal et al (2016) assessed the variability of the environmental impact of citrus farms in Spain and showed that a careful selection of management practices can allow conventional farms to attain similar impacts than organic farms. Despite the increasing importance of the environmental aspects, economic results are also of capital importance, and a sustainable food system must encompass a strong food supply chain in terms of jobs and growth.

The main goal of this study is to determine whether citrus organic and conventional production systems are comparable in terms of eco-efficiency. This comparison is carried out in terms of benchmarking. Benchmarking is the systematic comparison of the performance of one firm against other firms (Bogetoft and Otto, 2011); to this aim, the classic approach is to compare production units that transform the same type of resources to the same type of product. In this case study, we compare one farm against other farms as production units that cause some environmental impacts in order to obtain an economic result. To do this, we turn to the combination of Life Cycle Assessment (LCA) and Data Envelopment Analysis. There numerous research works combining both methods in agri-food systems, for instance, Lasso et al (2018a, 2018b), Beltrán-Esteve et al. (2017), Sanjuán et al. (2011). In this study we try to determine the existence of significant differences in the ratio economic result/environmental impact between organic and conventional citrus farms.

Material and methods

Source of data, LCA and LCC:

A survey was carried out on citrus farmers, 145 corresponding to organic production and 122 to conventional one. LCA was used to estimate the environmental impacts of farms, whereas the net income of each farm was measured by means of Life Cycle Costing (LCC). Two functional units (FUs), mass and area-based, were chosen. As for the system boundaries, a cradle-to-farm-gate boundary was defined. The stages taken into consideration are the production of fertilisers, the production of pesticides, farm machinery use (including fuel production) and farming inputs application. Nine impact categories have been studied: abiotic depletion fossil (ADPf, MJ), abiotic depletion elements (ADPe, kg Sb-equiv.), global warming (GWP, kg CO2-equiv.), ozone layer depletion (ODP, kg R11-equiv.), acidification (AP, kg SO2- equiv.), eutrophication (EP, kg PO4−3-equiv.), photochemical ozone creation (POCP, kg ethene-equiv.), ecotoxicity (CTUe) and human toxicity (carcinogenic and non-carcinogenic, CTUh). All of the impacts, except those related to toxicity, were characterised using the CML-2001. Ecotoxicity and human toxicity were calculated according to USEtox 2.0 methodology.

Eco-efficiency measurement:

The results of the environmental and economic assessment of each farm were integrated by means of Data Envelopment Analysis (DEA) in a unique measure for each farm. This measure serves as a basis to compare the farms in both environmental and economic terms. DEA involves the use of linear programming methods to construct a non-parametric piece-wise frontier over the data (Coelli et al 2005). The units (farms in this case) over the frontier will be the eco-efficient ones. A key point in the results integration is that they encompass several impact categories expressed with different measurement units. DEA design allows the integration to be carried out by generalizing the individual ratios "economic result / impact category". As the variables are expressed per ha or kg, constant returns to scale have been assumed, that is, there is no size effect within the study sample. Additionally, input orientation has been chosen, this means that the optimization has been carried out by minimizing the environmental impacts rather than by maximizing the economic result.

Cluster analysis:
In order to detect and group homogeneous farms, in terms of the level of environmental impacts, cluster analysis has been used.

Uncertainty treatment:
To test for differences between groups of farms in terms of eco-efficiency we have relied in the bootstrap applied to DEA. It replicates sampling uncertainty by creating repeated samples of the original one and thus being able to compute the confidence interval of the eco-efficiency of each farm. One thousand replications have been run.

All the analyses have been carried out by means of R (R Core Team, 2020, Bogetoft and Otto, 2019).

Results

Once the environmental impacts for the said categories and the economic result were obtained for each farm, the individual relationship impact category (x) and the net income (y) both per hectare and kg has been plotted in figure 1. It is made of 18 panels (9 impact categories x 2 functional units), where each panel is a graphic representation of the individual ratio "Net income/Impact category", or in other words, "Good output/Bad output" (or undesirable output) and illustrates the difficulty of integrating such aspects. At first glance, it can be noticed the greater impact of conventional farms in almost every category. It can be also observed that the relationship changes depending on the impact category and also the functional unit. The interpretation of the plot is straightforward, the greater the income and the lower the impact the better. This means that a sweet spot is located in the upper left corner of each panel and that an ascending frontier line can be drawn. In some panels, the conventional and organic points are mixed but in other panels, such as those for ADPe and EP, conventional farms impact in a higher degree (Ribal et al 2016).

When applying a DEA model to the whole sample, considering constant returns to scale, the mean eco-efficiency was 0.25 for organic farms and 0.09 for conventional farms, using 1 hectare as FU. Only 6 organic farms turned to be eco-efficient (weighted ratio = 1), and in most of the cases the eco-efficiency ratio was below 0.5. These results are very similar when using 1 kg of citrus as FU. As to the uncertainty of the eco-efficiency results, the bootstrap confidence interval showed significant differences in the eco-efficiency of both groups of farms (conventional vs organic). Nevertheless, the distribution of the efficiency ratio proves that there is a considerable difference between efficient and non-efficient farms. In order to find key variables influencing eco-efficiency, a correlation analysis was used, showing that neither area nor net income, expense or individual category impacts are correlated with eco-efficiency.

With the aim of refining the analysis a K-means cluster analysis was carried out using the environmental impacts per hectare as variables. The scree plot shows that the whole sample can be split up in 4 homogeneous farm groups attending to their environmental impacts and that 83% of the variability can be explained with two components. Table 1 gathers the average net income, the average impact measure for each category, the average eco-efficiency as well as the number of organic and conventional farms of each cluster. Clusters 1 and 2 are only made up by conventional farms with low eco-efficiency and a medium-high net income. Cluster 3 comprises conventional and organic farms with medium eco-efficiency, while Cluster 4 also includes both types of farms with hig efficiency, low environmental impacts and a medium net income. A figure analogous to figure 1 can be built for cluster 4 (not included), showing that the farms' position in each panel is much less scattered.

Focusing on Cluster 4, again the bootstrap confidence interval of the eco-efficiency shows that there is a significant difference in the eco-efficiency of both groups of farms (conventional vs organic). That is, after splitting up the whole sample and studying those farms with lower environmental impacts (cluster 4) there is still a significant difference in the eco-efficiency ratio "good output / bad ouputs".

Discussion and conclusions

DEA allows integrating individual "good ouputs/bad outputs" ratios in order to measure the performance of production units or agri-food systems in both economic and environmental terms. The results are expressed in relative terms within the studied sample. Therefore, it can be useful to select production systems or management practices but it is not useful in absolute terms or for systems providing different outputs or utility.

In the citrus sample, eco-efficiency results were not correlated with the economic results or any single environmental impact. This means that the eco-efficiency performance is more related with the balance between the variables than with one stand-alone variable. The results also showed that the integrated measure is not affected by the choice of the FU, whereas the individual ratios "economic result /environmental impact" are. This result deserves further research and deepening. Statistical inference can be worked out by using bootstrap DEA and, in our specific citrus case, results showed that, even after selecting those farms with the lowest environmental impacts, the average eco-efficiency ratio of organic farms was significantly lower than the one for conventional farms.

This is an ongoing work and the analysis will be extended to different economic measures such as the Economic Value Added (one by one) and also to several good outputs in the numerator ratio. The expansion of the good outputs is quite promising as it can include social variables. For instance, labour use could be included in the numerator and, in that way, it could somehow offset the negative effect of wages in the economic result.

Figure 1. Individual relationship net income vs impact category (whole sample, two functional units: hectare and kg)

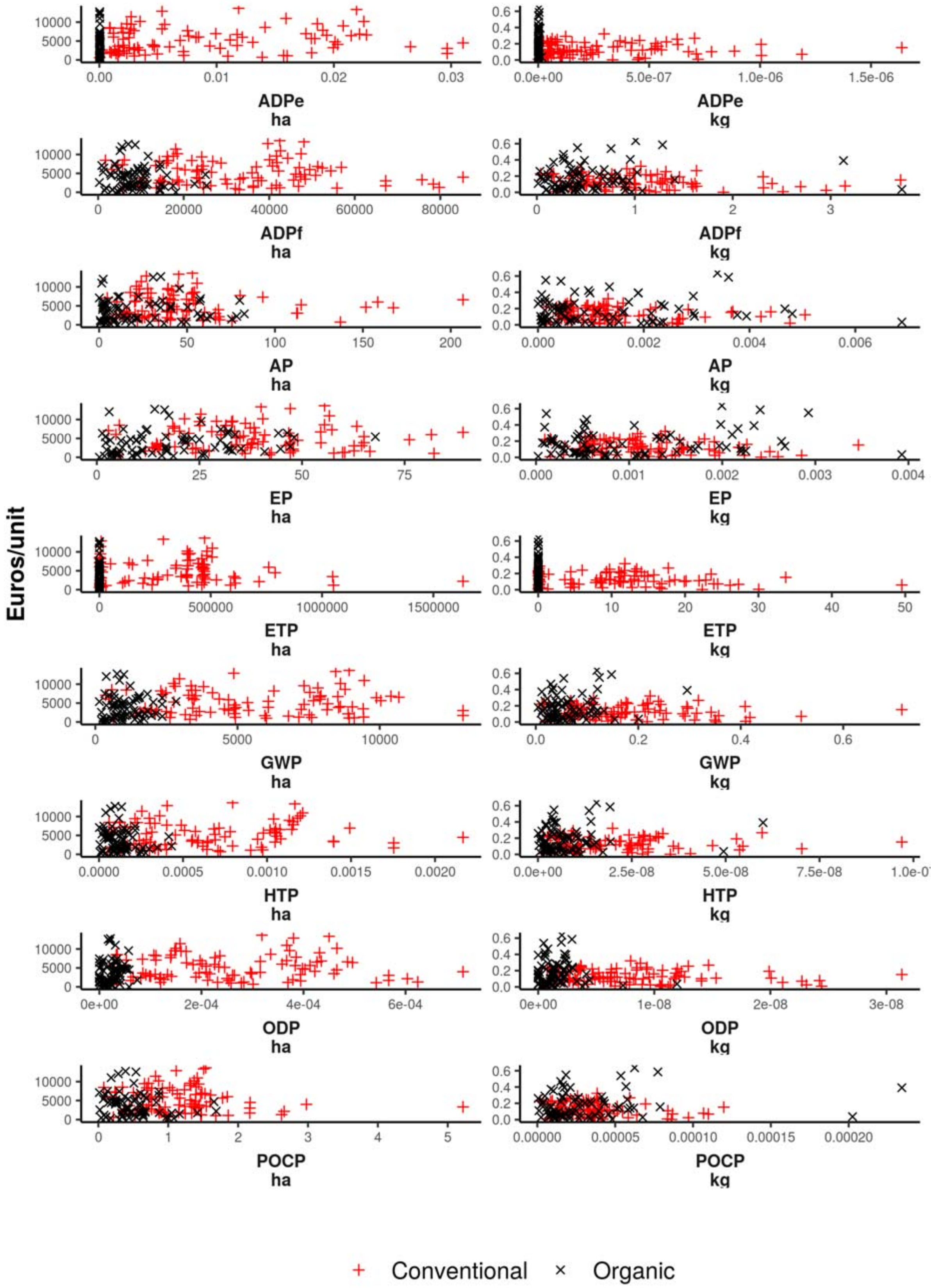

Table 1. Farm clustering. Mean values per ha.

Cluster	Type	n	EE	NI	ADPe	ADPf	AP	EP	ETP	GWP	HTP	ODP	POCP
1	C	37	0.0536	5314	0.01643	49918	69.88	49.80	367464	8380	0.00105	0.00041	1.69880
2	C	29	0.0760	4882	0.00532	26983	39.28	37.46	457667	4532	0.00050	0.00022	0.98461
3	C	14	0.1629	6270	0.00220	15128	30.58	26.74	44197	2691	0.00021	0.00012	0.64851
3	O	25	0.1500	3880	0.00004	11200	46.66	33.26	170	1713	0.00017	0.00002	0.68258
4	C	10	0.2415	3868	0.00145	8916	11.61	10.17	175318	1243	0.00017	0.00006	0.37670
4	O	48	0.3128	3739	0.00003	7385	10.49	10.14	134	732	0.00010	0.00002	0.39795

Farm system (Conventional, Organic), cluster size (n), Eco-efficiency (EE), Net income (NI), abiotic depletion fossil (ADPf, MJ), abiotic depletion elements (ADPe, kg Sb-equiv.), global warming (GWP, kg CO2-equiv.), ozone layer depletion (ODP, kg R11-equiv.), acidification (AP, kg SO2- equiv.), eutrophication (EP, kg PO4−3-equiv.), photochemical ozone creation (POCP, kg ethene-equiv.), ecotoxicity (CTUe) and human toxicity (carcinogenic and non-carcinogenic, CTUh)

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Measuring the contribution of agri-food products and services to the UN Sustainable Development Goals

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Abstract

Purpose. The UN Sustainable Development Goals (SDGs) have been ratified by all 193 UN member states and pose a globally accepted evaluation scale for sustainable development. However, there is still a lack of a tool to systematically measure the contribution of a product or company to SDGs. The main purpose of the study is therefore to develop an evaluation tool to measure the social and economic contribution of agri-food products and services to SDGs.
Methods. The development of the evaluation tool was based on indicators derived directly from SDGs. These indicators refer to the sub targets of the SDGs and are structured in two categories: case 1 indicators (C1), that measure the contributions of the product or service itself on the achievement of the sub target and case 2 (C2) indicators, that measure the contribution of the companies' activities involved along the product's or service's life cycle to the achievement of the sub target. Previous work has identified a total of 45 indicators that are relevant for a sustainability evaluation of agri-food products. Twenty indicators are C2 indicators and 25 are C1 indicators.
Results & discussion. Based on the 20 C2 social and economic indicators, an evaluation tool has been developed that allows for a systematic measurement of a product's contribution to SDGs. It is based on an evaluation scale from "+1" to "-1", where "+1" means that the product contributes fully to achieving the subtarget and "-1" means that the product negatively impacts the achievement of the subtarget. Since the SDGs do not always present a quantifiable sub-target, a priority approach was developed that allows the systematic setting of quantifiable targets for all social and economic indicators and thus enables a consistent measurement of the contribution to the SDGs. A case study was conducted to test the measurement of the contribution of a German vegetable producer to the SDGs.
Conclusions & recommendations. The study is among the first to provide a comprehensive set of indicators and an evaluation tool to measure the potential contribution of agri-food products or services to the SDGs. The presented approach allows in particular to evaluate their socioeconomic contribution. Thus, the approach is also a contribution to the further development of social life cycle assessment. Form the case study's results, concrete recommendation can be drawn. However, further case studies and validation of the tool are needed.

Keywords: *Sustainable Development Goals; SDG; sustainability; evaluation; method development*

Introduction

In 2015 the United Nations adopted the Sustainable Development Goals (SDGs) (UN 2015). The 17 goals and their 169 targets are based on a global participatory and political process with the claim of a holistic framework of goals for global sustainable development. Even though the SDGs are aimed at the country-level, companies worldwide are called to contribute. However, comprehensive sustainability assessment frameworks for companies and their products that are based on the SDGs

are still missing. Against this background, the method *SDG Evaluation of Products (SEP)* was developed to identify sustainability impacts of products and services and to assess their contribution to a sustainable development.
The aim of the study at hand was to develop an approach for the evaluation of agri-food products' or services' potential contribution to the SDGs along the product's life cycle. Based on indicators derived from the SDGs (Eberle & Wenzig, in preparation), an evaluation tool was developed. The focus was laid on socioeconomic indicators.

Material and methods

The development of the evaluation tool was based on indicators derived directly from the SDGs (Eberle & Schmid, 2019; Eberle & Wenzig, in preparation). These indicators refer to the sub targets of the SDGs and are structured in two categories:

- case 1 (C1) indicators, that measure the contributions of the product or service itself on the achievement of the sub target
- case 2 (C2) indicators, that measure the contribution of the companies' activities involved along the product's or service's life cycle to the achievement of the sub target.

In previous work, a total of 45 indicators were identified to be relevant for a sustainability assessment of agri-food products. Twenty indicators are C2 indicators and 25 are C1 indicators (Eberle & Wenzig, in preparation). Most of these indicators have been taken directly or with slight alterations from the General Indicator Framework of the SDGs (UN, 2019).

Results

The evaluation of the potential contribution of the individual C2 indicators to the SDGs is based on evaluation functions that show a relationship between the level of the indicator and the contribution to the SDG.
A scale from "-1" to "+1" was chosen to assess the potential contribution of the C2 indicators to achieving the SDGs:

- "+1" means that the product contributes fully to achieving the sustainability objective
- "-1" means that the product has a negative impact on achieving the sustainability target.

The full list of the socioeconomic indicators can be found in table 1. For example, the indicator #C2.1 "Workers earning below the UN poverty line" measures how many employees along the value chain earn below the extreme poverty line set by the UN of currently $1.90 per day. Accordingly, a full contribution to the SDG rated 1 means that all employees along the entire value chain earn above the poverty line (y=1). A neutral score of the SDG is obtained when the number of employees that earn below the current UN poverty line matches the national country average of people below the current UN poverty line (y=0). The function is expressed as linear as each employee less that earns below the current UN poverty line is considered a positive contribution to the SDG. The target value is based on the explicit SGD sub target to eradicate all extreme poverty.
For some indicators only a positive contribution is possible (0 to +1). For example, indicator #C2.20 "Availability of product-related sustainability information" assumes that the absence of sustainability information does not necessarily have negative effects. Nonetheless, any additional information, e.g. on the origin of the product or the sustainable use of the product, means a positive contribution to the achievement of the SDG.
Since the SDGs do not always specify a quantitative or quantifiable target, but this is necessary in the evaluation, a systematic approach has been developed for this purpose that defines how a quantitative target can be determined if the SDG itself only specifies a qualitative target.

Table 1: Socioeconomic C2-indicators (description of all indicators available at: www.sdg-evaluation.com).

#	**SDG**	**Indicator**
C2.1	1.1	Workers earning below UN poverty line
C2.2	1.3	Coverage of social security support
C2.3	2.4, 3.6, 5.1, 6.5, 6.6, 7.3, 9.3, 12.2, 12.3, 12.4, 13.2, 14.2, 15.1-15.6, 15.8, 15.9, 15.a, 15.b, 16.5, 16.a, 17.7, 17.11, 17.16, 17.17	Coverage of product-related sustainability (risk) management C2.3a: sustainable agriculture (SDG 2.4) C2.3b: driver/passenger safety/reduction of accidents (SDG 3.6) C2.3c: equal opportunities (SDG 5.1) C2.3d: water use&scarcity (SDG 6.5, 6.6) C2.3e: natural resources (SDG 12.2) C2.3f: food losses (SDG 12.3) C2.3g: chemicals (SDG 12.4) C2.3h: waste (SDG 12.5) C2.3i: climate change (SDG 13.2) C2.3j: marine biodiversity (SDG 14.2) C2.3k: terrestrial&freshwater biodiversity (SDG 15.1-15.5, 15.8) C2.3l: patents on natural resources (SDG 15.6) C2.3m: corruption prevention (SDG 16.5) C2.3n: human rights (SDG 16.a) C2.3o: promotion of environmental sound technologies in developing countries (SDG 17.7) C2.3p: energy efficiency (SDG 7.3) C2.3q: small scale suppliers/industry borrowers in supply chain (particular from least developed countries) (SDG 9.3) C2.3r: share of products/materials from developing countries (SDG 17.11) C2.3s: Investments in conservation and sustainable use of biodiversity/ecosystems (SDG 15.a, 15.b) C2.3t: Engagement in multi-stakeholder partnerships for sustainable development (SDG 17.16, 17.17)
C2.4	2.5	Use of different breeds&varieties
C2.5	3.8	Health insurance
C2.6	3.9, 8.8	Occupational injuries
C2.7	3.9, 8.8	Access to protective clothing
C2.8	4.4, 4.7, 13.3, 16.5	Training in sustainability issues C2.8a: ICT skills (e.g. technical and vocational) (SDG 4.4) C2.8b: sustainability in general (SDG 4.7) C2.8c: climate change (SDG 13.3) C2.8d: corruption and bribery prevention (SDG 16.5)
C2.9	4.5	Equal share of training for men and women
C2.10	5.1, 8.5	Equal wages for men and women
C2.11	5.5	Equal managerial positions for men and women
C2.12	6.1	Drinking water at work
C2.13	6.2	Adequate sanitation at work
C2.14	6.3	Wastewater treatment
C2.15	8.6	Employees under 24 years
C2.16	8.7, 8.8	Fulfillment of ILO conventions C2.16a: freedom of association C2.16b: child work C2.16c: forced labour C2.16d: discrimination C2.16e: collective bargaining for all employees C2.16f: minimum age C2.16g: equal remuneration of workers
C2.17	9.5	Investments in R&D
C2.18	10.2	Relative poverty rate
C2.19	10.3	Income Spread
C2.20	12.6, 12.8, 14.4	Product-related sustainability information

First priority was always given to the SDG itself: If the target value to be achieved is clearly defined here, then this was taken as a basis. This is the case, for example, with SDG 1.1, which states that no one in the world should earn below the UN's extreme poverty line. In the second priority the guiding statute of the SDGs "Leave no one behind" was used: This states that all countries, peoples, individuals, etc. must be included in sustainable development and that no one must be left behind (UN 2018). For the target value, this means, for example, in indicator #C2.2 that all employees along the value chain should benefit from social security and none should be excluded, for example in the upstream supply chain. The basis for considering this statute was the Sustainable Development Report, which proposes a comparable approach (SDSN & Bertelsmann Stiftung 2019). In the third priority, the average of the three best companies in the respective sector or the three best OECD countries was selected to define the target value. The fourth priority was to use expert knowledge to set objectives. As a last resort, if the definition of a target value was not possible in the way described, the topic in question was included in indicator #C2.3 "Coverage of product-related sustainability (risk) management" which asks how the company takes up the topic in management. The indicator covers all sustainability issues mentioned in the SDGs relevant for a comprehensive management in the companies sustainability (risk) management. It addresses the coverage of different sustainability issues (C2.3a – C2.3t; table 1) and the form of implementation of the issues in the management (input parameters a – c) which will be explained in the following. According to the Global Reporting Initiative (GRI 2016) management approach, there are three aspects of comprehensive management of sustainability issues: a) policies, goals and targets, b) responsibilities and resources, c) specific actions, such as processes, projects, programs and initiatives and measures. The evaluation is done per sustainability issue covered. Thus, the highest possible contribution (y = 1) is achieved when all management measures (policies / goals and targets; responsibilities / resources; specific actions / measures) are covered. The lowest contribution is assumed when no management measures are covered (y = 0) (equation 1).

Equation 1: Equation of indicator #C2.3 “Coverage of product-related sustainability (risk) management”

$$C2.3a, \ldots, C2.3t = \sum_{k=c}^{a} \left(\frac{k}{3}\right)$$

a = policies / goals and targets, b = responsibilities / resources, c = specific actions / measures

Following the priority approach described above, an evaluation function has been developed for all social and economic indicators that have been found to be relevant for agri-food products. The evaluation functions allow a consistent assessment of the products current social and economic contribution to the SDGs.

The approach for the evaluation of the sustainability (risk) management is tested using a case study of a vegetable selling company from Germany and indicators #C2.3g and #C2.3i (Coverage of product-related sustainability (risk) management, chemicals (#C2.3g) & climate change (#C2.3i)). The assessment is carried out from the farm to the gate of the vegetable producer. In the case study, two groups of actors are involved. The agricultural sector, which grows the vegetables, and the processing to the finished sales product. About 93% of the person-hours used to produce the finished end product (functional unit) are accounted for by agriculture and 7% by processing.

To evaluate indicator #C2.3g, based on the GRI management approach, the following questions have to be answered: Are chemicals addressed in product-related sustainability management? If so, how is the issue addressed: Have targets been agreed? Are responsibilities & resources defined? Are concrete measures planned? To evaluate indicator #C2.3i, based on the GRI management approach, the following questions have to be answered: Is climate change addressed in product-related

sustainability management? If so, how is the issue addressed: Are targets agreed? Are responsibilities & resources defined? Are concrete measures planned?
Results from the case study are that in agriculture and processing concrete measures for handling chemicals and responsibilities are defined. However, no targets are agreed upon. In contrast, climate change is only addressed in processing with goals, responsibilities and concrete measures to combat climate change.
This results in an assessment at actor level for #C2.3g of 0.67 and with respect to #C2.3i of 0 for agriculture and 1 for processing. The overall assessment is done by using the reference flow of working hours with respect to the functional unit which is one kilogram of the produced peas at processing gate. It results in 0.645 for indicator #C2.3g and 0.068 for indicator #C2.3i (Table 2).

Table 2: Evaluation of indicators #C2.3g & #C2.3i for a German vegetable producer

	C2.3g: Chemicals		C2.3i: Climate Change	
	Agriculture	Processing	Agriculture	Processing
Targets	0	0	0	1
Responsibilities & resources	1	1	0	1
Measures	1	1	0	1
Assessment at actor level	0,67	0,67	0	1
Share of working hours	93%	7%	93%	7%
Assessment according to share of working hours	0,62	0,045	0	0,068
Overall assessment	0,645		0,068	

Discussion & conclusions

The study is among the first to provide a comprehensive set of indicators and an evaluation tool to measure the potential contribution of agri-food products or services to the SDGs which represent the global value scale of sustainable development. The presented approach allows in particular to evaluate their socioeconomic contribution. Thus, the approach is also a contribution to the further development of social life cycle assessment. However, further case studies and a further validation of the approach are called for.
Form the case study's results, concrete recommendation can be drawn. Thus, they show clearly that to create a higher impact regarding the management of climate change along the life cycle, it is necessary to work with the farmers and implement measures. However, management of chemicals can be improved at both levels by implementing concrete goals.

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Assessing the eco-efficiency of different poultry production systems: an approach using life cycle assessment and economic value added

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Abstract

The consumption of poultry meat as a source of animal protein has been increasing worldwide, especially in emerging countries' economies. Due to the growing demand for this protein, we seek to evaluate the eco-efficiency of poultry production systems, namely positive pressure, dark house, and organic systems, in the South region of Brazil. To achieve the proposed objective, two methods were used: life cycle assessment and economic value added, considering the functional unit of one kg of live chicken ready for slaughter, specifically from the cradle to farm gate. The results show that most of the environmental impacts are from the production of grains for the manufacture of animal feed and, consequently, from the electric energy consumed by the equipment of the aviaries. Conventional systems show negative results for economic value added/kg, evidencing the destruction of the producers' economic value, that is, the capital invested is not remunerated proportionally to the risk assumed in the activity, with environmental impacts similar as dark house systems. Poultry produced in organic systems showed the best economic performance (economic value added/kg). However, they cause a slightly greater environmental impact than other systems. In order to minimize uncertainties regarding the results obtained, a sensitivity analysis and Monte Carlo simulation were performed, identifying net operating revenue and invested capital as the variables with the greatest and least impacts on the value of economic value added/kg in all types of production systems analyzed.

Keywords: *Bioeconomic performance; Value added; Risk analysis; Animal protein; Sales price.*

Introduction

Animal foods are important sources of nutrients, such as vitamins and minerals, and concentrate a significant amount of amino acids essential for maintaining human health (De Smet and Vossen, 2016). In this context, poultry production is considered a driving force in the supply of animal protein for the coming decades. It has a fast production cycle, an efficient feed conversion ratio, and requires little area during the rearing stage. Brazil is the largest exporter of poultry in the world, and the second in production, competing directly with the United States and China. Around 70% of all poultry produced in Brazil is consumed in the domestic market. The remaining 30% is exported to several countries across the globe. (ABPA, 2018; Valdes et al., 2015).

The bulk of poultry production in Brazil is conducted in intensive systems, with farmers adopting different technology levels, e.g., partially or fully automated housing systems (Valdes et al., 2015). The supply chain is verticalized, with farmers and processors setting long term cooperation contracts. Moreover, according to market demands, the target slaughter weight of the animals may vary from one production batch to another. These factors affect directly the efficiency of poultry production. Intensive poultry farming, as is the case of Brazil, could potentially lead to environmental impacts related to natural resources such as air, water, and soil in the sites where the production systems are installed (Macleod et al., 2013). As a result of such current and future challenges, several studies have been carried out in recent years seeking to analyze mainly the environmental impacts on the poultry sector in several countries. However, most of these studies evaluated only the environmental impacts of the production systems, disregarding the economic perspective. Yet, simultaneous analysis, linking environmental and economic dimensions in poultry production are still incipient.

In this paper, we fulfill this gap by linking life cycle assessment (LCA) and economic value added (EVA) to measure the eco-efficiency from three poultry production systems in Southern Brazil. Eco-efficiency is a management tool that aims to create value while improving the environmental and economic performance of products or services along the entire supply chain. So far, no study combining life cycle assessment (LCA) and economic value added (EVA) to evaluate poultry production has been conducted in Brazil. Therefore, the goal of this study was to evaluate the eco-efficiency of poultry production systems. The technologies considered were namely, positive pressure (PP), dark house (DH), and organic systems (ORG). For this, we specifically seek for: a) inventory and evaluate the environmental performance for each production system; b) calculate the Economic Value Added for each production system; c) compare the economic and environmental performance applying the eco-efficiency score.

Material and methods

The methodological procedures of this study go through the following steps: i) analysis of the environmental impacts of each production system using the methodological framework of LCA, ii) evaluation of the economic performance of each production systems using the EVA method, iii) measurement of eco-efficiency, iv) reduction of uncertainties regarding the estimates of EVA/kg calculated in different production systems through sensitivity analysis and Monte Carlo simulation.

Data for our study come from the production of poultry in the states of Paraná and Santa Catarina, which are the main producing states in Brazil. Most of the conventional poultry production is carried out in high productivity housing systems, more precisely the positive pressure (PP) and the dark house (DH) systems. In addition, organic systems (ORG) represent a growing market niche in Brazil. The database is made up of data referring to production using the DH and PP systems, collecting zootechnical and production indexes from 125 lots over a three-year period (2015-2017). Table 1 shows the technical coefficients for each housing system and product outputs. The products are named according to their classification and slaughter weights in the Brazilian poultry industry (i.e., Griller: 1.5 kg, Broiler: 2.9 kg, Heavy: 3.5 kg, and Organic: 3.3 kg).

The use of this database made it possible to conduct a robust LCA linked to the economic evaluation of the systems. In the ORG production system, the main difference is not the physical structure, but the inputs used in the rearing process.

Table 1: Technical coefficients for poultry production in dark house systems, conventional positive pressure, and organic systems.

	DH[a]			PP[b]			ORG[c]
Coefficient[d]	Griller	Broiler	Heavy	Griller	Broiler	Heavy	Organic
Slaughter age (days)	28	42	49	28	42	49	71
Feed conversion rate (FCR) (kg feed/kg weight gain)	1.40	1.67	1.82	1.40	1.67	1.82	2.57
Final weight (kg)	1.50	2.90	3.50	1.50	2.90	3.50	3.30
Birds per m^2	18.00	13.00	12.00	17.00	13.00	12.00	7.50
Mortality (%)	3.00	4.00	4.00	3.00	4.00	4.00	3.00
No. of lots/year	8.70	6.20	6.00	8.70	6.30	6.00	4.30
Interval between lots (days)	12.00	15.00	12.00	12.00	15.00	12.00	14.00
Water (L/bird)	2.50	3.98	5.78	2.50	3.98	5.78	9.94
Electricity (kWh/bird)	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Bed, shavings (m^3/bird)	0.0028	0.0041	0.0045	0.0033	0.0048	0.0054	0.0084
Firewood (m^3/bird)	0.0006	0.0008	0.0008	0.0009	0.0011	0.0009	0.0023

[a] DH 2400 - Dark house 2400 m^2; [b] PP 1200 - Positive pressure 1200 m^2; [c] ORG 600 - Positive pressure 600 m^2. [d] Technical indicators - Federation of Agriculture of the State of Paraná (FAEP).

The tool used evaluate the environmental performance was the life cycle assessment. The system boundary selected was from the cradle-to-farm gate and the functional unit (FU) 1 kg of liveweight ready to slaughter. Atmospheric emissions linked to nitrogen flows were estimated using the tier 2 method from EMEP/EEA air pollutant emission inventory guidebook (Amon et al., 2016). Methane emissions (CH_4) were estimated using the tier 2 method from IPCC (IPCC 2006). Phosphorus related emissions were assessed by applying the mass balance procedure. The life cycle impact assessment methods used were the CML-IA 2 baseline 2000 for assessing Acidification Potential (AP, kg SO_2 eq.), Eutrophication Potential (EP, kg PO_4^3 eq.) and IPCC 2013 for assessing the Global Warming Potential (GWP_{100a}, kg CO_2 eq.) (Myhre et al., 2013). The Economic Value Added has been calculate as EVA = {[(NOPAT / IC) x 100] - (MARR x IC)}, where NOPAT: net operating profit after taxes, IC: invested capital, and MARR: minimum attractiveness rate of return. The EVA performance measurement was used in order to identify whether the investment made in different poultry production systems creates or destroys economic value for producers. The functional unit based eco-efficiency (EE) was calculated by dividing the EVA per functional unit by the results of each impact category (WBCSD, 2005).

Results and Discussion

Table 2 presents the results for the life cycle impact assessment, EVA, and eco-efficiency related to each product and production system. In term of environmental performance, the ORG system showed slightly greater values in all categories of environmental impacts analyzed compared to the conventional DH and PP systems. The slaughter weight of in the ORG system (3.3 kg) was similar to the value of 3.5 kg for the Heavy product from conventional PP and DH systems, however, the FCR in the ORG system was ~ 41% higher than the conventional systems. The higher FCR associated with the higher impacts for producing organic feed was the main responsible for the lower performance of poultry produced in the organic system. Given the lack of databases for organic feed production in Brazil we used processes of organic soy and corn produced in Switzerland as proxy. When comparing the two conventional systems we found little difference in the environmental performance between then, Table 2. Conversely, when comparing products, we found that the heavier the slaughter weight of the animals the higher the environmental impact (i.e., Griller < Broiler < Heavy). The driving factor to this result is again the FCR that is significant lower for producing the Griller product.

Table 2: Global warming, acidification and eutrophication and economic value added and eco-efficiency (EE) results for the three production systems.

	Unit	DH			PP			ORG
		Griller	Broiler	Heavy	Griller	Broiler	Heavy	Organic
Global Warming Potential	kg CO_2 eq	1.334	1.488	1.550	1.335	1.466	1.556	1.620
Acidification Potential	kg SO_2 eq	0.015	0.017	0.018	0.015	0.016	0.018	0.028
Eutrophication Potential	kg PO_4 eq	0.029	0.034	0.035	0.029	0.033	0.035	0.044
$EVA \cdot FU^{-1}$	US$	0.012	0.014	0.010	0.002	0.008	-0.001	1.123
EE_GWP	-	0.0090	0.0094	0.0065	0.0015	0.0055	-0.0006	0.69
EE_AP	-	0.80	0.82	0.56	0.13	0.50	-0.06	40.1
EE_EP	-	0.414	0.412	0.29	0.07	0.24	-0.03	25.5

DH - Dark house 2400 m^2; PP - Positive pressure 1200 m^2; ORG- Positive pressure 600 m^2 - organic production.

EVA results show that organic poultry production created at least 80 folds more value per FU than the traditional systems. The magnitude of its value ($1.123/kg) concerning the other systems is determined by the higher sale price of the product (24.75 and 4.53 times higher for the producer and the consumer, respectively), the lower operating cost and the lower demand for invested capital. The higher price and lower cost increase profitability. Higher profit with less demand for invested capital produces a higher rate of return. A higher rate of return with a lower cost of capital increases the value of EVA/Kg ($1.123).

The EVA among the conventional systems was considerably higher in the DH system, meaning that farmers that use the fully automated Dark House systems created more value per kg of poultry produced. On the other hand, producers using the Positive Pressure barns created much less value per kg produced or even lost value if they produced the Heavy product, Table 2. EE scores were considerably higher in the ORG system than in the conventional systems. Between the two conventional systems, the DH system presented higher EE scores than the PP system. The EE scores for producing the Griller product were 6 times higher in the DH system compared to the PP systems. This difference was lower for producing the Broiler product (~1.7 times), but greater (10 times) for the production of the heavier animals. Overall these results indicate that farmers that invested in the past, before the introduction of Dark House systems, are at a competitive disadvantage in the Brazilian poultry production.

<u>Measurements of uncertainty and risk:</u> The variables that most influenced the economic value added (EVA) of the production systems were I - net operating revenue, II - lot operating cost, III - minimum attractiveness rate of return and, IV - invested capital. In order to verify which of the poultry production systems has the greatest risk for the investor, the Monte Carlo simulation was developed. It can be seen that the greatest impact on EVA/kg in this production system occurs when there are variations in net operating revenue (95.18%), followed by the impact produced by changes in minimum attractiveness rate of return (2.73%), operating cost (1.86%) and invested capital (0.22%).

The pressure on the production chain refers to the need to establish strategies so that it be more effective and, at the same time, reduce negative externalities (Dick et al., 2015). It is also noteworthy that the demand for animal protein consumption has increased worldwide due to the increase in consumption by emerging countries justified by the population increase and the availability of people's economic resources, expanding the demand for this protein (Boer et al., 2014). In the case of poultry meat, it has gained the consumer market due to i) its low price, ii) for providing a source of necessary nutritional components for people such as vitamin B, and iii) for its low fat contents, in the latter case being able to meet certain niche markets (FAO, 2012). Regarding measurements in the context of food production, different products have been evaluated based on LCA (Vasconcelos et al., 2018; Nikkhah et al., 2019).

In recent years, there has been an increase in the attention that society has paid to the sustainability of products, processes and services made available for consumption (Bauman and Tillman, 2004). However, a sustainable production must consider the issue of the environmental impact generated and the economic value created by the production (Desimone and Popoff, 2000). For this reason, we decided to use the concept of eco-efficiency in this research. It is a tool to compare products or production processes that can result in buying options and use options (Desimone and Popoff, 2000). Thus, the consumer, among the available alternatives, can choose the one that maximizes the producer's income and minimizes the environmental impact, that is, the one with the greatest eco-efficiency (Middelaar et al., 2011).

Concluding remarks

This study allowed a holistic view of the poultry production chain in Brazil and the main product of poultry, chicken, considering that we used information from the places with the greatest productive representativeness in Brazil. The quantification of the main environmental impacts was possible because there are national inventories of the main inputs to produce broilers, grains, and electricity.

Regarding the economic issue addressed, negative values for EVA/kg in a conventional system indicate the need for an analysis on the return of this productive system for those who work with it and even in the case of new investments. However, in Brazil, this productive form has not been stimulated for use and yet there are prospects for replacing systems that are in operation for the DH system. In addition, the type of chicken used in the production process can influence the results of productive eco-efficiency. However, before deciding the production process in a substitution, one needs to study if the type of chicken is accepted by the consumer market, that is, if it meets consumption needs.

It is also suggested that future work encompasses the analysis and scope of factories that process different types of agro-industrial by-products. The purpose of the research would change because the focus would be to compare the impacts of livestock production fed with different sources of proteins. Therefore, both tools have replicable structures in different production systems, being able to analyze eco-efficiency in different countries, even to compare whether there is a relationship between them.

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Topic 14:
LCA of Products
from Around the World

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Comparison of two crop sequences with and without legumes in Bulgaria

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Abstract

Agriculture is a major contributor to several environmental problems and pushes the earth system towards its planetary boundary limits. Currently, agriculture's share of total anthropogenic nitrogen (N) and phosphorous (P) use has been estimated at 86 and 90%, respectively. Moreover, the use of fertilizers is expected to grow. Low-input systems using legumes in crop sequences are a promising option for reducing environmental impacts caused by N-fertilisers.

We use Life cycle assessment to compare two crop sequences (CS) in Bulgaria; one sequence without legumes (CS1) and another sequence with legumes (CS2). Input data for agricultural production and yields are collected within the Legumes Translated project. We also conducted a plausibility check using a streamlined N-balance for the whole crop sequence (CS) and compared nitrogen recovery and calculated N-emissions based on N-fertiliser specific emission factors. We calculated the calorific value, cereal unit, raw protein and the usable protein (relevant for dairy feed) per hectare for each CS in order to compare them based on the area and product function.

In order to provide those functions CS1 requires 468 [kg N ha^{-1}] mineral N-fertiliser, while CS2 requires just 220 [kg N ha^{-1}] N-fertiliser, which is less than half of CS1. However, from 1.1 to 1.4-times more land is needed for CS2.

Based on area, CS2 causes less environmental impacts as CS1 in almost all considered impact categories. However, a fair comparison is just possible based on the provided function or service. For sake of simplicity, we use the usable protein (UP) to compare both CSs per kg UP. The legumes containing CS2 causes lower environmental impacts than CS1. The main reason is the reduced amount of mineral N-fertiliser needed to deliver 1 kg UP. The production of N-fertiliser is resource and energy intensive, thus causing GHG-emissions and natural gas depletion, but also causes emissions of various N-species, NH_3, NO and N_2O when applied on the field.

Crop sequences with legumes provide an option to reduce environmental impacts substantially due to lower input of agro-chemicals, particularly N-fertiliser but also pesticides. There was no trade-off between the considered environmental impacts. Although the reduction varies among the selected environmental impact categories and depend on the function, e.g. proteins or calories, in both cases legumes in the crop rotation provide environmental benefits, but require more land. Biodiversity related impacts are still work-in-progress but have to be taken into account when competing crop sequences are assessed.

Keywords: *N-fertiliser, N-balance, nitrogen recovery, crop rotation, soya, LCA*

Introduction

The world population is expected to reach 9 – 11 billion by mid of this century. Feeding the population is a serious challenge given the environmental impacts current agricultural practice has (van Beek, Meerburg et al. 2010). Agriculture is a major contributor to several environmental problems and pushes the earth system towards its planetary boundary limits (Steffen, Richardson et al. 2015). Agriculture drives land use change, freshwater consumption and causes biodiversity loss. Currently, agriculture's share of total anthropogenic N and P use has been estimated at 86 and 90%, respectively. Moreover, the use of fertilizers is expected to grow (Campbell, Beare et al. 2017).

In order to ensure food production and reduce agriculture's environmental impacts simultaneously low-input systems using legumes in crop sequences are a promising option (Schwenke, Herridge et al. 2015). The main advantage is the symbiotic nitrogen fixation and reduced use of fossil energy and N-fertiliser.

Crop rotations describe the chronological sequence of changing crops on the same field. Generally, they strive for maintaining and promoting soil fertility, yield stability and diversification. The physical, chemical and biological characteristics of agricultural soil change with the design of crop rotations (selection and sequence of crops grown, integration of catch crops, legumes, underseeds, perennial plants, green manure, fallow or incorporation of crop residues) (Ball, Bingham et al. 2005). For example, crop rotation influences plant hygiene (by interrupting the risk of spread of plant diseases and pests), nutrient supply (through crop-specific nutrient use, supply of different nutrients through crop residues, etc.) and the humus balance. Incorporated harvest residues and catch crops cause a nutrient transfer and supply of organic matter, improve the structural and aggregate stability and thus the hydraulic properties of the soil and influence the activity of soil organisms.

Crop rotation system produces multiple-products and including crop rotation effects adequately in life cycle assessment (LCA) is still a challenge (Goglio et al. 2018)). There are various approaches to deal with this challenge. The simplest and most commonly used method for evaluating individual agricultural products is to consider a single crop. This approach is used in the EU-RED (EU 2009) and is described in common LCI-data sets (Nemecek et al.2007, Nemecek et al. 2016, Paassen et al. 2019). This approach represents a product system with two temporally shifted system boundaries for calculating N_2O field emissions (Nemecek T 2007, Stichnothe, Schuchardt et al. 2014).

Another methodological approach for a single crop within a crop rotation is the system division and allocation of input, emissions and crop rotation effects based on specific criteria. The identified crop rotation effects must be quantified and their scope and distribution to the affected crop. Nemecek (Nemecek, Hayer et al. 2015) limit the direct effect to the preceding crop and thus break down the crop rotation into a set of two-tier crop combinations in order to derive new efficient crop rotations.

Another methodological approach for the preparation of a product life cycle assessment of a single crop rotation link consists in extending the system boundary to the entire crop rotation and allocating it on the basis of specific criteria. This involves collecting inventory data for the entire crop rotation and converting the output to a common denominator (Brankatschk and Finkbeiner 2015). They (Brankatschk and Finkbeiner 2014) recommend the cereal unit as denominator and Peter (Peter, Specka et al. 2017)) uses the biogas yield for a cropping system for biogas to allocate environmental impacts to single crops. The latter consider removed straw as to be outside the system boundary owing to the alinement with the EU-RED methodology.

Crop rotation effects can have a substantial impact on the total LCA result of each single crop in the rotation, however, currently there is no harmonized commonly agreed approach, how to include crop rotation effects. In this study, we use a whole-system approach and compare two complete crop rotations, one with and another one without legumes at one agricultural research station in Bulgaria.

Material and methods

We use an attributional approach to estimate the environmental impacts of the two crop sequences from cradle-to-field. All activities and inputs in the period from field preparation to harvest are allocated to the respective crop. Nutrient from crop residues are considered as input to the subsequent crop. For the LCI modelling the latest IPCC emission factors for NH_3, NO and N_2O to air and nitrate to water are used (IPCC 2019) and for phosphate emissions to water the approach of Prahsun (Prahsun 2006). Emission factors for gaseous nitrogen emissions are shown in Table1.

Tab. 1: Emission factors of N- fertiliser used in CS1 and CS2

% of N-Input	NH_3	N_2O	NO
AN	3.0	0.8	2.9
CAN	1.6	0.7	1.6
NPK	2.3	0.8	2.3
DAP	9.1	0.9	0.7

The Ecoinvent 3.5 database is used for background processes and the RECEIPE_2016 midpoint method is used to calculate environmental impacts.

Input data for agricultural production and yields are collected within the Legumes Translated project (for more details look at www.legumestranslated.eu). CS1 requires 468 [kg N ha^{-1}] mineral N-fertiliser, while in CS2 (with legumes) requires just 220 kg N-fertiliser *ha^{-1}, less than half of CS1. The comparison is done for the whole crop sequences rather than individual crops.

In addition, we conducted a plausibility check concerning the calculated N-emissions based on a streamlined N-balance approach. We assumed a closed-loop crop rotation, i.e. the first crop in the rotation becomes the subsequent crop after the last crop of the rotation and visa versa. The N-balance is calculated based on the following equations:

$N_{input} = N_{output}$, assuming that on average the soil-N does not change for the entire CS

$N_{input} = N_{fertiliser} + N_{atmospheric\ deposition} + \Delta N_{residues}$

$N_{output} = N_{uptake} + \Sigma\ N_{emissions}$, (NH_3-N + N_2O-N + NO-N + NO_3^--N + N_2)

N_{input} from crop residues ($\Delta N_{-residue}$) is calculated as different from residue-N of the previous crop minus residue-N of the harvested crop. The amount of residues and their N-content is calculated based on the yield and factors provided by (IPCC 2006) Vol.4 Ch. 11.

Results and Discussion

We compare two crop sequences (CS):

1. CS1: Winter rapeseed – winter wheat – sunflower grains – maize grains
2. CS2: Soya beans - winter wheat - sunflower grains - winter wheat

We calculated the calorific value, cereal unit, raw protein and the usable protein (relevant for dairy feed) per hectare for each CS as well as their environmental impacts. Results are displayed in Table 2 and the associated environmental impacts in Table 3.

Tab. 2: Functional performance per hectare

Functional performance	CS1 (Without legumes)	CS2 (With legumes)	Ratio CS1:CS2

LVC [MJ ha^{-1}]	397628.0	296920.0	1.34
Cereal Unit [kg ha^{-1}]	21940.9	16023.5	1.37
Raw protein [kg ha^{-1}]	2844.2	2489.0	1.14
Usable protein [kg ha^{-1}]	2753.1	2228.5	1.24

For each function (food, feed and/or energy) the area demand of CS2 is higher as CS1, although the ratios differ among the different functions. In order to get the same amount of raw protein 1.14 ha of CS2 is needed and in order to get the same quantity as cereal unit, it is 1.37 ha compared to CS1.

However, in order to provide those functions CS1 requires 468 [kg N ha^{-1}] mineral N-fertiliser, while in CS2 requires just 220 [kg N-fertiliser ha^{-1}], less than half of CS1.

Tab. 3: Environmental impacts of CS1 and CS2 per hectare and per kg UP

Environmental impacts	CS1	CS2	CS1	CS2	Ratio CS1:CS2 per kg UP
	[per ha]		[per kg UP]		
Metal Depletion [kg Cu eq.]	1.3E+02	4.6E+01	4.7E-02	2.1E-02	2.3
Fossil Depletion [kg oil eq.]	2.2 E+03	1.1E+03	8.0E-01	4.9E-01	1.6
Marine Eutrophication [kg N eq.]	1.1E+00	1.7E+01	4.0E-02	7.6E-04	0.5
Freshwater Eutrophication [kg P eq.]	2.5E+00	1.0E+00	9.1E-04	4.5E-04	2.0
Global Warming Potential (GWP_{100yr}) [kg $CO_{2eq.}$]	8.9E+03	5.5E+03	3.2E+00	2.5E+00	1.3
Photochemical Ozone Formation [kg $NO_{xeq.}$]	6.7E+01	3.3E+01	2.4E-02	1.5E-02	1.6
Stratospheric O_3 Depletion [kg CFC-$11_{eq.}$]	1.3E-01	9.3E-02	4.7E-05	4.2E-05	1.1
Terrestrial acidification [kg $SO_{2\ eq.}$]	8.3E+01	4.1E+01	3.0E-02	1.8E-02	1.6

Based on area, CS2 causes less environmental impacts than CS1 in almost all considered impact categories, except marine eutrophication (ME). Nitrate leaching does not occur, when transevaporation is higher than the precipitation according to IPCC, which is the case in Tarnovo, Bulgaria. Therefore, the difference in ME originates from background datasets only. No nitrate leaching is confirmed by a streamlined N-balance approach for CS1 assuming that the soil organic matter and thus the soil fertility remains constant. The overall nitrogen recovery efficiency varies then between 97% and 86% depending on the assumed atmospheric nitrogen deposition (0 to 15 [kg N ha^{-1} yr^{-1}]). Although the nitrogen recovery efficiency corresponds with the natural variability, the assumption that the N-pool in the soil does not change in the long-term after completing the whole crop sequence is still valid.

The reduction varies among the different impact categories on a per hectare basis, from 29% for stratospheric ozone depletion to 65% for metal depletion. However, a fair comparison is just possible based on the provided function or service. For sake of simplicity, we use the usable protein (UP) to compare both CSs as UP is more or less the average of all functionalities shown in Table 2. The ratio shown in the right column in Table 3 shows that the legumes containing CS2 causes lower environmental impacts than CS1. The main reason is the reduced amount of mineral N-fertiliser needed to deliver 1 kg UP, i.e. 170 g N * $kgUP^{-1}$ in CS 1 and 98 g N*$kgUP^{-1}$ in CS2. The production of N-fertiliser is resource and energy intensive, thus causing GHG-emissions and natural gas depletion, but also causes emissions of various N-species, NH_3, NO and N_2O when applied on the field. That is confirmed by results from Hayer et al., they have shown that introducing legumes to a typical crop rotation consisting of rapeseed, winter wheat and winter barley in France results in lower demand of fossil resources, lower GWP and eutrophication (Hayer 2010).

Conclusions

Crop sequences with legumes provide an option to reduce environmental impacts considerably due to substantial lower input of agro-chemicals, particularly N-fertilisers. There is no trade-off between the considered environmental impacts. Although the reduction varies among the selected environmental impact categories, legumes provide a broad range of environmental benefits. However, the investigated CS2 requires 1.1 to 1.4-times more area to provide the same product service with less environmental impacts.

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The potential of local production and processing in West Africa: How does the environmental footprint of rice and cashew from Nigeria and Ghana compare to rice imported from and cashew processed in Vietnam?

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Abstract

Purpose Even though West Africa is the largest cashew producing region, 90% of the raw cashew grown there is processed in Asia. Similarly, despite significant rice production in West Africa, large quantities are imported from Asia. The goal of this LCA is to assess the environmental impact of rice imported from and cashew processed in Asia, and compare it to the situation in which production and processing of rice and cashew happens locally, in West Africa.
Methods This LCA examines the environmental impact of 1 kg white rice (produced in Nigeria vs Vietnam) for the Nigerian market, and the impact of 1 kg cashew (produced in Ghana and processed in Ghana vs Vietnam) for the European market. Data on cultivation, transport and processing in West Africa was collected from Ghanaian cashew farmers and Nigerian rice farmers and processors linked to two GIZ projects: ComCashew and CARI. For Vietnam, data was obtained through the Institute for Agricultural Environment. The scope extends from cultivation up to transport to the end market. Climate change, particulate matter, land use, water use and fossil resource scarcity impacts were calculated using IPCC Guidelines, inventory data from Agri-footprint 5.0 and Ecoinvent 3.5 LCA databases, and ReCiPe 2016.
Results and discussion Nigerian rice has a lower environmental impact than Vietnamese rice for all impact categories under consideration, except for water use. The carbon footprint (1.37 kg CO_2-eq for 1 kg Nigerian rice and 2.6 kg CO_2-eq for 1kg rice imported from Vietnam) is mainly determined by CH_4 emissions from anaerobic conditions during flooding. Rice production in Vietnam is more resource and energy intensive and uses more intensive flooding.
Processing Ghanaian cashew in Ghana instead of Vietnam leads to 30% lower carbon footprint (2.2 kg CO_2-eq as opposed to 3.2 kg CO_2-eq for 1 kg), which is attributed to the lower transport needs. Applying sustainable farming practices (frequent drainage for rice and pruning for cashew trees) leads to significant lower environmental impacts for both rice and cashew.
Conclusions The results demonstrate the environmental benefit of production and processing in West Africa, and the effectiveness of stimulating sustainable farming practices. It should be noted that the data only refers to farmers linked to the two GIZ projects. Data quality could improve by actual measurements of GHG emissions from rice fields in West Africa, and by collecting primary data on processing of cashew nuts in Vietnam.

Keywords: *Life cycle assessment; rice; cashew, West Africa; impact assessment*

Introduction

This screening Life Cycle Assessment (LCA) focuses on rice and cashew in West Africa, two crops that are dominantly grown by smallholder farmers and play an important role in supporting local livelihoods. Even though West Africa is the largest cashew producing region in the world, 90% of the raw cashew nuts grown there are processed in South and South East Asia (Ton, Hinnou, Yao, & Adingra, 2018). At the same time, rice production in West Africa cannot meet domestic demand, and a large quantity is imported from South East Asia (Zenna, Senthilkumar, & Sie, 2017). The goal of this LCA is to assess the environmental impact of rice imported from and cashew processed in Asia, and compare it to the situation in which production and processing of rice and cashew happens locally, in West Africa.

For both rice and cashew, the system under consideration extends from crop cultivation (cradle) up to transport to the end market. For rice, the emphasis lies on investigating the environmental impact of different production practices (e.g. rain-fed vs. irrigation) and comparing the locally produced rice to imported rice from South East Asia. For cashew, the influence of applying good agricultural practices (GAP, such as pruning and fire protection) was assessed, as well as the impact of processing cashew locally instead of in South East Asia.

The LCA focuses on Nigeria for rice and Ghana for cashew, two countries that are part of GIZ's Competitive Cashew initiative (ComCashew) and Competitive African Rice Initiative (CARI). These projects aim to increase the competitiveness and productivity of rice and cashew value chains in East and West Africa, and strengthen linkages to national and international markets. Vietnam was selected to represent cashew processing and rice production in South East Asia, as it is the biggest processor of West African cashews (Trade for Development Centre, 2018), and also exports large quantities of rice to Africa.

The results of this LCA will be used by the CARI and ComCashew projects and its partners to gain insight in the environmental impact of enhanced localized production and processing, as well as the impact of applying sustainable farming practices as promoted by the projects. The study fills an important gap that exists when it comes to LCA data for food products originating from West Africa.

Method

This study is conducted in accordance with the ISO 14040 and 14044 LCA methodological standards, and is being externally reviewed at the time of submission of this paper. The study looks at the environmental impact of 1 kg white rice (produced in Nigeria or in Vietnam) for the Nigerian market, and the impact of 1 kg cashew (produced in Ghana and processed in Ghana or Vietnam) for the European market. Data on cashew and rice farming and processing in West Africa was collected from farmers and processors linked to the ComCashew and CARI projects.

For rice, data was obtained from irrigated and rainfed farms, and captured yields, input use, energy consumption, transport and farming practices related to flooding patterns during and before irrigation, the application of organic amendments, and the burning of crop residues. For cashew, data was obtained for farmers applying good agricultural practices, and a group applying conventional practices. The data collected includes yields, input use, on-farm energy use for pruning, farming practices, the use and value of the cashew nut and apple, and transport.

Data on rice production in Vietnam was obtained through the Vietnamese Institute for Agricultural Environment (IAE), data on rice processing was based on literature (Kamalakkannan & Kulatunga, 2018), and data on cashew processing was based on Jekayinfa & Bamgboye (2006). In order to make an equal comparison between production systems in Asia and Africa, it has been ensured to collect similar type of data for both regions, to use processes from the same LCA databases and to perform the same emission calculations.

To calculate the environmental impact, data on fertilizer and pesticide inputs, transportation, energy use, and packaging materials was linked to corresponding processes from Agri-footprint 5.0

and Ecoinvent 3.5 LCA databases. Direct and indirect emissions related to the application of fertilizers and organic amendments and to flooding (for rice) were calculated using the Tier 1 method as described in the IPCC guidelines (IPCC, 2019). The ReCiPe 2016 environmental impact categories for climate change, fine particulate matter formation, fossil resource scarcity, water use, and land use were taken into consideration (Huijbregts et al., 2016).

Economic allocation was applied for co-products generated during the cultivation stage and during processing of the rice and cashew. Emissions related to land use change were considered as a sensitivity analysis. As no primary data on land conversion in the past 20 years was available, default values were used from the Direct Land Use Change Assessment Tool (Blonk Consultants, 2018).

Results & Discussion

Rice

As shown in Figure 1A, the average Nigerian rice has a lower environmental impact for all impact categories under consideration, except for water use. Distinct differences can be observed between rainfed and irrigated rice, with rainfed rice having a lower carbon and water footprint, but higher land use due to its low yield.

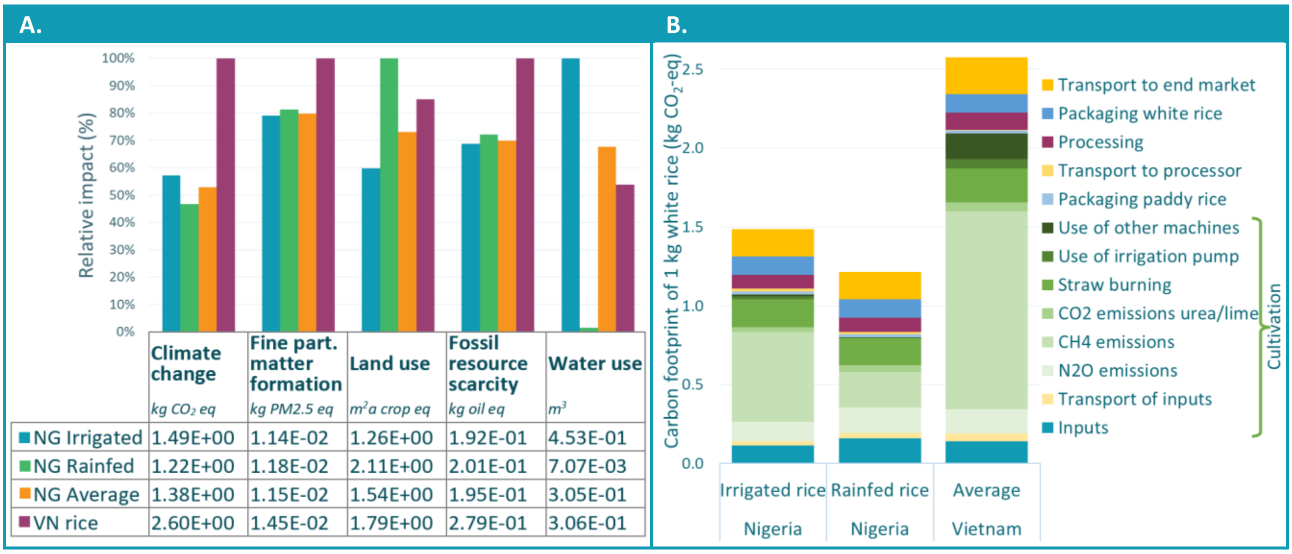


Figure 1 Environmental impact results for 1 kg of white rice: A) relative and absolute results for all environmental impact categories under consideration; B) contribution analysis for the climate change impact category

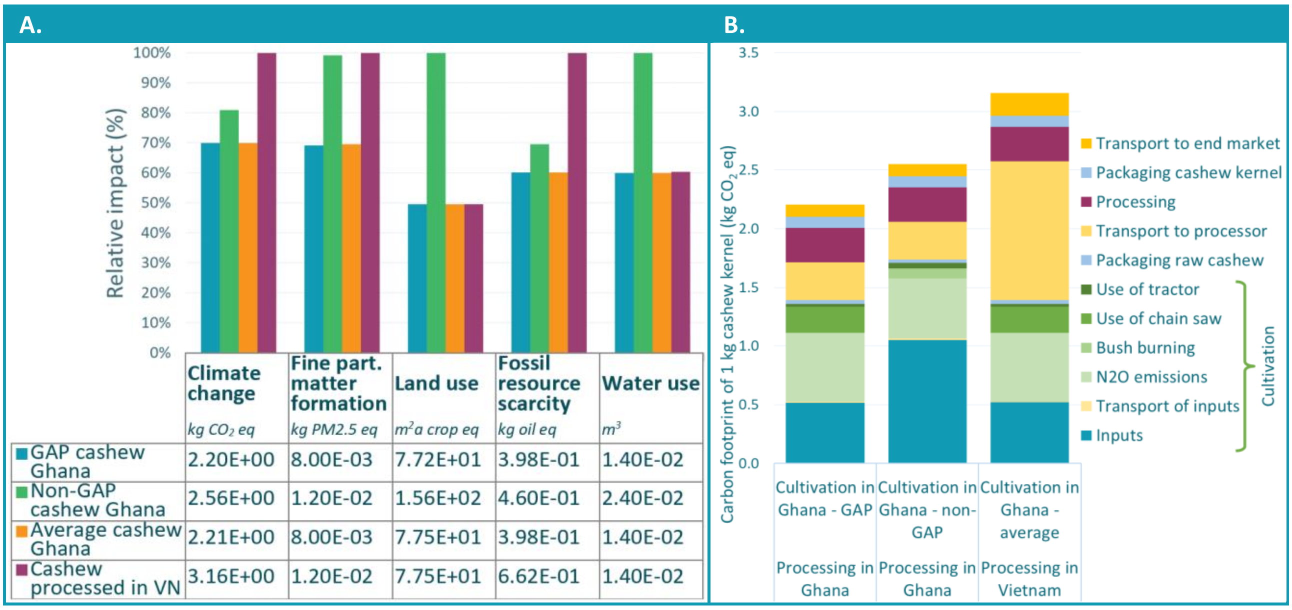
Producing rice in Nigeria instead of importing it from Vietnam, is associated with a 47% lower climate change impact (2.6 kg CO_2-eq for Vietnamese rice, 1.4 kg CO_2-eq for average Nigerian rice). The contribution analysis (Figure 1B) shows that CH_4 emissions are the main contributor to climate change. In Nigeria, the majority of irrigated rice is produced using multiple drainage periods, and most of the rainfed (upland) rice fields have no significant flooding, explaining the lower CH_4 emissions for these rice types. Rice cultivation in Vietnam on the other hand, is characterised by relative intensive flooding with few aeration periods. The higher mechanisation level (irrigation pumps, mechanical dryers, tractors and harvesters) and the frequent burning of crop residues further contributes to the higher footprint for Vietnam as opposed to Nigeria.

Adding land use change (6.75 ton CO_2-eq/ha/year for rice in Nigeria, 0 for rice in Vietnam) leads to an average footprint of 3.3 kg CO_2-eq for 1 kg of average Nigerian white rice. It should be taken into consideration, that the LUC as derived from the tool is not sensitive to site-specific conditions, as it uses country-level averages for the expansion of deforested areas and rice areas. In

Nigeria, deforestation is mostly occurring in tropical forests in southern Nigeria, whereas in northern Nigeria, where the rice is cultivated, the natural vegetation concerns savanna. Even if the sparsely vegetated savanna is converted, this would result in a much lower release of carbon than deforestation of tropical rainforest.

Cashew

Cashew that is grown with good agricultural practices (GAP) and processed in Ghana has the lowest environmental impact for all impact categories under consideration (Figure 2A). Processing the average Ghanaian cashew in Ghana instead of Vietnam, leads to a 30% lower carbon footprint (2.2 kg CO_2-eq as opposed to 3.2 kg CO_2-eq), which is attributed to the reduced transport needs.



	Climate change (kg CO_2 eq)	Fine part. matter formation (kg PM2.5 eq)	Land use (m^2a crop eq)	Fossil resource scarcity (kg oil eq)	Water use (m^3)
GAP cashew Ghana	2.20E+00	8.00E-03	7.72E+01	3.98E-01	1.40E-02
Non-GAP cashew Ghana	2.56E+00	1.20E-02	1.56E+02	4.60E-01	2.40E-02
Average cashew Ghana	2.21E+00	8.00E-03	7.75E+01	3.98E-01	1.40E-02
Cashew processed in VN	3.16E+00	1.20E-02	7.75E+01	6.62E-01	1.40E-02

Figure 2 Environmental impact results for 1 kg of cashew kernel: A) relative and absolute results for all environmental impact categories under consideration; B) contribution analysis for the climate change impact category

Due to its low yields, cashew that is produced with conventional practices (non-GAP) has a relative high impact on land use and water consumption. It should be noted that the impact for the average Ghanaian cashew resembles the impact of the GAP cashews, as only a small number of farmers were included that applied conventional practices.

As little to no processing data was available for cashew processing in Ghana and Vietnam, the study from Jekayinfa & Bamgboye (2006) on cashew processing in Nigeria was used (with the Vietnamese electricity mix). The sensitivity analysis points out that even if processing in Ghana would have a 50% less efficient and in Vietnam 50% more efficient, cashew processed in Ghana would still have a lower carbon footprint.

Land use change associated with cashew production in Ghana was zero according to the Direct Land Use Change Assessment Tool.

Conclusions

The results demonstrate the environmental benefits of stimulating local production and processing of rice and cashew in West Africa. The application of sustainable farming practices as promoted by the two GIZ programs, leads to a significant lower environmental footprint for both cashew and rice.

The footprint of Nigerian rice could be further lowered by incorporating organic material long before cultivation, using rice straw productively (e.g. in rice processing), and by stimulating more frequent drainage periods. Results can become more accurate by carrying out actual CH_4 measurements in rice fields, which are currently lacking for African conditions, and by a more detailed study into the impact of land use change. Land use change data is currently based on a country-level average for Nigeria, with a high level of deforestation of tropical forests (and thus high footprint), that is not representative of the savanna of Northern Nigeria where the rice is cultivated.

For cashew production, the environmental impact could be further lowered by using the cashew apple productively, instead of leaving it in the field. Data quality would improve by collecting primary data on cashew processing in Ghana and Vietnam.

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Single score of bottled wines: comparison of Beaujolais wines using latest life cycle impact assessment methods and comparing PEF and ecoinvent® datasets

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Abstract

Purpose *:* The goal of this study is to compare the single score of bottled wine from the latest LCIA methods that, namely ReCiPe 2016, Impact World + and EF method and to discuss the results in the eco-labelling context.
Methods: Six 2017 wines produced in the Beaujolais region are assessed. The systems boundaries include winegrowing, winemaking, packaging and distribution stages. Product Environmental footprint (PEF) category rules for still and sparkling wine are applied for LCI and LCIA. We also provide sensitivity analysis for (i) the LCI phase with the use of the ecoinvent®, and its comparison with PEF database and for (ii) the LCIA phase with the use of ReCiPe2016, ImpactWorld+ (IW+) single score, and their comparison with the PEF method.
Results and discussion: The study shows that the three LCIA method provide the same single score ranking for the different wine. Nonetheless, the difference between products is variable depending on the method, which is mainly due to the difference in the winegrowing stage and the impact of agricultural fuel and fertilization according to each method. The contribution of impact to the single score is also varying depending on the method with several notable elements: Climate change is has a high contribution for all methods, the impacts related to the use of fossil fuels (particulate matter, resource use) and to the land use are also important for PEF and ReCiPe while the impact of water consumption is significant in IW+ single score. This study should be complemented with cases from different wineries to observe if the consistency in the raking is still conserved.

Keywords: *Life Cycle Assessment, Environmental Labelling, Wine, PEF, LCIA comparison*

Introduction

Life Cycle Assessment (LCA) has proved to be a powerful tool for ecodesign, identification of environmental hotspots and continuous improvement. However, the method has yet failed to enable the comparison of products arising from different LCA studies within a sector, due the methodological discrepancies that are inherent to each LCA. Different approaches are promoted to enable the comparison between products, including the harmonized procedure proposed by the European commission through the PEF (Product Environmental Footprint) category rules. Nonetheless, the procedure has undergone some criticism, especially related to the choice of impact assessment method and the normalization and weighting scheme that enables computing a single score (Finkbeiner, 2014). In this study, we wish to compare the results obtained applying the PEF recommendations and two other recently updated methods: ReCiPe 2016 (Huijbregts et al., 2016) and Impact World + (IW+) (Bulle et al., 2019), which also propose single score results. IW+ does not propose weighting factors but suggest the use of the Stepwise approach (Weidema, 2009), and ReCiPe single score is obtained through normalization and weighting of the endpoints. We propose to conduct this comparison in the wine sector. The environmental impact of the wine production has been scrutinized by the academics for more than ten years. This has been translated into a non-negligible scientific paper production, as shown in the literature reviews of Rugani et al. (2013), Ferrara and De Feo (2018) and Jourdaine et al. (2020). The authors show the differences in the boundaries, the complexity to compare results due to methodological variability inherent of the studies. Recently, under the PEF project, a specific harmonization procedure was proposed for still and sparkling wine (CEEV, 2018). Such category rules can be used to communicate impacts related to wine to the consumers, specifically for eco-labelling

The objective of this study is to assess the variability derived from the LCIA and background datasets used for evaluating the impact of bottled wine. We aim to answer the following research questions:

- Are the aggregated results (single score) provided by different LCIA methods lead to the same conclusions?
- Which impacts are the most contributive to the single score for each LCIA method in the wine sector?

Material and methods

In order address these questions, we conduct LCA on a wine producing organization: a French winery located in the protected designation of origin (PDO) of Beaujolais. The six most important wines in volume are assessed. The study has been conducted in 2019 with the data of the 2017 vintage. The system boundaries include the grape growing, wine making, packaging and distribution to retailers, with a functional unit being the "production and distribution of a 0,75L bottle of wine". The elements considered in the life cycle inventory corresponds to the ones suggested in the PEF guidelines:

- grape growing stage: the water, electricity and agricultural fuel consumption, pesticides, fertilizers and land use, as well as transportation of goods and the trellis system.
- winemaking stage: the water, electricity and fuel consumption are included in the assessment, as well as the oenological products, the barrels used for ageing
- the packaging material (glass, cardboard, cork stopper, cap, paper labels) The end of life of elements are included for the packaging materials, as well as the barrels and the trellis system, using the circular footprint formula.
- the transportation of goods. For the distribution stage, the transport of the bottles to the retailer and the transport from the retailer to the consumer have been considered.

Foreground data were collected on site and direct emissions were modelled using the PEF recommendations for the pesticides and fertilizers dispersion in the environment (p. 57 & 58 CEEV, 2018).

The sources of variability of a LCA result are multiple. It can be related to the modeling of the foreground data, the type of background data used, or the impact assessment method used. In this study, different background LCI data and LCIA method are tested. Our comparison includes 2 types of LCI background datasets and 3 LCIA methods:

- LCI: EF 2.0 and ecoinvent® v3.5 AP database
- LCIA: EF, IW+, ReCiPe 2016 methods

The modelling and calculations have been conducted using SimaPro 9.0.

Results & discussion

Table 1 shows the single score results for each LCI/LCIA configuration. The score ranking of the different wines is the same for all of them. The white wine number 1 has the lowest score per FU, while the white wine 2 has the highest.

However, the difference between the products varies depending on the assessment method used. Differences in the single score ranges from 25% for IW+ method to 43% for ReCiPe 2016. The variability is directly linked to the inputs of the winegrowing stage. Indeed, the packaging material for each wine are the same, as well as the most impactful inputs of the wine making stage (electricity and water consumption, which are allocated on the base of the hectoliter produced). The difference in score is linked to the land necessary to produce a functional unit, as well as the agricultural fuel, the pesticide and fertilizers used for each wine. In the case of EF and ReCiPe, for which the land use category, as well as the global warming and the fine particulate matter formation categories that are mainly driven by the agricultural land occupation and the combustion of agricultural fuel, the difference between the products is more important compared to IW+. The use of ecoinvent® database lead to the same results in the wines' ranking. An increase in the score with IW+ method is observed, which is due an increased contribution to score of the electricity consumption.

Table 1: Single score of the different wine depending on the LCIA methods and datasets used (Ranking: 1rst has the lowest score)

	Dataset and LCA method					
	PEF Datasets, EF method	PEF datasets, IW+ method	PEF datasets, ReCiPe method	ecoinvent dataset, EF méthod	ecoinvent dataset, IW+ méthod	ecoinvent datasets + ReCiPe method
Ranking (1rst has the lowest score)	Score (milli-pt)	Score (EURO2015)	Score (milli-point)	Score (milli-pt)	Score (EURO2015)	Score (milli-point)
1rst : white 1	0,15	0,92	56,03	0,17	1,19	52,28
2nd : red 1	0,17	0,96	59,73	0,18	1,23	56,49
3rd : red 3	0,18	1,00	63,79	0,19	1,27	61,10
4rth : red 4	0,18	1,01	64,84	0,20	1,28	62,29
5th : red 2	0,19	1,03	67,20	0,20	1,30	64,97
6th : white 2	0,22	1,15	79,15	0,24	1,42	78,54

While the product ranking is similar for all the assessment method, this is not the case for the contribution of the different life cycle stage. The wine growing stage generates the highest share of the single score for the PEF and ReCiPe method (respectively 43% and 41%), while the packaging stage is the most contributing for IW+ with 44% (25% of the single score for the wine growing stage). To understand this difference, the impact categories contribution is compared and presented in table 2.

Table 2 : impact contribution to single score for the different methods, average of the 6 wines_(ni: impact category not included in the method)*

Impact categories	Contribution EF	Contribution IW+	Contribution ReCiPe	Contribution EF (ecoinvent)
Global warming	17%	52%	30%	15%
Stratospheric ozone depletion	0%	0%	0%	0%
Ionizing radiation	9%	0%	0%	7%
Ozone formation	4%	0%	1%	4%
Fine particulate matter formation	11%	8%	31%	12%
Terrestrial acidification	6%	2%	1%	6%
Freshwater acidification	ni*	0%	ni*	ni*
Marine acidification, long term	ni*	3%	ni*	ni*
Freshwater eutrophication	8%	0%	1%	8%
Marine eutrophication	2%	0%	0%	2%
Eutrophication terrestrial	4%	ni*	ni*	3%
Terrestrial ecotoxicity	ni*	ni*	0%	ni*
Freshwater ecotoxicity	ni*	7%	0%	ni*
Marine ecotoxicity	ni*	ni*	0%	ni*
Human carcinogenic toxicity	ni*	1%	1%	ni*
Human non-carcinogenic toxicity	ni*	3%	14%	ni*
Land use	15%	6%	19%	13%
Mineral resource scarcity	ni*	ni*	0%	ni*
Fossil resource scarcity	ni*	ni*	1%	ni*
Resource use, energy carriers	2%	ni*	ni*	3%
Resource use, mineral and metals	20%	ni*	ni*	24%
Water categories	2%	18%	2%	4%
Thermally polluted water	ni*	0%	ni*	ni*

The impact contribution is varying among the 3 methods. For the EF method, global warming, respiratory inorganics, land use and the fossil resource use are the most contributive categories. Climate change and fine particulate matter formation are the dominating categories in ReCiPe 2016 approach, accounting for a 30% of the total single score each. Human non-carcinogenic toxicity and land use are the other contributive categories. For IW+, climate change and the water availability indicators are responsible of 70% of the total score, climate change accounting for more than half of the total score. The variability in the contribution is due to the difference existing in the midpoint indicators considered, in the damage pathway, and in the normalization and weighting scheme. The following elements are in explaining part of the differences. (i) the different consideration of toxicity impacts: they are excluded of the weighting scheme of the EF method. IW+ toxicity evaluation is based on Usetox 2.0 (Fantke et al., 2017), while ReCiPe toxicity impacts categories are based of USES LCA 2.0 (Van Zelm et al., 2009). In the first case, ecotoxicity has a higher contribution (7% vs less than 1%) related to the use of pesticide, whereas in ReCiPe the human non carcinogenic toxicity has an important contribution of 14% to the single score due to the agricultural fuel combustion mainly. (ii) The reduced water availability and the related damage to human health, which is included in IW+ and not in ReCiPe (Bulle et al., 2019). The direct consumption and water consuming processes, such as the production pesticide and the production of glass bottle are responsible of most of IW+ single score (iii) The exclusion of mineral and fossil resources consumptions in IW+ weighting scheme (iv) The choice of the weighting scheme: PEF weighting scheme is strongly related by the impact driven by fossil fuel use and land use, which appear to be close to ReCiPe results. Eutrophication impacts also have a non-negligible contribution

in the EF method, emphasizing the impact of fertilizers. ReCiPe and IW+ single scores are based on weighting schemes of endpoints. Human health damages are dominating the endpoint contribution to the single score for IW+ and ReCiPe 2016, with respectively 75 % and 70% of the total score, while the ecosystem damages represent 25% and 27,5% (the resource depletion corresponds to the last 2,5%). The impact contribution was also compared with two different databases (PEF databases and ecoinvent® v3.5) with the EF method. Slight variability is observed, climate change as well as land use weighting less in the case of the use ecoinvent®, while the category "resource use, energy carriers" is weighing 4% more in the case of use of ecoinvent®. This is mainly explained by the stronger impact of electricity and the use of uranium in the French mix in ecoinvent® database (19.8 µPt/bottle in the case of the use of ecoinvent® versus 13.6 µPt/bottle in the case of the use of PEF database, which uses GaBi database for electricity modelling).
A study conducted for the European Commission on the most effective mean to communicate environmental profile of products provided the following conclusions "two label elements were selected by a majority of consumers: (1) the overall performance score (71%) and (2) information on the most relevant impact categories (55%)" (European-Commission, 2019, p. 90). In our case study, the three methods are consistent in the results provided for conclusion (1) while they are not for conclusion (2). In order to increase the consistency between LCIA methods and in future ecolabelling, consensus should be built in the normalization and weighting schemes among the LCIA method developers and policy makers. As a final observation, toxicity impacts don't have a high contribution in any of the methods. While pesticide is often scrutinized as an important environmental concern in the wine sector, their use isn't reflected in the single scores. However, pesticide's contribution is underestimated due to the incompleteness of the databases since more than 50% of the elementary flow corresponding to the pesticide's active molecules are missing. Further research should be conducted to be able to conclude on the real contribution of pesticide's use.

Conclusions

This case study presents the results of three LCA single score obtained with the latest LCIA methods. Nonetheless their methodological differences, the ranking of the products is similar in all the cases. Different impact categories are composing the score. The similarity in the ranking is related to closeness of the production itinerary and the related inputs of the different wine studied. The scores of different wines from different organization should complete this study in order to discuss the consistency of the results obtained with the different methods in different production contexts.

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Life-cycle assessment of grape cultivation in Piedmont, Italy

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Abstract

The main objective of this paper is to present a comprehensive life-cycle assessment (LCA) of grape cultivation for wine, in Piedmont, Italy. A cradle-to-gate approach was followed for grape cultivation (functional unit: 1 kg of grapes), based on data collected for the Barbera and Moscato varieties. Life cycle environmental impacts were analysed for the following categories: fossil depletion (FD), global warming (GW), terrestrial acidification (TA), freshwater eutrophication (FEUT) and freshwater ecotoxicity (FWecot). The calculation of impacts included fertilization (nitrogen and urea field emissions), application of plant protection products (PPPs), diesel combustion in agricultural operations, and production of agricultural inputs. FWecot impacts of pesticide application were assessed by combining a framework developed for the inventory of pesticide emissions to different compartments (off-field natural soil, agricultural soil, and air) with characterization factors from USETox.

Results show that energy use in agricultural activities (diesel) was the largest contributor to GW and FD (more than 70 %). For TA, the largest contributors were PPP and diesel (44 % and 40 %, respectively). Fertilizers and PPPs represented 57 % and 34 % of FEUT impacts, respectively. PPP field emissions alone represented 93 % of FWecot impacts. The equipment used in agriculture activities represented less than 8 % of the total impacts. Overall, impacts due to pesticide application (including diesel use) represented 27 to 56 % of impacts, except FWET where it represented nearly 100 % of impacts. This paper shows the importance of LCA to identify improvement opportunities to reduce environmental burdens related with grape cultivation, namely adopting strategies to decrease the amount of fertilizer and pesticide applied (and associated energy use). Furthermore, it highlights the importance of assessing the application of PPP in current agriculture practices in a comprehensive way, especially when assessing toxicity categories (where PPPs dominate impacts).

Keywords: *Grapes, life cycle assessment, toxicity impacts, plant protection products, fertilizers*

Introduction

Grape cultivation for wine is an important economic activity in Italy – the world-leading producer in 2018 with 54.8 million hectolitres. The main objective of this paper is to present a life-cycle assessment (LCA) of grape cultivation for wine in a vineyard located in Nizza Monferrato, Piedmont region, Italy, addressing comprehensively the application of plant protection products (PPPs) and fertilization (nitrogen and urea field emissions), in contrast to most studies that neglected the assessment of PPP application or performed outdated inventory modelling that restricted and overestimated the assessment of PPPs impacts (Margni et al. (2002) and Nemecek et al. (2007)) (e.g. studies ignoring several factors that affect PPP fate in the environment, such as PPP characteristics, application method, wind drift and plant growth stage). For freshwater ecotoxicity (FWecot) impacts of PPP application, we combined a framework developed for the inventory of PPP emissions to different compartments (off-field natural soil, agricultural soil, and air) with characterization factors from USETox. This study is part of the project OPTIMA – "Optimised Pest Integrated Management to precisely detect and control plant diseases in perennial crops and open-field vegetables", funded by the European Union's Horizon 2020 Research and Innovation Programme.

Material and methods

The agriculture operations considered for grape production were PPP application, fertilization, and other field operations (e.g., pruning, trimming, harvest). The vineyard is assumed to be at full production; therefore, only grape production was considered and vineyard planting and end-of-life were excluded from the assessment as these stages represent minor impacts due to the long (and uncertain) lifespan of the vineyard. The functional unit is one kg of grapes. Table 1 shows the primary data related to agricultural operations for 2018. Fifteen different active ingredients (AIs) of PPPs were applied.

Table 1. Inventory data for vineyard per kg of grapes (2018)

Inputs	Amount	Units
Fertilizers		
N	19.9	
P	9.3	g
K	7.9	
PPPs (active ingredients)		
metiram	0.078	
cymoxanil	0.011	
meptyldinocap	0.016	
isopropylamine salt	0.108	
dimethomorph	0.039	
folpet	0.100	
pure sulphur	4.477	
mancozeb	0.489	g
carfentrazone-ethyl	0.007	
metalaxyl-m	0.022	
penconazol	0.007	
metalic copper	0.760	
potassium phosphonate	0.336	
chlorpyrifos methyl	0.038	
thiamethoxam	0.006	
Energy		
Diesel	55.22	g
Outputs		
Grapes	1	kg

Life cycle environmental impacts were analysed for the following categories: fossil depletion (FD) (Huijbregts et al. 2017), global warming (GW) (IPCC 2013), terrestrial acidification (TA) (Huijbregts et al. 2017), freshwater eutrophication (FEUT) (Huijbregts et al. 2017) and freshwater ecotoxicity (FWecot) (Rosenbaum et al. 2008). Direct and indirect N_2O emissions and CO_2 emissions from urea application were calculated following Nemecek et al. (2015). For FWecot impacts, results are present for recommended (rec.) and indicative (ind.) USEtox characterization factors. Recommended factors correspond to substances for which the USEtox model is considered appropriate and the underlying substance data are of sufficient quality to support a recommendation based on scientific consensus, in line with Hauschild et al. (2008). In cases where relatively high uncertainty in addressing fate, exposure and/or effects of a substance is expected, the related characterization factors are labelled as indicative (Fantke et al. 2015).

Results and Discussion

The environmental life cycle impacts per kg of grapes are presented in Table 2. Overall, results show that energy (associated with diesel consumption) used in the various agricultural activities had the largest environmental impacts in GW and FD. The largest contribution to FEUT was fertilization. PPP production and field emissions presented the largest contribution to FWecot and TA. The main contributor for TA was the application of pure sulphur. For FWecot, considering only recommended characterization factors, the main contributors were folpet and chlorpyrifos methyl; for indicative characterization factors, the main contributor was metalic copper. It should be noted that, for FWecot calculated with USEtox recommended characterization factors, 10 out of 15 AIs are covered (i.e. assessed), while, for indicative characterization factors, the coverage is 14 out of 15 AIs.

Table 2. – Life cycle impacts in all agricultural activities per kg of grapes produced in a vineyard farm in Nizza Monferrato (Piedmont, Italy).

Indicator	Unit per kg of grapes	Equipment	Energy (diesel)	Fertilizer (production + field emission)	PPP (production + field emission)	Total
GW	kg CO_2 eq.	2.00E-02	1.76E-01	3.59E-02	1.23E-02	2.45E-01
FD	kg oil eq.	6.33E-03	6.01E-02	7,64E-03	6.88E-03	8.09E-02
TA	kg SO_2 eq.	9.77E-05	1.43E-03	4.71E-04	1.60E-03	3.60E-03
FEUT	kg PO_3^{4-}eq.	1.11E-05	2.81E-06	8.92E-05	5.42E-05	1.57E-04
FWecot-rec	CTUe	4.02E-04	2.95E-04	1.69E-05	1.67E-01	1.68E-01
FWecot-in	CTUe	4.83E-01	7.68E-02	1.14E-03	2.31E+03	2.31E+03
←Lower impacts					Higher impacts →	

Conclusions

We assessed environmental life cycle impacts of grape production in a vineyard in Piedmont region addressing comprehensively PPP application and fertilization. Results showed the significant contribution of pest management to FWecot impacts, mainly due to PPP field emissions. Results also showed a high contribution of energy use in agriculture operations for global warming and fossil depletion. This paper shows the importance of LCA to identify improvement opportunities to reduce environmental burdens related with grape cultivation, namely adopting strategies to decrease the amount of fertilizer and PPP applied (and associated energy use). Furthermore, it highlights the importance of assessing the application of PPP in current agriculture practices in a comprehensive way, especially when assessing ecotoxicity categories (where PPPs dominate impacts).

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Life Cycle Assessment of Pineapple Supply Chain in Benin, West Africa

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Abstract

Purpose: To track how development actions contribute to development, the European Commission supported an environmental analysis of the pineapple value chain in Benin (West Africa). Like the other previous studies, this Value Chain Analysis for Development (VCA4D) study cover the tree dimensions of sustainability, but this paper focuses on the environmental analysis.
Methods: Following the VCA4D methodology, a cradle-to-Benin gate LCA study was performed for 7 pineapple supply chains, covering fresh fruits sold in Benin, African and European markets, and juices sold in Benin, African and European market. After a functional analysis of the value chain, primary data were collected in Benin through survey in 2019. A sample of 39 farms (organic and conventional) and 6 juice factories (from artisanal to industrial production) were surveyed for all inputs and outputs.
Potential environmental impacts were calculated with ReCiPe 2016 at both midpoint and endpoint. A Monte Carlo analysis was performed to quantify results uncertainty.
Results and discussion: The pineapple grown in Benin is mainly Sugarloaf (a variety that is green when ripe), without irrigation or pesticides and almost no herbicides. Yields and fertilizer inputs showed a large variability across the range of farms.
Impact results shows that farming is the largest contributor for all supply chain, mainly due to fertilizer manufacture and emissions. Organic pineapple has lower impact per hectare but also per kilogram of pineapple, mainly due to the little difference with conventional farming (apart from the use of urea) and similar low yield. There are many opportunities to increase yield without increasing farm inputs, by fractioning fertilizer application for example. Fruit and juice losses are very large, especially during transport stages, and represent a 40% potential reduction of impacts.
Conclusions: This study allowed to identify mitigation options by confronting LCA results with an agronomic expertise. Farmer practices can be improved to bridge the yield gap while optimizing farm inputs, thus reducing impacts on the environment.
A recommendation from this work is to put efforts in the improvement of crop management practices and to not focus solely on providing a better fertilizers and chemicals access to farmers in Benin.
This study should be updated in a couple of years once a census has been done to reduce uncertainty associated with product flows and yield, but also to address the effect of the numerous changes the pineapple value chain is facing.

Keywords: *Supply chain; LCA; Pineapple; Fruit; Juice*

Introduction

The European Commission/International Cooperation and Development is supporting value chain analysis across a range of agricultural commodities and countries. These Value Chain Analysis for Development (VCA4D) studies cover the tree dimensions of sustainability in order to track how development actions contribute to development. This paper discuss results from the environmental analysis of the pineapple value chain in Benin.
The objectives of this environmental analysis is to provide a first benchmark and identify environmental hot spots across the pineapple supply chains in the country.

Material and methods

After a detailed functional analysis of the whole pineapple value chain, analyzing the various pineapple products, markets, stakeholders, and flows between them (Desclee et al. 2018), 7 main pineapple supply chains were identified.
A cradle-to-Benin gate LCA study was performed for 7 pineapple supply chains, covering fresh fruits sold in Benin, Nigeria, the "continental region" (e.g. Burkina, Niger..) and European markets, and juices sold in Benin, the "continental region" and European market.
Figure 1 shows a simplified diagram of the supply chains studied, with a clear distinction between conventional and organic supply chains.

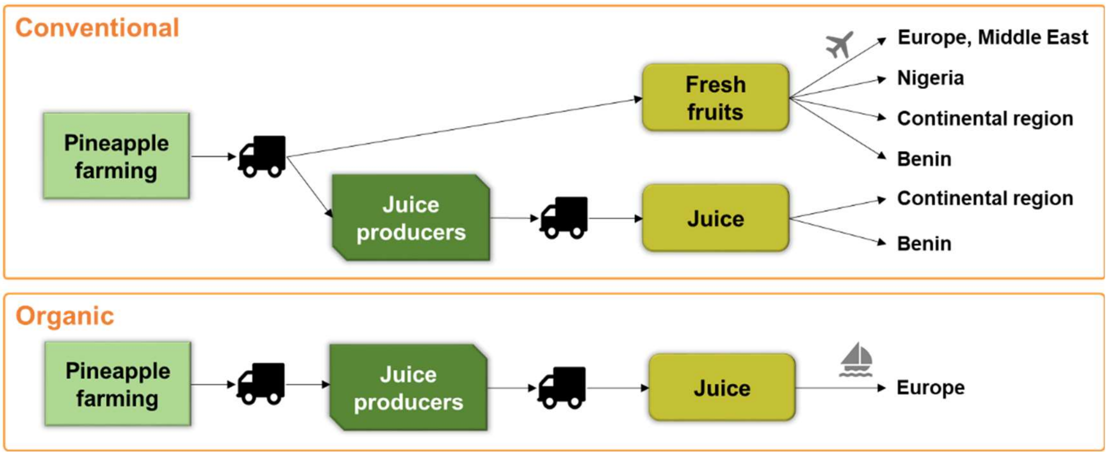

Figure 1. Diagram representing the 7 pineapple supply chains modelled in this work. Note this is a simplified view not showing the specific stakeholders involved for each destination market.

Primary data were collected in Benin through survey in 2019. A sample of 39 farms (organic and conventional) and 6 juice factories (from artisanal to industrial production) were surveyed for all inputs (fertilizers, (agro)chemicals, water, fuel, packaging…) and production volume (fruit yield, juice production).
Field emissions were assessed with IPCC 2019, SALCA-P and SALCA-SM, and pesticides were considered emitted to soil.
Environmental impacts were calculated with ReCiPe 2016 (Huijbregts et al. 2016) at both midpoint and endpoint. A Monte Carlo analysis was performed to quantify results uncertainty.
Following the VCA4D methodology (EC 2018), the system boundary is at the country gate (fruit of juice product ready to leave Benin), but we also extended the modelling to the European markets for discussion (Cf. grey plane and boat in Figure 1).

Results and discussion

Benin pineapple specificities - The pineapple grown in Benin is mainly Sugarloaf (75%), a variety that is green when ripe, the rest of the production (25%) is Cayenne pineapple (Desclee et al. 2019). Since European consumers are expecting yellow colored-pineapple, a communication campaign was launched promoting the "Green Benin sugarloaf pineapple" to inform consumers on its natural green color.

The duration of a full pineapple crop cycle was 2 years on average (from land preparation to uprooting). Pineapple farming in Benin do not use irrigation, no pesticides and almost no herbicides. Estimated yields showed large variation across farms, with an average of 43t/ha for conventional Sugarloaf and 53t/ha for conventional Cayenne (for farms that are part of farmer association). Fertilizer inputs also showed very large variation across farms, with an average of 425 kg N/ha for conventional and 110 kg N/ha for organic farms. Urea and NPK fertilizers are used in conventional farming whereas locally made organic fertilizers are used in organic farming. Floral induction is managed with calcium carbide.

Regarding juice production, transformation rates from fresh pineapple fruits into juice were ranging from 1,8 to 2,5 kg fruit per L depending on the type of producer and technology used (ranging from manual to fully industrialized). Various type of juice packaging were sold depending on the market: glass bottle (various size), can, tetrapack and large plastic containers.

Contribution analysis - Impacts associated with the pineapple value chain as a whole (aggregating the 7 supply chains depicted in Figure 1 using a weighted average) were calculated by expressing impact per kg "pineapple equivalent" (juice was expressed in "fresh fruit equivalent", accounting for specific transformation rates from pineapple fruits into juice).

Results shows farming is the largest contributor for most impact categories for all supply chain, mainly due to fertilizer manufacture and emissions after their application on the field (Figure 2). Pineapple juice packaging (bulk plastic bag, glass bottle, can…) is also a large contributor to the impacts. These results are confirmed by calculated endpoints: human health damages ($2,8 \times 10^{-6}$ DALY/ kg pineapple $_{eq}$) are mainly due to NH_3 and N_2O emissions, ecosystems damages ($2,4 \times 10^{-8}$ species.yr/ kg pineapple $_{eq}$) are mainly due to land use and land use change from savanna into crop, resources damages ($6,45 \times 10^{-2}$ USD/ kg pineapple $_{eq}$) are mainly due to fertilizer manufacture and fuel use.

It is important to emphasize that these impacts score are also accounting for the share of the 7 pineapple supply chain on the market.

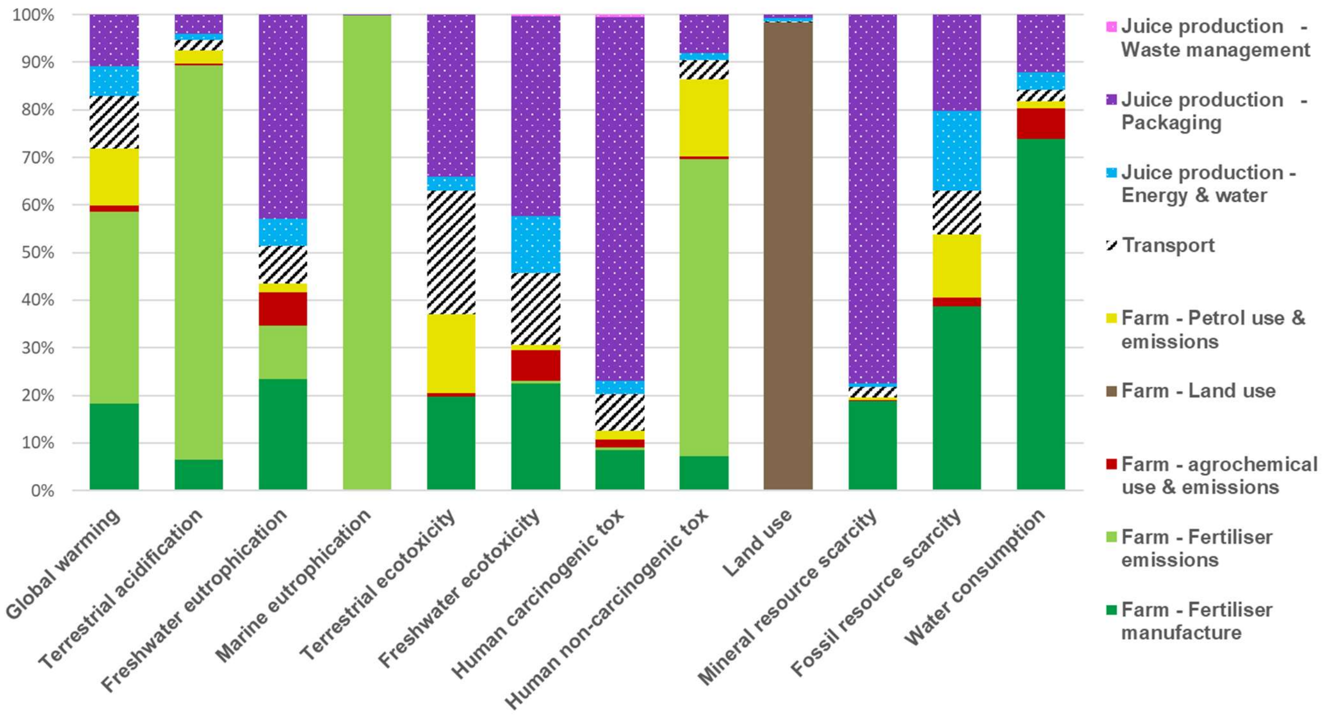

Figure 2. Contribution analysis of the overall pineapple value chain in Benin (weighted average) for selected midpoint impact categories. Impact results expressed per kg "pineapple equivalent" at country gate (Benin) calculated with ReCiPe 2016 Midpoint (H) V1.03 / World (2010) H.

Supply chains comparison - Among the pineapple juices, the organic one is showing the lowest damages to human health and ecosystem quality, mainly thanks to lower field emissions in organic farming.
Among the fresh pineapples fruits, the one directly send on the Benin local market is showing the lowest damages to all areas of protection.

Organic vs. conventional - Organic pineapple has lower impact per hectare but also per kilogram of pineapple, mainly due to the little difference with conventional farming (apart from the use of urea) and similar low yield.
There are opportunities to increase yield without increasing farm inputs, by fractioning fertilizer application and optimizing floral induction treatment for example. Agro-ecological practices such as the use of a "service crop" would also present several benefits.

Losses and transport - Fruit and juice losses are very large, especially during transport stages. A scenario without post-harvest losses (damaged fruits, broken bottles…) showed a 40% potential reduction of damages (up to the Benin border).
The VCA4D methodology is based on a country-gate boundary, thus neglecting impacts from transport to non-local markets. It means that impacts from transporting fresh fruits from Benin to Europe by plane does not have to be reported although it multiplies damages on resources by 47.

Uncertainty - The Monte Carlo analysis revealed a large uncertainty on the impact results (with a coefficient of variation ranging from 16 to 26%). Performing a country-representative assessment is very challenging when farmers are not identified or recorded in a census, and when production volumes are hardly known. This study should be updated in a couple of years once a census has been done. This will allow reduce uncertainty associated with product flows, losses and yield in particular.

Comparison with literature - Comparison with published studies showed that pineapple from Costa Rica (a major exporter on the international market) has a lower impact on climate change with 0.1854 kg CO_{2eq}/kg (vs. 0.218 kg CO2eq/kg for Benin) (Ingwersen et al. 2012). This is mainly due to a yield gap for Benin pineapple.

Conclusions

Mitigation options can be drawn from this LCA study especially when the hot spot identified are confronted with an agronomic expertise. Indeed, agricultural practices can be improved to increase yield and optimize farm inputs, also aiming towards more agro-ecological systems.
Thus, a recommendation from this work is to put efforts in the improvement of crop management practices and to not focus solely on providing a better fertilizers and chemicals access to farmers.
A restitution and stakeholder workshop should be held in Benin late 2020 (Covid-dependant) to further discuss implications of this study, also by integrating the economic and social analysis results.

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Comparing PEFCR and balance accounting methods in the environmental assessment of pasta production

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Abstract

This paper considers the Product Environmental Footprint (PEF) of an Italian food product, the "Spaghetti Dedicato", with a life cycle approach. The study was carried out according to the requirements of the ISO standards 14040 and 14044(ISO, 2006a, b) and following the Product Environmental Footprint Category Rulesof Dry Pasta 3.0 (PEFCRs, 2018).
In this study the agricultural phase was modelled both with the approach described in the PEFCRs of Dry Pasta 3.0 (Profile 1) and also with an approach that takes into account site specific data (Profile 2). The environmental footprint (of the agricultural phase) of Profile 2 was then compared to that of Profile 1.
Specifically, for the Profile 2, an agricultural input balance accounting method, adapted to the local conditions of the Apulian Region, in which the agricultural phase is modelled by considering site specific information, such as soil type, climate conditions and agricultural management practices was used (Montemayor et al. 2019). This information, taken from the HARMONIZED WORD database available on the FAO SOILS website, was used to combine the IPCC (2006) and EEA (2016) agricultural input balance accounting methodologies in order to obtain the Profile 2 in which different emission calculation methods and assumptions are used. In particular, the differences concern the modelling of nitrates (NO_3), of ammonia (NH_3) and of nitrous oxide (N_2O) in the agricultural phase (all other primary data and other methodological choices are the same as those used in the PEFCR defined approach).
Profile 1, obtained from the strict application of PEF methodology, has single score of 95,67 mPt. Profile 2, obtained from the application of the alternate method, shows a better environmental profile with a single score of 94,90 mPt. The difference is mainly observable in the following impact categories: acidification, terrestrial eutrophicationand marine eutrophication.
Concluding, substituting the model of the agricultural phase, described in the PEFCRs of Dry Pasta, with a different one which is adapted to the local conditions of the Apulian Region, is more time consuming and needs a detailed study of additional aspects such as soil type, climate conditions and agricultural management practices. However, its implementation in a pasta PEF study doesn't significantly affect the environmental profile result of the study when compared to that obtained from a fully PEFCR compliant study.

Keywords: *Life Cycle Assessment, Pasta, PEF, PEFCR*

Introduction

The Product Environmental Footprint (EC, 2013) harmonized methodology, for the calculation of the environmental footprint of products, based on a life cycle approach, has been developed with the aim of setting the basis for better reproducibility and comparability of the results of PEF studies by reducing the methodological choices available to the LCA practitioner.
The PEF methodology provides a general guidance that needs to be contemplated together with the Product Environmental Footprint Category Rules (PEFCRs)which describe life-cycle based rules that provide further methodological details for specific product categories. The PEFCRs, in fact, play an important role in increasing the reproducibility, consistency and relevance of the results because they focus on the most important parameters, reducing time, effort and costs involved in conducting a PEF study. For this reason, the PEFCRs suggest the application of fixed parameters to the emissions (Product Environmental Footprint Category Rules Guidance version 6.3, 2018).
However as the agricultural phase needs site specific data rather than fixed parameters, it could be modelled by considering the soil type, the climate conditions and the agricultural management in which the cultivation of wheat takes place via the IPCC (2006) and EEA (2016) input accounting methodologies.
This paper entails the calculation of a PEF of an Italian food product, the "Spaghetti Dedicato"(Granoro, 2020). Specifically, this work compares the agricultural phase modelling described in the PEFCRs of Dry Pasta 3.0 (Profile 1) with that of an approach (Profile 2)that considers an input balance accounting method adapted to the local conditions of the Apulian Region in Italy.In both approaches the industrial phase and transports are modelled in the same way in compliance with the PEFCRs. For this reason, in this study only the agricultural phase was investigated.

Material and methods

As already mentioned, Profile 1was obtained by modelling the agricultural phase of the "Spaghetti Dedicato" by following the PEFCRs of Dry Pasta 3.0; to determinate Profile 2, the same agricultural life cycle phase, was modelled following the IPCC (2006) and EEA (2016) input accounting method. In particular, nitrates (NO_3), ammonia (NH_3) and nitrous oxide (N_2O) were modelled differently taking into account all nitrogen inputs and outputs and in particular nitrogen from fertilization, soil, previous crops, rainfall and harvest. The functional unit chosen for each environmental profile is 1 kg of dry pasta ready to be cooked at home or at restaurant.

Results

The life cycle inventory was modelled according to the two approaches, as shown in Table 1. This allowed a comparison between the two profiles.
The life cycle impact assessment results of the two profiles, in terms of single score, are reported in the Figure 1. Considering each category of impact individually, there are some differences: Profile 1 has a 31% lower acidification potential indicator value, due to a different N value, a 33% lower terrestrial eutrophication indicator value and a 73% higher marine eutrophication indicator value, due to a different NO_3 value, as shown in Table 1. However, the total score of Profile 1 is 95,67 mPt and that of Profile 2 is 94,90 mPt.

Table 1: Life Cycle Inventory of agricultural phase for the cultivation of wheat in 1 ha of the two Profile

A.Outputs	Unit	Average Profile 1	Average Profile 2
1. Wheat	kg	4731	4731
2. Straw	kg	5000	5000
B. Inputs			
1. Diesel	L	183	183
2. Lubrificant Oil	L	1.6	1.6
3. Seed	kg	280	280
4. Fertilizers			
a. Urea (46,0,0)	kg	165.54	165.54
b. Ammoniun nitrate (26-0-0)	kg	150.84	150.84
c. NP fertilizer (21-15-0)	kg	153.34	153.34
5. Chemical class (pesticide)			
a. Iodosulfuron-methyl-sodium	L	0.001	0.001
b. Mesosulfuron-methyl (prop)	L	0.005	0.005
c. Clopyralid	L	0.076	0.076
d. Florasulam	L	0.00024	0.00024
e. Fluroxypyr	L	0.138	0.138
C. Emissions			
1. Air emissions (from fertilizers)			
a. NH_3 from N	kg	17.92	25,68
b. N_2O from N	kg	3.25	3.30
c. CO_2 from Urea	kg	121.5	121.5
2. Water emissions			
a. NO_3 from N	kg	196	29.36
b. Phosphorus	kg	0.5	0.5
3. Soil emissions			
a. Iodosulfuron-methyl-sodium	kg	0.001	0.001
b. Mesosulfuron-methyl (prop)	kg	0.005	0.005
c. Clopyralid	kg	0.076	0.076
d. Florasulam	kg	0.00024	0.00024
e. Fluroxypyr	kg	0.138	0.138

Conclusions

The use of an agricultural input balance accounting method, adapted to the local conditions of the Apulian Region, in which the agricultural phase is modelled by considering site specific information, applied to the Profile 2, shows that differences in the results of life cycle impact assessment don't significantly affect the environmental profile but is more time consuming and needs a detailed study of additional aspects.
In fact, requirement specified in the PEF method are consistent and close to the recommendations of similar, widely recognised product environmental accounting methods and guidance documents such as ISO 14040, ISO 14044, ISO 14067, ISO 14046, ILCD, Greenhouse Gas Protocol, PAS 2050, ENVIFOOD Protocol. Even if these other methods provide alternatives for a given methodological decision point, the purpose of the PEF method is (where possible) to recommend a single requirement for each decision point, or to provide additional guidance in order to conduct studies more robust,

consistent and reproducible (Zampori, 2019).

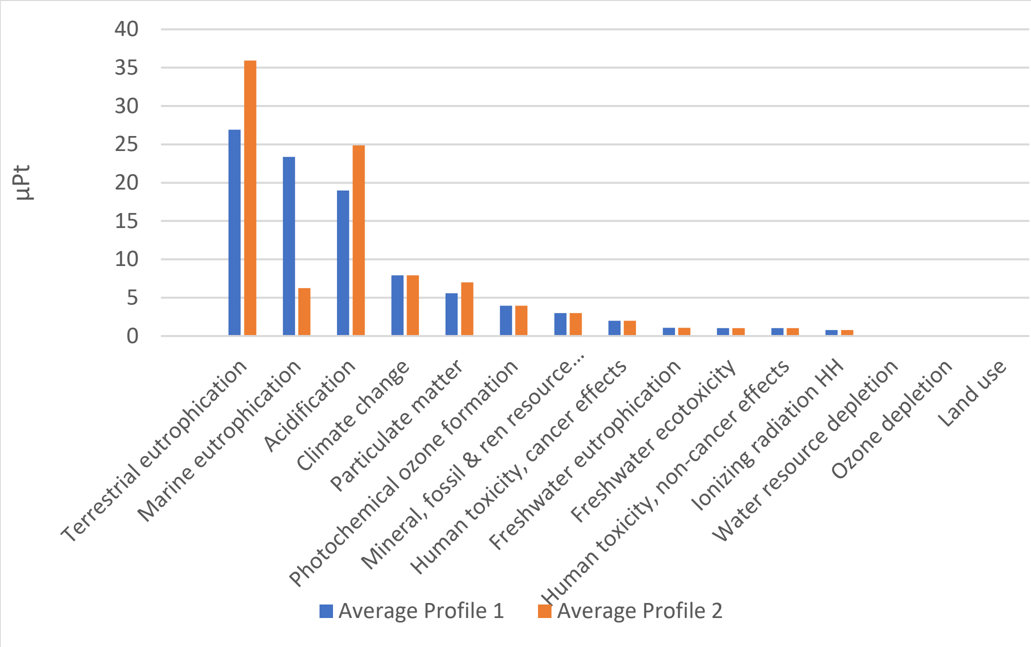

Figure 1: Impact assessment of agricultural phase of two profile in terms of single score

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Topic 15:

Land and Water Effects

Abstract code: ID 11

Water Footprint as a management tool for the agricultural production: from global to local scale

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Abstract

Purpose: Continuously increasing demand for food alongside with growing water shortage in many parts of the world reinforces the need to consider water in decision-making in agricultural production systems. In this research, we demonstrate how the water footprint (WF) can serve for this goal on a global and local scale by means of two WF studies whose results are made available in two online tools.
Methods: The first study uses the WF method on a global scale by connecting the virtual water demand of agricultural goods and water scarcity aspects in production regions to the international agricultural trade flows. The blue water consumption and water scarcity footprint (WSF) according to ISO 14046 (ISO 2014) are determined for the agricultural imports to the EU and Germany. The region-specific tool is developed for the cotton cultivation in the province Punjab in Pakistan. Besides the WSF assessment, the tool allows for the calculation of the impacts resulting from water pollution due to the fertilizers and pesticides application.
Results and discussion: The global tool includes the assessment of over 100 agricultural products aggregated to 36 product groups for the EU and 43 for Germany. It visualizes agricultural trade flows by mass, blue water consumption and WSF and demonstrates the hotspots on a product (e.g. cotton, rice and almonds) and country level (e.g. USA, Turkey and Pakistan). The region-specific tool addresses the hotspots associated with the cotton production in Pakistan and allows evaluating the reduction potential of different mitigation strategies, e.g. drip irrigation and organic production. The introduced tools demonstrate how the WF can be included in the decision-making processes on different scales as a supporting instrument to prioritize efforts in mitigating water stress.
Conclusions: The global tool allows identifying water use related hotspots on a country and product level and may be used as a supporting instrument to prioritize efforts in mitigating water stress related to global trade flows. The region-specific tool provides spatially explicit information, which can support for decision-making with regard to the WF reduction strategies for the agricultural production on a local scale.

Keywords: *water footprint; water scarcity; virtual water trade; regionalization; impact assessment; tool*

Introduction

Agricultural water withdrawals contribute to 70% of world's freshwater use on average and continuously increase to meet growing demand for food, which is predicted to raise by 60% by 2050 (FAO 2017). The most share of applied water is consumed by the crops during the evapotranspiration and therefore is not available locally anymore. Extensive abstraction of irrigation water can lead to the overuse of freshwater resources, which may cause increasing water scarcity and negative impacts on local ecosystems and population. The water consumption and virtual water flows associated with the international food trade were recently addressed in several studies. With the growing volume of the international trade with agricultural commodities (e.g. an increase by 1,5-times for the soybeans between 2000 and 2015 (Chatham House 2018)), the need for considering water use related aspects in the decision making in agricultural industry emerges.

One of the methods to tackle this issue is the Water Footprint (WF), which quantifies the amount of water consumed during the life cycle of products. The amounts of water are differentiated between blue (surface and groundwater) and green (soil moisture that originates from natural precipitation) water as well as grey water, which reflects water pollution and is calculated as hypothetical amount of freshwater needed to dilute the contamination to a water quality threshold (Hoekstra et al. 2011). During the past decades, the WF method was enhanced for the quantification of local impacts associated with the water consumption by considering local water scarcity. The Water Scarcity Footprint (WSF) is calculated by multiplying water consumption (blue water) by a characterization factor (CF) that reflects water scarcity in a country or region (ISO 2014).

In our research, we integrate the WF study results in a tool to support the application of the WF method as an instrument for decision making in politics and industry. We provide two online tools on different scales, each with a different scope of application. The global tool visualizes the agricultural imports to Germany and the European Union (by mass), associated virtual water flows and resulting WSF in the exporting countries. The region-specific tool provides temporally and spatially explicit evaluation of the water use and pollution intensity of cotton cultivation in Pakistan on a local level.

Material and methods

The global tool was developed based on the statistics for the agricultural imports to Germany and the EU (Chatham House 2018). Applied database includes fourteen agricultural commodities (e.g. cereals), which are divided in product categories (e.g. rice) and products (e.g. rice husked). Mass-based cut-offs were applied due to a very broad import-mix, which resulted in including 100 agricultural products aggregated to 36 product groups for the EU and 43 for Germany. In the next step, the blue water consumption associated with the imports was calculated based on the data provided by Mekonnen and Hoekstra (2011) for crops and Mekonnen and Hoekstra (2012) for animal products. Finally, the WSF was calculated by multiplying the blue water by the water scarcity CFs provided by the AWARE model (Boulay et al. 2017) on a country and annual level. A more detailed information on the method and underlying data sources can be found in the publications by Finogenova et al. (2019) for Germany and Dolganova et al. (2019) for the EU. The results were integrated in a web-based tool, which visualizes the flows by mass, blue water and WSF.

The region-specific tool was developed within the project InoCottonGROW for the cotton cultivation in the province Punjab in Pakistan. The region is located in the eastern part of Pakistan on the border to India and decisively shaped by extensive water withdrawals for irrigation and seasonal water scarcity (InoCottonGROW 2019). Within the project, spatially and temporally explicit water scarcity CFs and WSF of locally produced cotton were calculated on the level of irrigation subdivisions, i.e. the administrative units for water allocation in Punjab. The calculation was done by developing local water consumption and availability model (Mikosch et al. 2020). Furthermore, grey WF, eutrophication potential and human toxicity were calculated based on the local data on the fertilizers and pesticides applied in the cotton cultivation. The tool was expended by considering world's top-ten cotton producing countries. For the latter, the calculation was conducted based on the water consumption statistics for cotton (Mekonnen and Hoekstra 2011) and the water scarcity factors provided by the model WAVE+ (Berger et al. 2018). The inventory data for the calculation of the toxicity and eutrophication impacts was compiled based on the literature data on pesticide and fertilizer application. Furthermore, the reduction potential of the optimization strategies (drip irrigation, BCI/organic cotton, and deficit irrigation) was evaluated and integrated in the tool based on the project results.

Results

The global tool presents the results of our study by visualizing the agricultural imports to Germany and the European Union (by mass), the associated virtual water flows and the resulting WSF in the exporting countries. The interactive map shows twenty most relevant flows with regard to the aforementioned parameters and the thickness of the flows represents the respective amounts. By clicking on a country, the composition of the exports is shown. Clicking on Germany and the EU additionally shows the shares of products or exporting countries. Additionally, results of individual products (e.g. almonds or wheat) can be selected (see Figure 1).

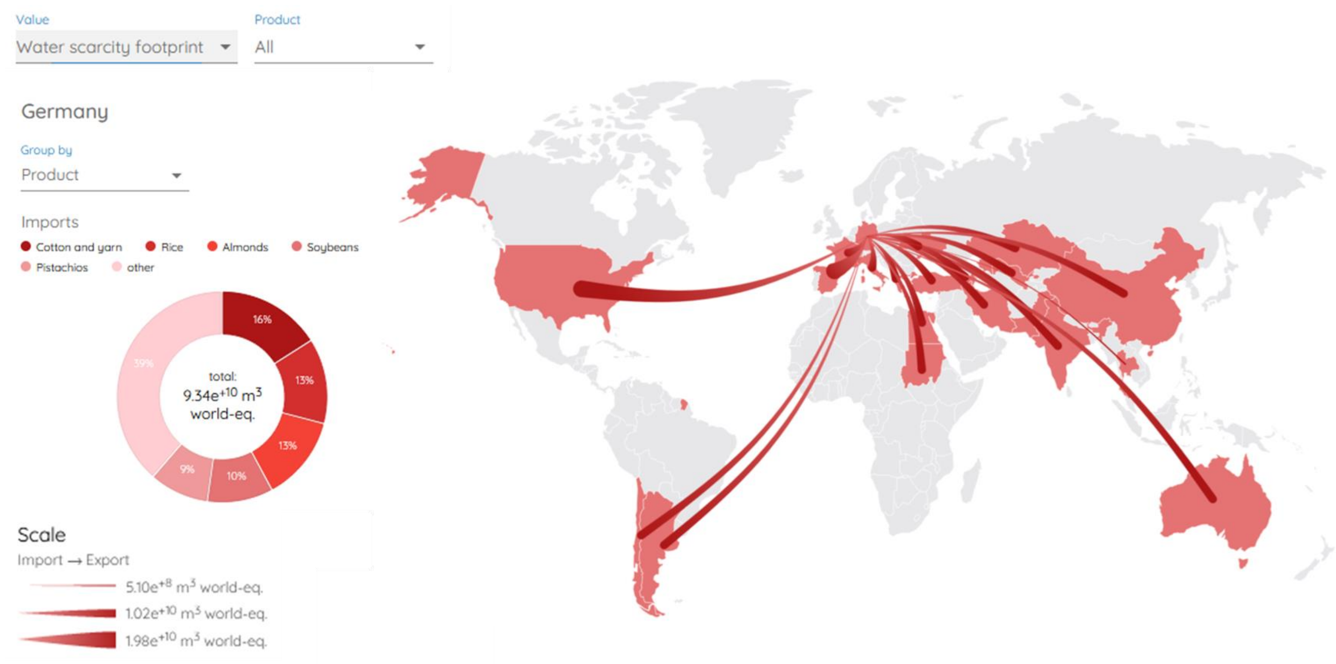

Figure 1: Global WF tool for the agricultural imports to Germany (TU Berlin 2020a)

The region-specific tool enables to conduct a spatially and temporally explicit analysis of the WF associated with the cotton cultivation in eight irrigation sub-divisions in Punjab, Pakistan. For the calculation, the origin and supplied amount of cotton need to be specified. Further parameters (e.g. nitrogen and pesticide input, share of organically produced cotton) can be specified, if data is available. Otherwise, the calculation is done based on the default factors integrated in the tool. The results related to the water use include water use and consumption (including green and blue water and water losses in the convenience system and on the field) and the WSF. A detailed monthly WSF is calculated for each irrigation sub-division. Furthermore, the results for water pollution are calculated, which include grey WF, human toxicity and eutrophication. The tool allows for evaluating the effect of different mitigation strategies on all aforementioned results. The user can select following mitigation strategies: drip irrigation, deficit irrigation, organic cotton or Better Cotton Initiative (BCI) cotton. The tool allows for calculating several scenarios simultaneously, which allows comparing the results for different irrigation sub-divisions and/or mitigation options. All results are visualized in bar charts (see Figure 2). Both tools are free of charge and available online.

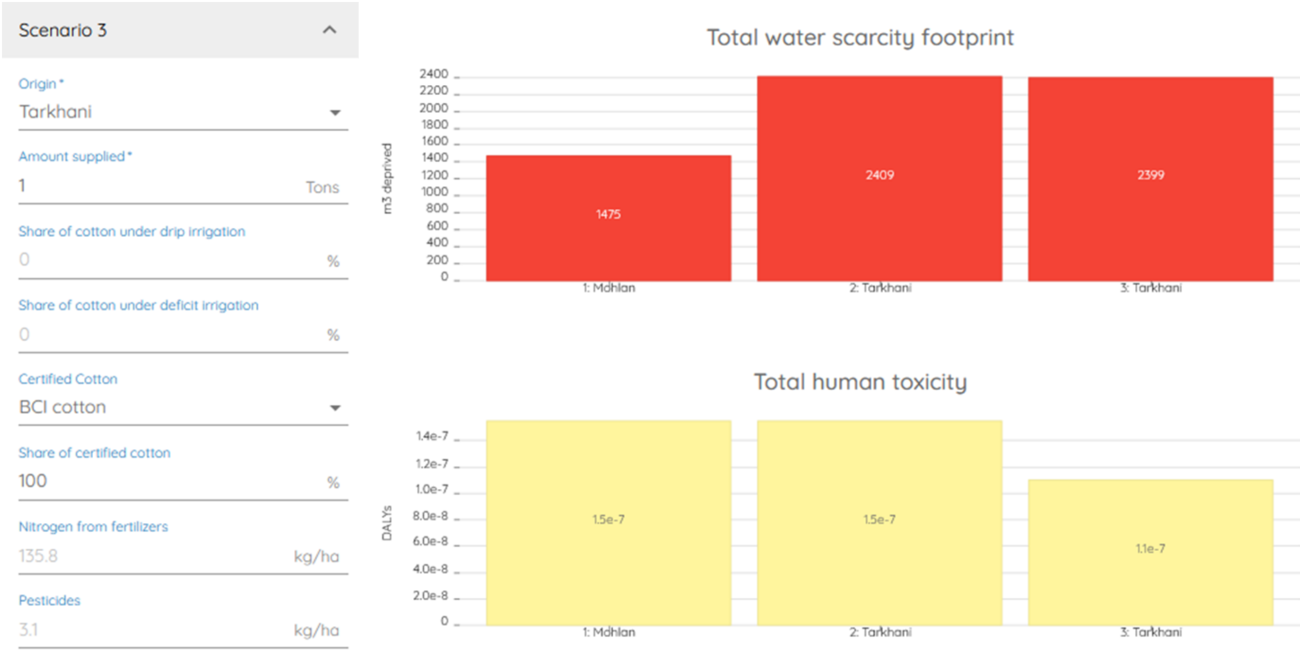

Figure 2: Region-specific WF tool for the cotton cultivation in Pakistan, exemplary results for WSF and human toxicity (TU Berlin 2020b)

Discussion and Conclusions

The global tool allows to identify WF hotspots in terms of products (e.g. nuts and cotton) and countries (e.g. USA and Spain), which can serve as a starting point to mitigate water stress caused by the imports of agricultural products. Nevertheless, it should be considered that for large countries with different climate zones, e.g. USA, China or Russia, a more detailed analysis with a higher spatial resolution, for example on the water basin level, might be necessary to provide more robust results. Currently, the tool allows for calculating the imports by mass, blue water and WSF. The consumption of green water was not included in the tool due to the absence of an operational method for the quantification of related environmental impacts. Since agricultural production significantly contributes to water quality deterioration, including water pollution related impacts, e.g. toxicity and eutrophication, might significantly enhance the tool by providing additional information for the users. It should be noted that the results provided by the tool are not intended to support such recommendations as moving production sites to water abundant regions or putting taxes on the water intense goods imported from water scarce countries, since these measures may harm economies of the exporting countries. In contrast, identified hotspots can be used for developing mitigation measures, e.g. investing in water saving technologies or starting water stewardship projects.

The region-specific tool is intended to support decision-making on a local scale in Punjab, e.g. in regional water allocation, by providing spatially and temporally explicit WF results. Furthermore, the results provided by the tool can serve for selecting mitigation options like drip irrigation or organic production. Nevertheless, although high spatial and temporal resolution serve well for the analysis on a local scale, conducting the inventory analysis and impact assessment with such level of detail may be challenging.

Acknowledgements

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Defining baseline scenarios as reference to meet sustainability targets for agricultural crop protection

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Abstract

Purpose Reducing the pressure on natural ecosystems associated with agricultural activities is a key goal to address worldwide biodiversity loss. Starting point for reducing impacts on environmental sustainability is to define reliable baseline scenarios, which can serve as benchmark and indicate current impact levels, and evaluate the suitability of related impact reduction options. We aim at proposing an iterative approach for defining such baseline and reduction scenarios for environmental impacts of crop protection practices.
Methods We propose to iteratively increasing the level of detail from the identification of initial focus areas to the evaluation of improvement options. At each level, we propose to follow the source-to-impact framework for quantifying environmental impacts with focus on chemical pesticides and their alternatives. For pesticide emissions and ecotoxicity impacts, we build on PestLCI and USEtox as consensual models, using for each level of refinement input data of different resolution. Throughout the assessment levels, the assessment approaches are aligned in a way to yield baselines and reduction scenarios that are consistent while showing a progressing level of assessment detail.
Results and discussion We defined four consistent assessment levels of refinement, so-called 'tiers' for developing environmental impact baselines and evaluating related improvement options. Initial results from Tier 1 and Tier 2 have identified a wide variability across both, crop-country scenarios as well as across individual pesticides contributing to ecotoxicity-related impacts. Within crop-country scenarios, individual pesticides can contribute up to 98% to the total ecotoxicity impact score of the scenario, often driven either by large quantity applied (herbicides) or by high impact potential (insecticides). While the initial focus was on assessing freshwater ecotoxicity impacts, other aspects should be included in the future to provide a more balanced picture of environmental impacts from crop protection practices.
Conclusions Overall, our proposed approach helps to develop an assessment framework that can be applied to understand the current state and options for reducing the environmental impacts from agricultural crop protection. Results should be combined with other impacts associated with crop protection and other crop production elements, such as impacts from greenhouse gas emissions and water use, in support of overall impact reduction and the identification of relevant trade-offs.

Keywords: *baseline scenario; pesticide; ecotoxicity; environmental impact; sustainability targets; crop protection*

Introduction

Reducing the pressure on natural ecosystems associated with agricultural activities, ranging from land-use change to pesticide emissions, is considered one of the key goals to address worldwide biodiversity loss (Köhler and Triebskorn 2013). To achieve these goals, companies in the agrifood sector have started to address environmental sustainability, aiming to strike a balance between crop protection and environmental preservation. For example, Bayer is currently implementing a strategy to reduce environmental impacts of its crop protection portfolio by 30% by 2030 across relevant crop-country combinations (Bayer 2019). A useful starting point for identifying, evaluating and measuring progress toward reducing environmental sustainability impacts is to define reliable baseline scenarios, which serve as benchmark and indicate current impact levels, and evaluate the suitability of impact reduction options. We aim at proposing an approach for defining such baseline and reduction scenarios for environmental impacts of crop protection practices to understand the current state, as well as improve current practice and measure related progress toward more sustainable agriculture.

Material and methods

We started with structuring information required for defining environmental impact baseline and reduction scenario information. In an iterative approach, we propose to systematically increasing the level of detail from the identification of initial focus areas (i.e. scenarios representing different combinations of agricultural crops, applied crop protection agents, and geographical regions) to the evaluation of improvement options (i.e. quantifying the impact reduction potential of different practices, such as substituting certain chemical pesticides by functionally equivalent alternatives or changing the pesticide application method). At each assessment level, we propose to follow the source-to-impact framework for quantifying environmental sustainability impacts associated with agricultural practices with focus on chemical pesticides (Fantke 2019). To evaluate scenarios predominantly with respect to field emissions, we considered a farm field-to-field gate assessment scope. For quantifying pesticide emission fractions and corresponding impact characterization factors, we followed the recommendations of the latest consensus-building efforts around PestLCI (Rosenbaum et al. 2015; Fantke et al. 2017) and USEtox (Rosenbaum et al. 2008; Fantke et al. 2018a,b), building for each assessment level of refinement on respective sets of input data of different resolution. For example, at the level of identifying crop-country combinations that constitute impact hotspots related to crop protection, we recommend to apply a high-throughput data estimation approach for deriving input data for ecotoxicity effect factors. In contrast, at the level of evaluating specific improvement options, we recommend to explore more detailed approaches for determining effect factors, such as splitting species sensitivity distribution (SSD) data per pesticide according to the corresponding pesticide-specific mode of action (Posthuma et al. 2002). Throughout the assessment levels, these various approaches are aligned in a way to yield baselines and reduction scenarios that are consistent while showing a progressing level of assessment detail.

Results

We defined four consistent assessment levels of refinement, so-called 'tiers', in line with representing different levels of detail in other assessment frameworks, such as health risk assessment (Swartjes et al. 2013) or chemical prioritization (Leonard and Tan 2019), for developing environmental impact baselines and evaluating related improvement options (Table 1). At Tier 1, results identify primary focus areas for crop protection, i.e. ranked crop-country scenarios according to their environmental impact potential. At Tier 2, results reflect screening-level baselines, i.e. impact category hotspots within each crop-country scenario and quantified contribution of individual pesticides and application characteristics (e.g. applied dose, application method) to impact hotspots. At Tier 3, results represent refined baselines, i.e. quantified contributing factors within each individual pesticide application scenario driving impact performance profiles within each crop-country scenario, to enable an evaluation of different types of improvement options (e.g. function-based substitution, adaptations in application method). Finally, at Tier 4, results help evaluating alternatives and/or other impact reduction measures for those pesticides that are mainly contributing to impact performance profiles per crop-country scenario for crop protection to select viable practices with measurable impact reduction potential.

Table 1. Proposed tiered assessment approach for evaluating environmental impact baselines and related improvement options in support of moving toward more sustainable crop protection.

Tier	**1: Primary focus areas**	**2: Initial baselines**	**3: Refined baselines**	**4: Improvement options**
Purpose	Determine crop-country combinations with largest environmental impact potential	Identify impact category hotspots within crop-country combinations and among possible impact reduction measures	Quantify contribution to impact hotspots within crop-country combinations	Propose alternatives or reduction measures for main contributors to impact hotspots within crop-country combinations
Target	Focusing of impact reduction technology portfolio on most relevant crop-country combinations	Selection of possibly viable impact reduction strategies within crop-country combinations	Focusing of portfolio of available alternatives on relevant impact hotspot contributors within crop-country combinations	Selection of viable/best-in-class alternatives with measurable impact reduction potential
Comparison focus	Crop-country combinations per impact category	Impact categories per crop-country combination	Flows per impact category and crop-country combination	Alternatives per flow and crop-country combination

Initial results from Tier 1 and Tier 2 have identified a wide variability across crop-country scenarios and across individual pesticides contributing to ecotoxicity-related impacts per scenario (Figure 1). In our initial tiers, pesticide use scenarios vary mainly as function of amount and type of applied pesticides, and substance properties. Pesticides differ in terms of amount used, emission and toxicity potential. When aggregated at country level for a given crop, country-crop scenario impacts are dominated by broad acre crops due to their treated area, while impacts per hectare are usually driven by vegetables and fruits/nuts due to the relatively high application amount. Within crop-country scenarios, individual pesticides can contribute up to 98% to the total ecotoxicity impact score of the scenario, often driven either by large quantity applied (herbicides) or by high impact potential (insecticides). These initial results require as next step a refinement in the assessment along the entire impact pathway, with focus on refining the emission estimates to account for environmental conditions and various types of management practices related to crop protection as well as on refining the input data of the ecotoxicity impact characterization, such as ecotoxicological effect factors.

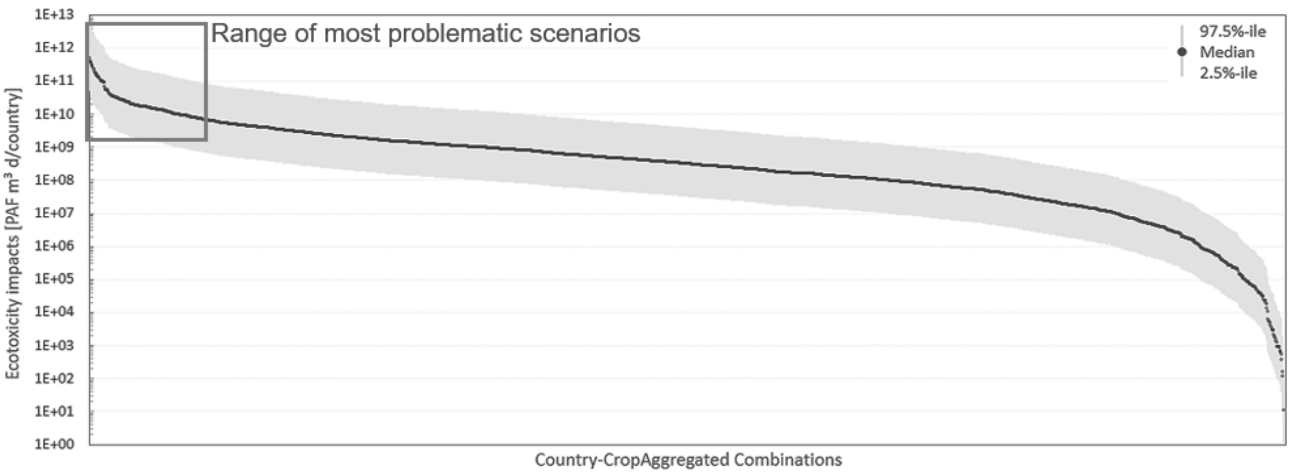

Figure 1. Initial ecotoxicity impact ranking of >1900 crop-country scenarios in Tier 1.

Discussion

While our Tier 1 and Tier 2 scenarios can help identifying focus areas for possible environmental impact reduction and pinpoint related hotspot scenarios, candidates for replacing most impacting pesticides and options for reducing related impacts is difficult as available alternatives may be rare and several factors cannot be easily influenced (e.g. pest pressure, environmental conditions). Especially for pesticide with high contribution to ecotoxicity impacts of a given crop-country scenario it is important to check whether these substances are already identified by regulation for phase-out. In these cases, related impact reduction is legally enforced rather than attributed to a voluntary reduction effort. Further research is needed to explore additional options for either reducing the use of most impacting pesticides or mitigating emissions, exposure or hazard. While the initial focus is on assessing freshwater ecotoxicity impacts, other aspects should be included in the future to provide a more balanced picture of environmental impacts from crop protection. These aspects should include soil terrestrial ecosystems, pollinator exposure, and human exposure (worker, bystander, and crop residue exposure). The assessment scope can be further adapted, for example, beyond farm field-to-field gate, and include supply chain emissions.

Conclusions

Overall, our approach helps to develop an assessment framework that can be applied to understand the current state and options for reducing the environmental impacts from agricultural crop protection. Results should be combined with other impacts associated with crop protection and other crop production elements, such as impacts from greenhouse gas emissions and water use, in support of overall impact reduction from crop production systems and the identification of relevant trade-offs.

Acknowledgements

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Abstract code: 112

Characterization factors for land use impacts on functional plant diversity

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Abstract

Purpose Biodiversity conservation mainly aims to preserve ecosystem functioning. However, to properly link biodiversity to ecosystem functioning, biodiversity assessments must go beyond the typically used taxonomic measures like species richness. Functional diversity, derived from the traits of species, is more representative and meaningful. This study provides a framework for designing natural experiments that allow inferring cause-effect relationships between land use and functional diversity. It demonstrates the proof of concept in Germany.

Methods The study exploits the large databases on plant traits and species composition that have recently become available. Three complementary functional diversity indices describe different components of functional diversity: richness, evenness, and divergence. Since environmental covariates could confound the analysis of land use effects on biodiversity, the observational study was designed as a natural experiment with equivalent control and treatment groups. Propensity score matching identified sample pairs of natural forests (control group) and agricultural land use (treatment group).

Results and discussion Results show significant losses in functional plant diversity in agricultural fields compared to forests, resulting in positive characterization factors. Despite differences among subclasses of land use, functional richness consistently decreases strongly and functional divergence moderately upon land occupation. Interestingly, functional evenness exhibits trends opposite to that of functional richness and divergence. The highest deviation among characterization factors for functional richness suggests that functional richness is most decisive for differences in functional diversity loss.

Conclusions A data-driven approach combined with natural experiments offer great potential for deriving characterization factors used in biodiversity impact assessments. While the proof of concept is demonstrated in Germany, representing temperate regions, the framework can be applied to larger scales and even globally. Moreover, the same framework can be applied to other impact categories, which makes it flexible and facilitates harmonization of biodiversity impact assessments.

Keywords: *biodiversity; functional diversity; plant trait; land occupation; method development; life cycle impact assessment*

Introduction

Biodiversity is rapidly declining and threatens ecosystem functioning. However, to properly link biodiversity loss to impacts on ecosystem functioning, biodiversity assessments must go beyond taxonomic measures like species richness, as typically used in life cycle assessments. Functional diversity, which is derived from the traits of species, is more representative of ecosystem functioning and, thus, more meaningful. Previous limitations due to lack of trait data are fading, and this offers the opportunity to bring biodiversity impact assessment to the next level.

So far, only Souza et al. (2013) proposed a method for assessing impacts on functional diversity. They also developed characterization factors for land use impacts and derived them from existing meta-analyses. Their study was limited to the Americas and to functional richness as the only component of functional diversity.
This study provides a framework for designing natural experiments that allow inferring cause-effect relationships between land use and functional diversity (Scherer et al. 2020). Natural or quasi-experiments are only emerging within the context of life cycle assessments and have not yet been used for the development of characterization factors. Assessing impacts on functional diversity in life cycle assessments is also still in its infancy. In contrast to the previously proposed methodology, our approach is data-driven and considers multiple aspects of functional diversity. Three functional diversity indices describe functional richness, evenness, and divergence. They measure how much of the functional space species fill, how regularly species abundance is distributed within this space, and how dissimilar the species are in terms of their functional characters.

Material and methods

The study exploits the large databases on plant traits (Kleyer et al. 2008) and species composition (Jansen et al. 2015) that have recently become available, for a proof of concept in Germany. Traits were selected with the aim to achieve high species coverage per trait, a low correlation among traits, and coverage of different functional categories. This resulted in the selection of four traits: canopy height, specific leaf area, seed number, and seed mass. The species names allowed to match plant traits to abundance data. Species abundance represents the sum of mean cover percentages across the multiple vegetation layers. As recommended by Ahmed et al. (2019), the three functional diversity indices – richness, evenness, and divergence – were calculated based on Villéger et al. (2008).
The location of the vegetation plots further allowed to link the functional diversity to spatial data on land use and environmental covariates. Land use was available mostly at a six-year interval and assigned to the vegetation data based on their collection date. Environmental covariates, such as climate and soil characteristics, could confound the analysis of land use effects on biodiversity, but this can be avoided by designing the observational study as a natural experiment with equivalent control and treatment groups. Environmental covariates were selected based on high correlations with functional diversity and low correlations among the covariates. This resulted in the selection of three environmental covariates: annual precipitation, minimum temperature, and sand content. Additionally, the fraction of species with known trait values at a plot was considered as a covariate. Sample pairs of natural forests (control group) and agricultural land use (treatment group) were matched by propensity scores. The matching is expected to improve the balance of covariates between control and treatment groups, which indicates its quality. The statistical significance of the difference in functional diversity between land use pairs was evaluated with the Wilcoxon signed-rank test. Finally, characterization factors (CFs) were derived based on the ratio of the paired functional diversity (FD) of agriculture and forests:

$$CF = 1 - \frac{FD_{agriculture}}{FD_{forest}} \quad (1)$$

The CF is dimensionless and can be interpreted as the potentially disappeared fraction of functional diversity. More details on the methodology are given by Scherer et al. (2020).

Results

Results show losses in functional plant diversity in agricultural fields compared to forests (Figure 1). Overall, the propensity score matching improved the balance of covariates and most differences in functional diversity are statistically significant. The losses also depend on the specific subclass of land use. For example, impacts on broad-leaved forests are more severe than on coniferous forests. Complex cultivation patterns cause the most significant loss of functional diversity. The only land use pair where agriculture does not seem to affect the functional diversity of former forests is for the

comparison of pasture and coniferous forest. Still, across different forests and agricultural systems, functional richness consistently decreases strongly (median ratio of 0.18) and functional divergence moderately upon land occupation (ratio of 0.88). Interestingly, functional evenness exhibits trends opposite to that of functional richness and divergence (ratio of 1.05).
The positive characterization factors also reflect the significant losses in functional plant diversity (Figure 2). The deviation among characterization factors for different land-use pairs is highest for functional richness (interquartile range IQR = 0.35), followed by functional evenness (IQR = 0.29) and lastly functional divergence (IQR = 0.09). As such, functional richness is most decisive for differences in functional diversity loss.

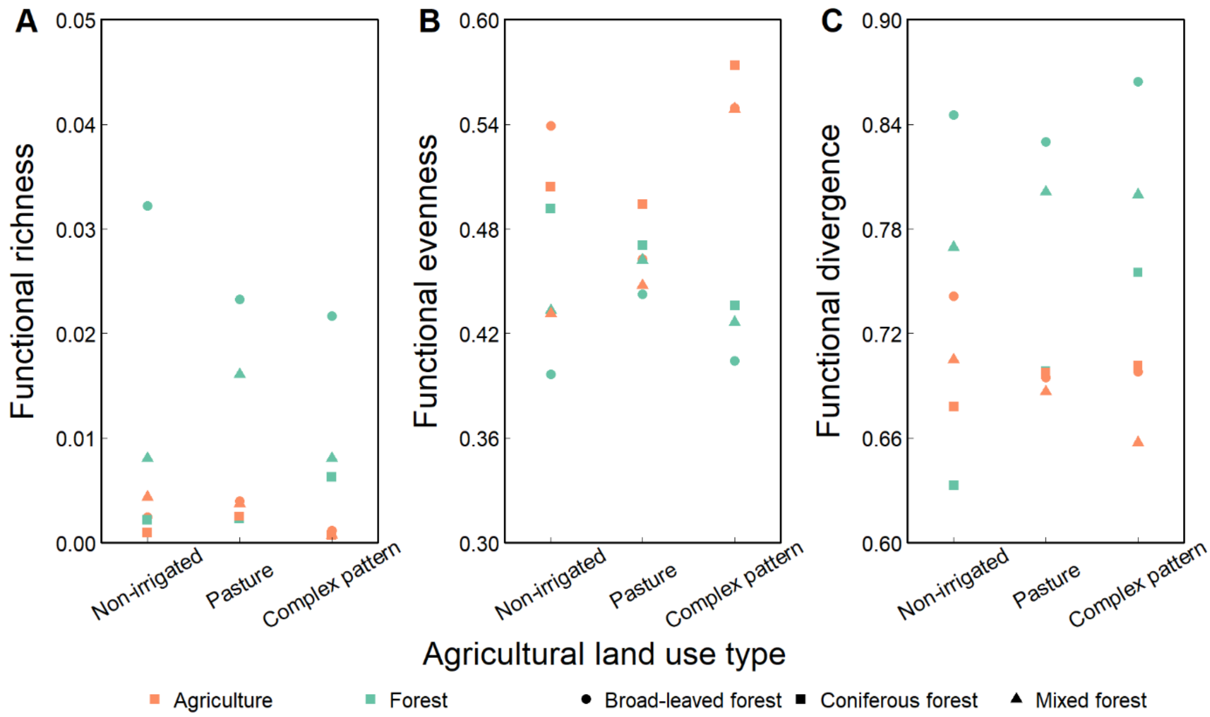

Figure 1. Median functional diversity of forests and agriculture.

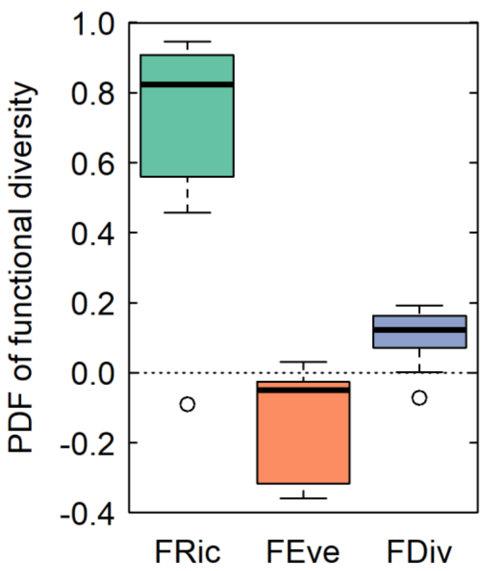

Figure 2. Characterization factors for land-use driven loss of functional plant diversity. PDF: potentially disappeared fraction, FRic: functional richness, FEve: functional evenness, FDiv: functional divergence.

Discussion

Both the design of the natural experiment and the calculation of functional diversity entail several choices that can influence the results and require transparent documentation. The choice of covariates (e.g. climate and soil characteristics), the matching approach (here propensity score matching), and specific settings used in the matching approach all determine the assignment of plots into control and treatment groups for the natural experiment. The choice of functional diversity components (here richness, evenness, and divergence) and metrics as well as the number (here 4) and identity of traits influence the estimation of functional diversity and its loss. The identity of traits also depends on the choice of taxa. This study focused on plants due to its role at the base of the food web and its importance for ecosystem functions.

The study offers more detailed land use classes than usual, by distinguishing different agriculture and forest types. It could still go a step further by considering different land use intensities.

The characterization factors of this study represent the local loss of functional diversity. Some existing characterization factors for land use and other impact categories translated the local loss of species to regional and global losses. Further research is required to apply a similar scaling to functional diversity.

Functional diversity loss is not only more complex to calculate, but also to communicate. Trade-offs between the three functional diversity metrics complicate decision-making. Results can be aggregated in several ways. One way is the use of multi-criteria decision analysis, for which the weights can be determined based on the deviations among the characterization factors. In this study, it would result in the highest weight given to functional richness. Aggregation, however, should not replace the presentation of the results for the individual functional diversity components.

Conclusions

A data-driven approach and natural experiments offer great potential for deriving characterization factors used in biodiversity impact assessments. While the proof of concept is demonstrated in Germany and the characterization factors are likely to represent temperate regions, the framework can be applied to larger scales and even globally. Moreover, other impact categories can be examined using the same framework. It is flexible and facilitates harmonization of biodiversity impact assessments.

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Abstract code: 099

Reconsidering the land resource for food production: quantifying feed-food competition in dairy systems

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Abstract

Purpose Land used in agricultural production provides different services and causes various impacts. The potential of the land resource to produce biomass can e.g. be reflected by exergy-based methods using net primary productivity indicators. However, the potential to produce food, feed, fuel and fibres is currently not considered by common resource indicators. In this study, indicators for quantifying the feed-food competition in animal production in terms of energy and protein supply for human consumption were used.
Methods The *food-competition indicator* reflects the direct competition and quantifies human edible protein and energy contained in the feedstuffs used in relation to the milk and meat produced. The *land-competition indicator* refers to the indirect competition for land use, and quantifies the potential of the land used to produce protein and energy for human nutrition by food crops relative to human edible proteins and energy from milk and meat. Protein quality (using the DIAAS method) was systematically taken into account for both indicators. They were applied to 25 Swiss dairy farms.
Results The food-competition indicator (0.01-0.54 for protein, and 0.03-0.68 for energy) showed a low direct competition. There was a strong correlation with the use of concentrates per unit of milk. The use of by-products from food and feed production led to lower food competition. The land-competition indicator showed a strong competition in most cases (0.69-2.64 for protein, and 1.52-5.93 for energy). Only two farms had an indicator value of <1 for protein. Determining factors were the arable land area, its yield potential, and milk-production efficiency parameters (feed utilisation, restocking rate). Both indicators showed lower competition with regard to protein than with regard to energy, as the protein quality in animal products is rated higher than that of the protein in food crops.
Conclusions The food-competition and land-competition indicators describe different aspects of competition and do not correlate. The combination of indicators helps to assess feed-food competition in a comprehensive way. Furthermore, the land-competition indicator can be used in agricultural LCA studies to describe the food production potential of the land occupied.

Keywords: *Land resource indicators, feed-food competition, land-competition indicator, dairy production*

Introduction

Land used in agricultural production provides different services and has various impacts. The aspects of biodiversity and soil quality are typically included as impact categories in LCA. The potential of the land resource to produce biomass can e.g. be reflected by exergy-based methods using net primary productivity indicators (Alvarenga *et al*., 2013). However, the potential to produce food, feed, fuel and fibres is currently not considered in common LCIA resource indicators. Particularly in animal production systems, conflicts between food and feed production can occur, which should be quantified. Cows and other grazers are able to convert biomass not usable by humans, such as herbage, into human-edible food. If, however, animal feed is used which could also be consumed directly as food by humans, or which is produced on land which could otherwise be used to grow arable crops, we are then faced with competition between the growing of feed for milk production on the one hand and food for human nutrition on the other. The ability to measure and strategically reduce feed-food competition between animals and humans is crucial for this efficient use. In this study (Zumwald *et al*., 2019), two indicators for determining feed-food competition in terms of energy and protein supply for human consumption were applied to Swiss dairy farms.

Material and methods

The *food-competition* indicator reflects the direct competition between animal feed and human food (Ertl *et al*., 2016). It originates from nutritional sciences and answers the question "What is the contribution of milk production, in the form of milk and meat, to human protein and energy supply, compared to the feedstuffs used?" This indicator refers to the utilised feedstuffs, and describes their proportion of potentially human-digestible energy (Eq. 1) or protein (Eq. 2) in relation to their use for the production of milk and meat:

$$FC_{hde} = \frac{HDE_{feed}}{HDE_{milk} + HDE_{meat}} \tag{1}$$

$$FC_{hdp} = \frac{HDP_{feed} * PQ_{feed}}{HDP_{milk} * PQ_{milk} + HDP_{meat} * PQ_{meat}} \tag{2}$$

where

FC_{hde} = food competition related to human digestible energy [-]
$HDE_{feed/milk/meat}$ = human digestible energy of feedstuffs/milk/meat [MJ]
FC_{hdp} = food competition related to human digestible protein [-]
$HDP_{feed/milk/meat}$ = human digestible protein of feedstuffs/milk/meat [kg]
$PQ_{feed/milk/meat}$ = protein quality (DIAAS) of feedstuffs/milk/meat [-]

By contrast, the *land-competition* indicator refers to the indirect competition for land use (van Zanten *et al*., 2016), and answers the question "To what extent could the direct production of foodstuffs on the land used for dairy production contribute to human protein and energy supply compared to dairy production?" Based on LCA theory, this indicator refers to land use, and describes the food production potential in terms of the digestible energy (Eq. 3) or protein (Eq. 4), which would be made available to humans. This potential is also compared to the effective food from dairy production on the land area used:

$$LC_{hde} = \frac{HDE_{land}}{HDE_{milk} + HDE_{meat}} \tag{3}$$

$$LC_{hdp} = \frac{HDP_{land} * PQ_{land}}{HDP_{milk} * PQ_{milk} + HDP_{meat} * PQ_{meat}} \tag{4}$$

where

LC_{hde} = land competition related to human digestible energy [-]
HDE_{land} = human digestible energy production potential on the land used [MJ]
$HDE_{milk/meat}$ = human digestible energy of milk/meat [MJ]
LC_{hdp} = land competition related to human digestible protein [-]
HDP_{land} = human digestible protein production potential on the land used [kg]
$HDP_{milk/meat}$ = human digestible protein of milk/meat [kg]

PQ_{land} = protein quality (DIAAS) of the potential production on the land used [-]
$PQ_{milk/meat}$ = protein quality (DIAAS) of milk/meat [-]

For the food and land competition indicators, values of >1 mean that the feed or the arable land provides more human edible protein or energy than contained in the milk and meat produced. Similarly, values of <1 mean a net contribution of milk and meat production to the food supply. Protein quality (using the DIAAS method) was systematically taken into account for both indicators, in order to reflect the suitability of protein for human nutrition.
Both indicators were implemented in the context of Swiss dairy farming, and the methodology was refined and adapted. The list of the feedstuffs considered was substantially expanded, so that a wide range of feedstuffs can be taken into account. The yield potential of crops was based not only on the best crop, but on an optimised crop rotation. The arable potential of the land was estimated in detail for Switzerland on the basis of available spatial information and farm data.
Both indicators were applied to 25 selected commercial dairy farms (Table 1). They differ according to region, production zone, milk yield, type of farm (organic, integrated) and the proportion of forage production on arable land. The farms are located on the Swiss Central Plateau and in the hill and mountain regions. The farms studied do not constitute a representative sample of Swiss dairy farms.

Table 1: Characteristics of the investigated farms.

Characteristics of the farms	Number of farms or value
Integrated/organic	21/4
Lowlands/hills/mountains	14/7/4
With/without arable crops	14/11
Milk yields below/above 8'000 kg ECM/cow/year	14/11
Average milk yield kg ECM/cow/year	7'545 (±1'598)
Average concentrate feed (kg DM/kg ECM)	0.108 (±0.073)

Results

For the food-competition indicator, the farms had values between 0.01 and 0.54 for protein, and 0.03 and 0.68 for energy (Figure 1). This indicates that there is low direct competition with respect to the utilised feed, or that the milk-production system produces more protein or energy that can be utilised for human nutrition than was contained in the forage. The food-competition indicator values correlate strongly with the use of concentrates per unit of milk produced. For farms using only small amounts of concentrates or none at all, values stand at around zero. Farms which have low indicator values despite using a significant proportion of concentrates in their total ration are increasingly using by-products from food and feed production as feed, such as rapeseed cake, feed potatoes or brewer's spent grain.
For the land-competition indicator, results range between 0.69 and 2.64 for protein, and 1.52 and 5.93 for energy. Only two farms have an indicator value of <1 (for protein). In most cases, growing arable food crops would contribute more to human nutrition than milk production on the land area used. The decisive factor for the indicator values of a farm is the arable area. This applies in particular to the farm's own land, since in the majority of cases it accounts for most of the differences. The two farms with the lowest indicator values are in the mountain zone; 100% of their acreage was judged as unsuitable for arable farming. Furthermore, the milk-production efficiency parameters (feed utilisation, restocking rate) play an important role. In addition to the land requirement per unit of milk produced, the suitability of the land for arable crops is of major importance.

Both indicators showed lower competition with regard to protein than with regard to energy, as the protein quality in animal products is rated higher than that of the protein in food crops.

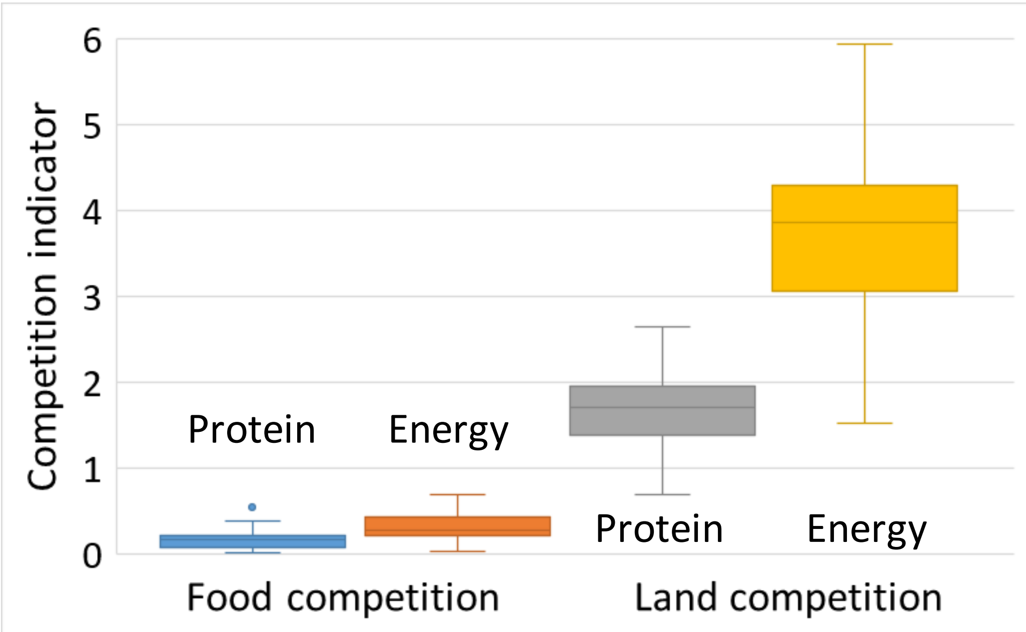

Figure 1: Food and land competition for protein and energy for 25 Swiss dairy farms.

Discussion

The results of the studied farms cannot be extrapolated to Swiss milk production as a whole, since the sample investigated was too small and not representative. Nevertheless, the results indicate that land competition between milk production and arable use for direct human consumption is stronger than food competition between animal feed and human food.

Both indicators show lower competition with regard to protein than to energy. This is because in relation to human requirements, dairy products contribute more to protein consumption than to energy consumption, and because high losses occur when ruminants convert feed energy into animal products. In addition, the quality of the protein in the animal products is rated higher than that of the protein in the feed. The food-competition and land-competition indicators describe the same issue with a different focus, which is why they do not correlate with one another on the farms studied. Nevertheless, the combination of indicators helps to assess feed-food competition more thoroughly from two different perspectives, so that it is measurable as a whole. A farm which uses only small amounts of concentrates, but which uses arable land for forage production, has low food competition; by contrast, its land competition is high. Conversely, a farm that produces its forage on non-arable land, but which uses high amounts of concentrates, has low values for land competition, but higher ones for food competition.

Conclusions

The indicators from the two approaches enable the objective representation of land and food competition in dairy production, and thus help to improve food security. They can also be applied to other types of land-based animal production like meat or eggs. The land-competition indicator can be used in agricultural LCA studies to describe the food production potential of the land occupied. If the land occupation (m^2*a) of a production system is related to the production potential for human edible protein and energy, it can be directly used as a resource indicator in LCA, which allows to cover this important aspect.

Acknowledgements
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Abstract code: 146

Assessing global impacts of compaction and water erosion on agricultural soil productivity

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Abstract

Purpose

In order to guide us towards sustainable agriculture, the assessment of soil degradation should be part of environmental assessments such as LCA. However, existing LCIA methods have several limitations. Therefore, we developed methods for assessing potential impacts of compaction and water erosion on agricultural soil productivity. In this study, we combine these methods with information from LCIs and global data on agriculture for a global assessment of potential soil productivity losses.

Methods

We combine several datasets to calculate spatially resolved inventory information and flows that can be used in combination with the characterization factors of our methods. For compaction, we allocate crop production inventory data for different machinery sizes to a newly created machinery size raster dataset. For erosion, we adjust crop factors, which indicate the potential to reduce erosion, to local productivity and consider shares of reduced and zero tillage management. We assess three main crops with regard to global area cultivated: wheat, maize and soybeans (for rice the compaction model is not valid). Based on crop production data for the year 2010 at 5-minute resolution, we calculate impacts assuming the three crops to be grown in rotations.

Results and discussion

Impacts are calculated for four different production systems considered in the crop data: irrigated, rainfed high inputs, rainfed low inputs, and subsistence production. Results for the production systems differ as no mechanization and no conservation measures are assumed for low inputs and subsistence production and as higher productivity reduces erosion impacts. Aggregated potential global soil productivity losses expressed in % area are 6.2% for high inputs production (irrigated + rainfed) and 26.2% and 35.6% for low inputs and subsistence production, respectively. Assumptions behind model input parameters come with uncertainties but a sensitivity analysis in a previous study has shown that results do not change by more than a factor of 2 even for most optimistic assumptions.

Conclusions

Calculated potential losses are in the single- and double-digit percentage range. While acknowledging that results might rather be an overestimation, we conclude that compaction and erosion impacts are considerable and hence should be part of agricultural LCAs. It also shows that compaction and erosion might be limiting agricultural productivity in the long run and potentially lead to additional land use change.

Keywords: *Soil productivity, Soil quality, Soil degradation, Compaction, Erosion, LCIA method*

Introduction

In order to guide us towards sustainable agriculture, the assessment of soil degradation should be part of environmental assessments such as LCA. However, existing LCIA methods have limitations such as being midpoint methods only, being developed for land use elementary flows and thereby lacking in assessing details of agricultural management practice, or having low spatial resolution. Following the framework developed by Stoessel et al. (2016, 2018), which allows capturing details of agricultural practice such as machinery choice or tillage system by calculating new inventory flows, we developed methods for assessing potential impacts of compaction and water erosion on agricultural soil productivity – a potential endpoint indicator for impacts on soil (Sonderegger et al. 2020). Here, we combine information from LCIs, global data on agriculture, and the characterization factors we developed for a global assessment of potential soil productivity losses caused by current agricultural practice.

Material and methods

Compaction modeling is based on the TONKM model by Arvidsson and Håkansson (1991) as adapted in Stoessel et al. (2018) and Sonderegger et al. (2020), erosion modeling is based on the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1997). We combined several datasets to calculate spatially resolved inventory information and flows (green boxes in Figure 1). The functional unit is land use in ha-yr. Details about inventory flows can be found in Sonderegger et al. (2020). For compaction, machinery induced pressure is modeled in so-called "corrected tkm". The CP-factor in erosion modeling is the combination of the cover management factor (C) and the practice factor (P) from the RUSLE model.

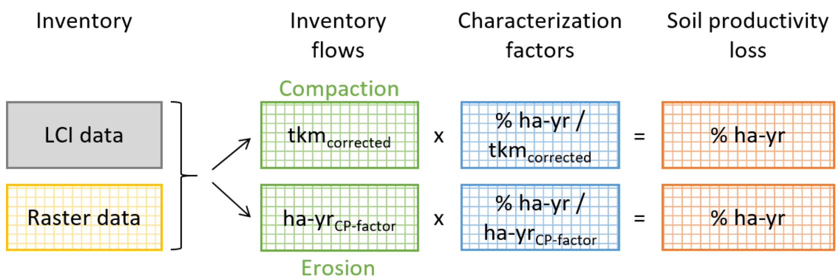

Figure 1. Simplified framework for calculations; CP is the combination of the cover management factor (C) and the practice factor (P) from the RUSLE erosion model; gridded shapes indicate raster data

We assess soil productivity loss for three main crops with regard to global area cultivated: wheat, maize and soybeans (FAO 2020) (for rice the compaction model is not valid). Crop production data (area, yield, production) is from the Spatial Production Allocation Model (SPAM) (You et al. 2014). Data is for the year 2010 at 5-minute resolution (approximately 10x10 km at the equator) and differentiates four production systems: irrigated production, rainfed high inputs production, rainfed low inputs production, and subsistence production. Irrigated production is generally considered high input production (You et al. 2014), but for some regions this does not seem to match mechanized production. We therefore modeled the fraction of irrigated production that is mechanized based on the share of high inputs production in the same cell and proxy indicators such as fertilizer use and value added (Sonderegger et al., in preparation). For spatially differentiated compaction inventory flows, we created crop production inventory datasets for different machinery sizes and allocated these to a machinery size raster dataset created with spatial information on field size and income groups per country (Sonderegger et al., in preparation). For spatially differentiated erosion inventory flows, we adjusted crop factors (the only sub-factor used for calculation of the C-factor) to local productivity and considered shares of reduced and zero tillage management per country for the P-factor (Sonderegger et al., in preparation). For each production system, we assumed crops to be grown in a rotation and calculated inventory flows for the rotation. These were then multiplied with characterization factors from Sonderegger et al. (2020) (Figure 1), which indicate the soil productivity loss [% ha-yr] per inventory flow. The calculated impact is the potential long-term cumulative soil productivity loss as a percentage of current productivity caused by one year of cultivation (for a discussion of long-term cumulative impacts and the choice of a time horizon see Sonderegger et al. (2020)).

Results

Figure 2 shows the results for compaction (A) and water erosion (B) for high inputs rainfed production. While for compaction, maximum losses (97.5%-percentile) are around 20%, they go up to 100% for erosion (about 13% of cells), meaning that soils may become completely unproductive in the long term. Regional differences are due to a combination of different inventory results, e.g. larger machinery or different choices of crops with different resulting CP-factors, and different characterization factors, i.e. different local susceptibilities. Table 1 shows aggregated potential global losses of agricultural area and production.

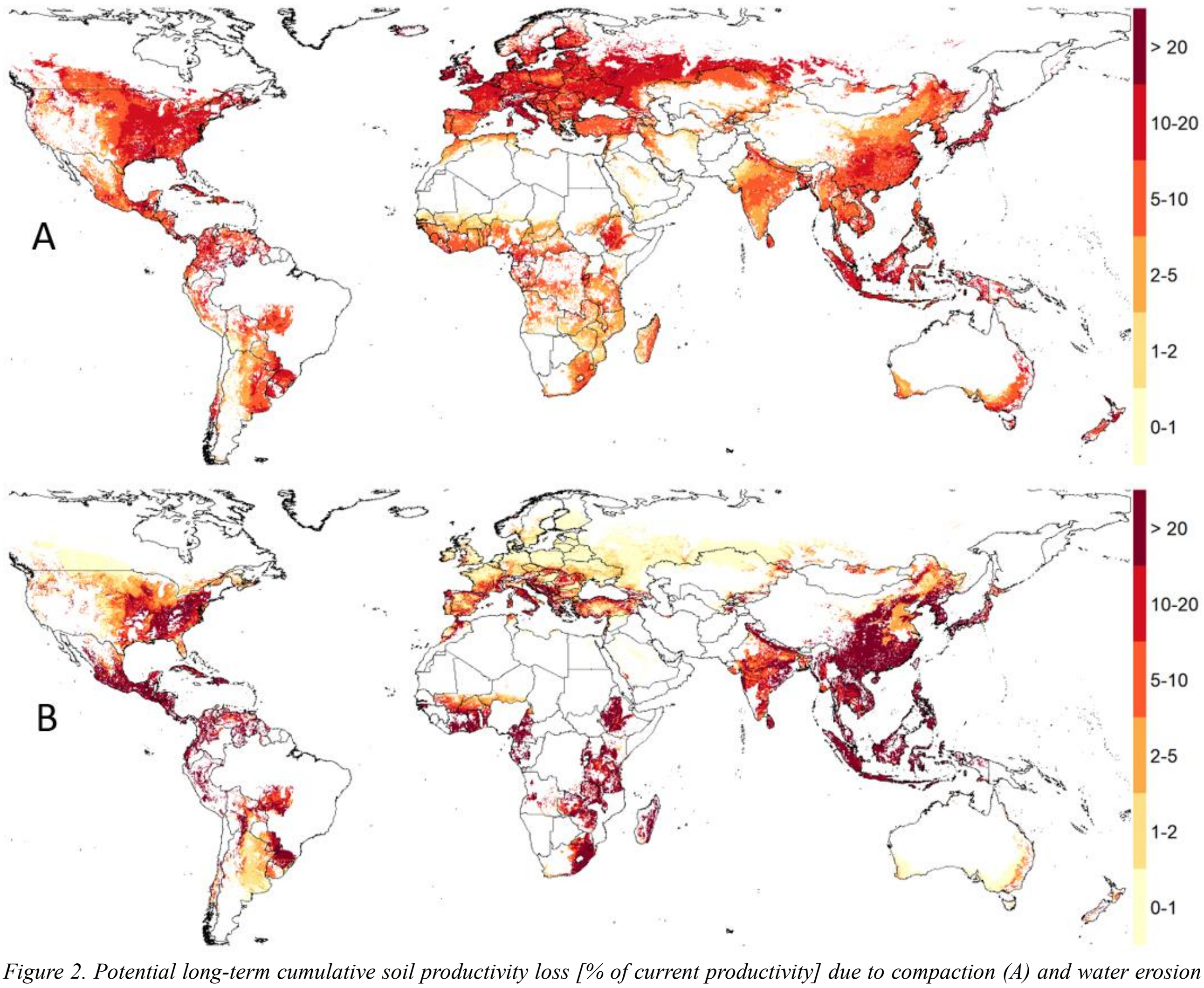

Figure 2. Potential long-term cumulative soil productivity loss [% of current productivity] due to compaction (A) and water erosion (B) impacts caused by one year of cultivation high inputs rainfed production crop areas; maize, wheat and soybean are considered and they are assumed to be grown in a rotation.

Table 1. Aggregated potential global soil productivity losses expressed in % area loss and % production loss; i_mech: irrigated (mechanized), i: irrigated (mechanized and not mechanized), h: high inputs rainfed production (mechanized), l: low inputs rainfed production (not mechanized), s: subsistence production (not mechanized)

Mechanism	Production system	% area loss	% production loss
Compaction	i_mech + h	9.9	10.9
Erosion	i + h	6.0	10.0
Combined	i + h	6.2	19.7
Erosion	l	26.2	33.5
Erosion	s	35.6	30.6

Discussion

Numbers in Figure 2 and Table 1 confirm the relevance of both soil degradation mechanisms from a simple assessment (Sonderegger et al. 2020). However, our findings reveal lower impacts, even with regard to the high numbers for low inputs and subsistence production. This might be due to the assumption that crops are grown in rotations since, for example, the comparatively higher erosion potential of maize cultivation is leveled out to some degree by the other crops. The spatial adjustments of inventory information is another reason for the changes. Nonetheless, the numbers are still relatively high and might be an overestimation. For compaction, for example, good agricultural practice, i.e. not using machinery during wet conditions, is not captured by the method (also restoration measures such as subsoiling are not part of the model). Furthermore, several model parameters (for both the compaction and the erosion model) are chosen based on assumptions. A sensitivity analysis exploring extreme input parameter settings in Sonderegger et al. (2020) has shown that results do not change by more than a factor of 2. Accordingly, they remain in the single-digit percentages for irrigated and high inputs production and even in the double-digits for low input and subsistence production. These relatively higher values can be explained by the productivity adjusted crop factors and no consideration of conservation measures.

The modeling used could profit from several improvements. On the inventory side, bottom-up information from LCIs cannot be used as data needed for models used here is often missing. With regard to erosion, compilations of available crop factors are often lacking data on the field studies they are based on. Especially a compilation of crop factors depending on productivity could improve RUSLE based assessments. On the impact assessment side, one main limitation for both degradation pathways is the missing long-term data to calibrate or validate the results. Therefore, it is hard to quantify the long-term productivity losses caused by single compaction and erosion events and the time horizon for calculations becomes a normative choice (see Sonderegger et al. (2020) for further discussions). The compaction model was built on field trials but has not been widely applied (Sonderegger et al. 2020). While the RUSLE model, also built on field trials, has been widely applied, there seem to be issues still with large-scale modeling. Results in Figure 2 show especially high erosion impacts in mountainous and tropical regions. The erosion rates for these areas tend to increase rapidly into extreme heights due the topography factor (LS-factor) and the erosivity factor (R-factor) of the RUSLE equation. Both seem to contribute to erosion rates beyond extremes from literature (see Sonderegger et al. (2020)) but, to the best of our knowledge, this is not discussed in literature, especially not in other large scale assessments (e.g. Panagos et al. 2015a, b, 2017; Borrelli et al. 2017). Regional average values can level out extreme values to some degree. Finally, erosion assessment is limited to water erosion. Globally, wind erosion affects 28% of total area affected by erosion according to Lal (2003) and contributes less than 10% to totally eroded soil on agricultural land according to Quinton et al. (2010).

Conclusions

We improved the assessment in Sonderegger et al. (2020) by modeling spatially differentiated inventory flows. Calculated potential losses are somewhat smaller but remain in a single- or double-digit percentage range, also considering sensitivities of results to input parameters. Therefore, we conclude that compaction and erosion impacts are considerable and hence should be part of agricultural LCAs. Furthermore, results show that compaction and erosion might be limiting agricultural productivity in the long run and potentially lead to additional land use change.

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Abstract code: 56

Towards consideration of ground cover management in pesticide emission modelling in LCA

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Abstract

Purpose Ground cover management (GCM) is an important agricultural practice to reduce weeds and consequently herbicides application, limiting erosion and runoff with pesticide transfer through surface water and improving soil fertility. In the present study, we hence investigated how to account for GCM in the modelling of pesticide emissions as part of Life Cycle Assessment to evaluate environmental sustainability of agricultural practices.

Methods We implemented GCM into the mass balance of initial and secondary pesticide distributions of the PestLCI Consensus web-tool, considering living plant cover, spontaneous or planted. We thereby considered the following parameters: i) cover crop occupation between the rows of main crop, ii) cover crop canopy density and iii) cover type (e.g. *Pooideae*). Processes occurring on the main crop leaves were adapted for cover crop leaves, i.e. wash-off, degradation, leaf uptake and volatilization, and were summed up to the same processes occurring on the main crop and distributed in fractions to the air, soil, off-field surfaces and water. Several modalities of cover canopy density [0.4; 0.7; 1] and soil surface covered by the cover crop [0.4; 0.7; 1] were tested, for 2 main crop growth stages (leaf development and flowering), with a control scenario without cover crops. Simulations were performed for two cropping systems: tomato in Martinique and viticulture in the Loire Valley in France.

Results and discussion Our results highlighted that the higher the effective area that is covered by cover crop, the lower the fractions emitted to soil and groundwater, with a decrease by more than half of emissions between extreme scenarios. Consequently, the emissions to field soil decreased with the reduction of bare soil in a plot. Due to a higher degradation rate on leaves than on soil, the degraded fraction was up to 3 times higher with a cover compared to the control. Similar trends were observed for tomato and viticulture with a higher degradation in the tomato case mainly due to the use of a hand application method (knapsack sprayer) which reduces the emission to air and off-field surfaces.

Conclusions The modelling of GCM allowed highlighting the potential of soil cover to limit pesticide emissions to field soil and outside the cultivated plot, reducing losses by water flows and increasing degradation processes. This further implied to account for the impact of pesticides in crop residues and unharvested cover crop. Indeed, if crop residues and unharvested cover crop remain on the field, there will then be emissions to soil and air depending on pesticide degradation rates, whereas, if these fractions are removed from the field, impacts will depend on their use.

Keywords: *Active ingredient; Ecotoxicity; Cover crop; Modelling*

Introduction

In LCA, the most up-to-date model to estimate pesticide emissions to the environment (air, soil, crop, groundwater, off-field surfaces), PestLCI, takes into account pedoclimatic conditions, field characteristics and few farming practices (e.g. tillage type, presence of irrigation) (Dijkman 2013). However, other agricultural practices affect pesticide emissions (Mottes et al. 2014) and in particular practices influencing the hydraulic processes in and on the soil, such as ground cover management (GCM). Indeed, soil cover provides many agricultural and environmental benefits, limiting weeds and consequently herbicides application, limiting erosion and runoff with pesticide transfer through surface water, improving soil fertility and bearing capacity. Consequently, ground cover management is a common practice in agriculture. As shown by Renaud-Gentié et al. (2015) and Gentil et al. (2019), GCM should be taken into account for modelling pesticide emissions. The most up-to-date version ("Consensus" version) of the model has recently been operationalized as a web-tool. The aim of our study is to propose the modelling of GCM in the PestLCI Consensus web-tool for both initial and secondary distributions, and first of all the modelling of a living plant cover, spontaneous or planted. The modelling was tested in two contrasted case studies, tomato crop in Martinique and viticulture in the Loire Valley in France.

Material and methods

Based on literature, the GCM was taken into account defining three new input parameters: i) cover crop occupation between the rows of the main crop (i.e. area fraction of crop-free field that is cover crop), ii) cover crop canopy density (i.e. area fraction of cover crop that is covered by leaves) (Renaud-Gentié et al. 2015) and iii) type of cover (e.g. *Pooideae*). All the processes occurring on main crop leaves were modelled for cover crop leaves, i.e. wash-off, degradation, uptake and volatilization and were summed up to the same processes occurring on the main crop and distributed in fractions to the air, soil, off-field surfaces and water. New outputs were created: for the initial distribution, a fraction deposited on the cover; for the secondary emissions, an uptake fraction by the cover including the fraction left on leaves not yet taken up by the cover crop. The degradation on cover crop leaves was integrated in the total fraction of degradation. We defined an effective area fraction of crop-free field that is covered by cover crop (leaves or canopy) by multiplying the area fraction of crop-free field that is cover crop and the area fraction of cover crop that is covered by leaves. Several modalities of effective area fraction of crop-free field that is cover crop were tested, for 2 main crop stages (leaf development and flowering), with a control scenario without cover. Forty scenarios were simulated. Two contrasted situations in terms of crop, climate, soil and application method were considered (Table 1) while other input data were the same (no drift reduction, field length and width of 100m, slope of 10%, no drainage system, no irrigation and no tillage). In both case studies a cover crop composed of *Pooideae* was considered and the insecticide abamectin (CAS number: 71751-41-2) was applied.

Table 1: Case studies characteristics for crop, climate, soil, application method and time assessed

Crop	Localization	Climate type	Soil type	Application method	Time assessed* (days)
Grapevine	Loire Valley (France)	Beaucouzé weather station	Sand on calcareous formation	Recycling sprayer (Ganzelmeier and Rautmann 2000)	4
Tomato in open-field	Martinique (French West Indies)	Le Prêcheur, Meteo France weather station	TV vitric andosol (from FAO database)	Knapsack sprayer (García-Santos et al. 2016)	3

*Until the first rain event occurs, corresponding to the rain frequency of the month of application.

Results and discussion

Our results highlighted that modelling GCM reduced the fractions emitted to the environment and to the field soil and increased the fraction degraded. Figure 1 presents the results for initial distribution fractions for the leaf development crop stage (crop interception of 0.3) for the two case studies, tomato and viticulture. In this figure, different values of effective area fractions are presented. At the flowering stage (crop interception of 0.8), similar trends to those for crop interception of 0.3 were observed between initial and secondary distributions, with lower emissions to field soil, higher degradation on leaves and cover uptake, and higher pesticide fraction left on cover leaves due to crop wash-off. Indeed, the higher the effective area fraction of crop-free field that is covered by cover crop, the lower the fractions emitted to soil and groundwater, with a decrease by more than half of the emissions between extreme scenarios (no cover on the one hand and an effective area fraction of crop-free field that is covered by cover crop of 1 on the other hand). Consequently, the emissions to field soil decreased with the reduction of bare soil in a plot, which is the main result for both case studies and also for both distributions. In addition to the influence of application method and plot size, when considering GCM, secondary emissions off the field and to field soil were influenced by three factors: i) the active substance characteristics (e.g. DT50) involved in pesticide degradation, volatilization, runoff and uptake by leaves, ii) the cover characteristics (density of canopy, soil surface covered and its type) and iii) the main crop characteristics (growth stage). Indeed, according to these two last factors, the fraction intercepted by the crop, the soil and the cover crop may change drastically. Furthermore, due to higher degradation rates (DT50) on leaves than on soil (Juraske et al. 2008), the degraded fraction was up to 3 times higher with a cover. Similar trends were observed for tomato and viticulture with a higher degradation on tomato production mainly due to the use of a hand application method (knapsack sprayer) which reduces the emission to air and off-field surfaces.

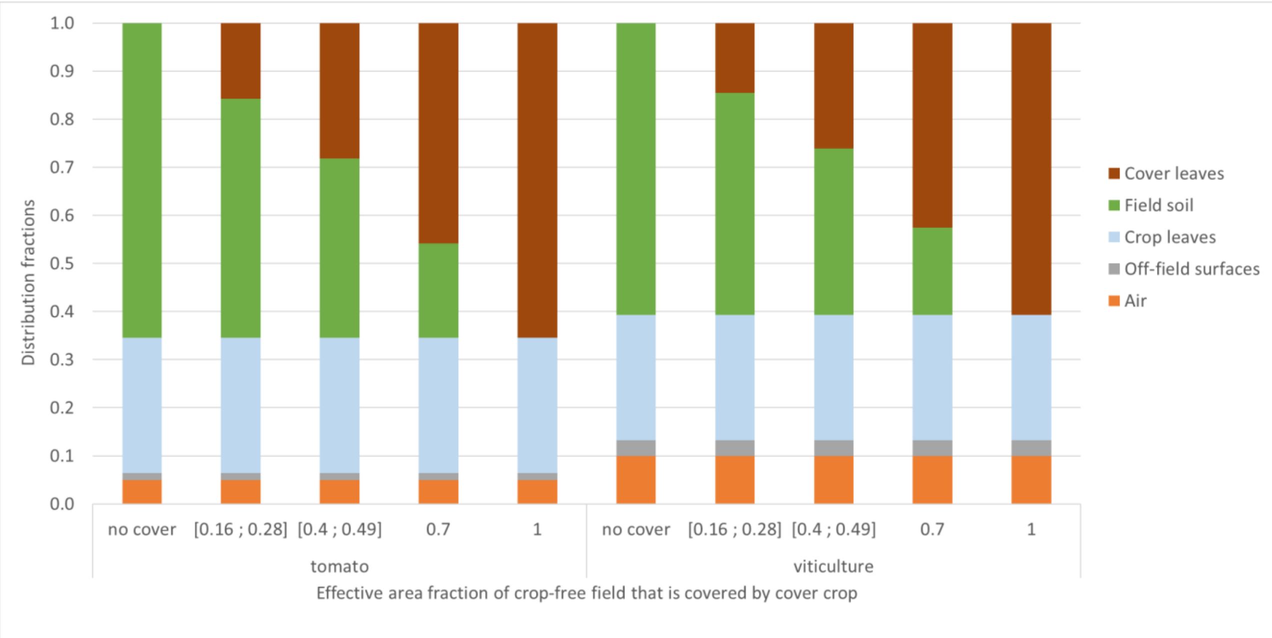

Figure 1: Synthesis of initial distribution fractions for the leaf development crop stage for the two case studies, tomato and viticulture, for a variability of effective area fraction of crop-free field that is covered by cover crop (product of area fraction of crop-free field that is cover crop and area fraction of cover crop that is covered by leaves) considering an average of scenarios for the effective area fractions [0.16 ; 0.28], [0.4 ; 0.49] and [0.7], with a control scenario without cover and a scenario with an effective area fraction of 1.

The emissions to ground water were very low (order of magnitude 10E-04), but the freshwater ecotoxicity is very sensitive to them since the characterization factors for continental freshwater in USEtox^{TM} are high and assigned to ground water emissions. With GCM, the emissions to ground water were reduced on average by 45% due to reduced macropore flows and leaching processes due to the diminution of pesticides emitted to bare soil. As a result, the impact score from ground water emissions (in PAF.m3.day/kg active substance applied) was reduced by up to 8 times for the viticulture case. The degradation fraction could vary according to the pesticide applied and its own characteristics. Testing more scenarios of application with different active substances, especially with a large range of degradation rates would be useful for better understanding the effect of GCM on pesticide emissions.

Conclusion

The modelling of GCM allowed highlighting the potential of soil cover to limit pesticide emissions outside the cultivated plot and to field soil, reducing losses through water flows and increasing degradation processes. From the initial work on vine of Renaud-Gentié et al. (2015), the consideration of this common farming practice opened the possibility to model it more widely for all crops with cover crop especially those in the tropics but also orchards, and it opened the path towards the modelling of pesticide emissions in double cropping systems, widely conducted in market gardening in particular in tropical conditions. The impact of pesticides in crop residues and unharvested cover crop should now be accounted for, but this issue already existed for the crop-only version of PestLCI. Indeed, if crop residues and unharvested cover crop remain on the field, there could then be further emissions to soil and air except if all pesticides have already been degraded. Of course, cover crop will stay in place much longer that a few days as simulated in this study. If some pesticides remain, and these fractions are removed from the field, impacts will depend on their use (e.g. burned). Finally, further researches are also required to consider the effect of several rain events on pesticide secondary emissions and to avoid double counting with the impact model USEtox.

Acknowledgements

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Abstract code: 443

The C-Sequ project: a conceptual proposal for methodological guidelines for on-farm carbon sequestration in LCA

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Abstract

Purpose: The C-Sequ project is a multistakeholder initiative bringing together industry, academia, and policy to bridge the gap of carbon sequestration accounting in LCA and GHG reporting. The purpose is to provide actionable Guidelines to include the benefits and impacts of influencing on-farm carbon sequestration in order to encourage changing and keeping farm-level practices in the beef and dairy sector that sequester more carbon for longer time periods.
Methods: Due to the subjective nature of setting new carbon accounting rules and the need for a high level of technical input, to draft the Guidelines there was an extended consultation process (>1 year) with academic experts and key stakeholders. As a critical step, the project will make the Guideline available for a public consultation before finalization and subsequent launch for completion. *This abstract presents where we are currently with the conceptual proposal for the Guideline prior to public release and is not a final suggestion.* Methods to account for carbon sequestration were chosen to align with global warming potential (GWP) 100 for the characterization of CO2-equivalents and build on dynamic CO2 accounting.
Results and discussion: Impacts and benefits of influencing on-farm carbon sequestration shall be included if there is a net change in on-farm carbon stock within a responsibility period. Inventory is the *cumulative net amount* of CO2 (stoichiometric) lost or gained and estimated with field data (soil samples), or models (IPCC Tier II or the site-specific Tier III) and is characterized into GWP100 CO2-equivalents as -0.01 kg CO2eq/kg CO2 stored/year and 1 kg CO2eq/kg CO2 emitted/year. Suggested responsibility period are 100 years, 50 years, and 20 years. Losses of CO2 that were gained since a responsibility window has begun, e.g. due to manure or compost amendments are characterized as neutral.
Conclusions: The proposed continuous credit approach encourages growing and increasing the longevity of carbon stocks on farms to begin and continue good practices. Deciding the responsibility period influences the results. Other impact indicators can also be relevant when a farmer changes practices and should be considered for decision making.

Keywords: *Carbon sequestration; regenerative agriculture; soil; dynamic LCIA; farm-level*

Introduction

Carbon dioxide (CO2) dynamically cycles between the atmosphere and agricultural systems. There is evidence that increasing the amount and longevity of biogenic carbon storage could reduce associated atmospheric radiative forcing (Canadell and Schulze 2014).

Recently, there is interest in the potential to store CO2 in agricultural systems through carbon sequestration—defined here as a net increased *removal of CO2 from the atmosphere and storage in on-farm biogenic sinks (e.g. soil, trees)*. Despite academic activity and media attention, there exists no Guidance for how losses and gains of sequestered carbon can be included in GHG accounting or LCA. Furthermore, there are inconsistencies across assessments where for example stoichiometric CO2 is used incorrectly in place of CO2eq. This leads to confusion and incomparability across the LCA field and beyond.

Given the state of the science and motivation for industries to mobilise to find solutions to the climate crisis, there is an opportunity to bridge the divide between the academic discourse of dynamic CO2 accounting and how industry measures and manages GHG accounting at the farm-level. This project is a first step to provide practical guidance to account for carbon sequestration specifically to support farm-level management changes in the dairy and beef sectors. The quantitative framework is built on existing academic work and aims to incentivise land management that reduces atmospheric CO2 for longer periods of time.

To bridge the gap between academic knowledge and practice, the Guidance recommends pragmatic and robust simplifications to limit the number of manual operations to be carried out by the practitioner. As with all GHG accounting there is a subjective nature to the decided rules and thereby the Guidance aims to be a transparent proposal for how to account for carbon sequestration in farm-level LCAs.

Material and methods

Due to the subjective nature of setting new carbon accounting rules and the need for a high level of technical input, to draft the Guidelines there was an extended consultation process (>1 year) with academic experts and key stakeholders. Through this process literature review and multi-stakeholder debate was performed. Inspired by greenhouse gas (GHG) accounting challenges, we identified many academic methods that aim to quantify the effect of removal of CO2 from the atmosphere on climate (Levasseur et al. 2011; Guest et al. 2013; Cherubini et al. 2013; Breton et al. 2018; Brandão et al. 2018; Bessou et al. 2019). Common among most existing methods is that the reduction in carbon footprint is tied to the

1) amount of CO2 removed from the atmosphere (inventory, stoichiometric CO2).
2) impact on climate change of the time period CO2 is removed from the atmosphere (characterisation, CO2-equivalents).

The foundation of obtaining CO2eq, is the measure of the relative global warming potential (GWP) of a GHG to the *impact of a pulse of CO2 over a fixed time window;* commonly this time horizon is 100 years and referred to as GWP 100. The Guidance suggests that losses and gains of sequestered carbon should also align with the GWP 100 framework. Practically, this means accounting 1 kg CO2 stored as biogenic carbon in a tree or soil in one year is not the same as -1 kg CO2eq unless it is stored permanently (>100 years). Thus net 1 kg CO2 stored in an *assessment year* and stored for less than 100 years cannot "cancel" the (fossil) emission of 1 kg CO2eq. The Guidance suggests methods to gather inventory, characterize the inventory, and lastly suggests a responsibility window over which net changes in sequestered carbon are to be estimated and impacts and benefits distributed (similar to Land Use Change guidance).

As a critical step, the project will make the Guideline available for a public consultation before finalization and subsequent launch for completion. *This abstract presents where we are currently with the conceptual proposal for the Guideline prior to public release and is not a final suggestion.* In this work, methods to account for carbon sequestration were chosen to align with global warming potential (GWP) 100 for the characterization of CO2-equivalents and build on dynamic CO2 accounting.

Results

Following a stakeholder and expert engagement process, a conceptual proposal has been developed to provide recommendations for when and how to account for farm-level carbon sequestration in practical LCA and GHG accounting. The derived approach consists of the following steps which are described in detail below:

1. Evaluate if carbon sequestration can be included in the assessment
2. Obtain inventory as stoichiometric CO2
3. Characterize inventory as CO2eq
4. Apply the responsibility window

Step 1: Before going forward, a practitioner must understand *if* carbon sequestration can be included in the assessment. Given the relative nature of impact assessment and the need for a reference state (Hauschild and Huijbregts 2015), the recommended "reference state" is the year just before a land management or land use change or just before the beginning of a responsibility window if there has been no land use or management change. Carbon sequestration can be accounted for if there is a net change from the baseline reference. **Table 1** provides a non-exhaustive list of land management changes and the associated form of carbon sequestered, i.e. as soil organic carbon (SOC) and perennial biomass.

Table 1. Subset of land management changes relevant for dairy farms

Land management change	Sequestered carbon form
Changing from till to no-till with high organic amendment	SOC
Changing from residue removal to residue application	SOC
Reaching and controlling a C/N equilibrium in amendments	SOC
Changing from intermittent bare soils to cover crop management	SOC
Changing from high intensity grazing to lower intensity grazing	Perennial biomass and/or SOC
Changing from no or few trees or hedges to more trees and hedges	Perennial biomass and/or SOC

Step 2: Inventory is collected as a cumulative carbon stock net gain or loss since the year prior to the assessment year, or prior to land management or land use change up until an assessment year when considering a responsibility window. Biogenic emissions of CO2 are not considered net loss unless there is a stock change. The net carbon stock gain since the change can be estimated as molecular carbon and multiplied by 44/12 to obtain stoichiometric CO2. Thereby if a hedge has been growing for 5 years, the total amount of stock gained through that hedge since it was planted can be inventoried as stoichiometric CO2. The practitioner can choose a

method to obtain inventory (e.g. measurements, or models). Recommended methods include using IPCC Tier I/II soil organic carbon modelling approaches that are outlined in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 : AFOLU. Tier III models such as RothC, Century, etc. can also be a more accurate and site-specific way to obtain carbon stock change for soils. For trees, allometric equations that are sensitive to the region, tree species, and physical aspects can be applied.

Step 3: Stoichiometric CO2 inventoried can be characterized into negative CO2 equivalent using the characterization factor (CF) of -0.01 kg CO2eq / 1 kg CO2 / year. The interpretation of this CF is that credit is given in the assessment year for keeping CO2 removed from the atmosphere for 1 year out of a 100 year time horizon that is key to the calculation of CO2eq under GWP 100. This method is an adaptation of the International Reference Life Cycle Data (ILCD) by the European Commission (JRC-IES 2010) and is simpler in comparison to other dynamic accounting methods, e.g. using the Bern Carbon Cycle.

Figure 1 demonstrates the steps outlined above. In this figure, carbon sequestered in tons of stoichiometric CO2 (tCO2) is inventoried for a hypothetical situation where a land management change occurs at time 0. Carbon stock gain occurs for 20 years until it reaches saturation with a net change of 100 tCO2. After this time, the land management continues to keep the carbon stored. Retrospectively, this example would allow for a total of -90 tCO2eq to be accounted for in a 100 year period, or -0.9 tCO2eq per assessment year benefit on average.

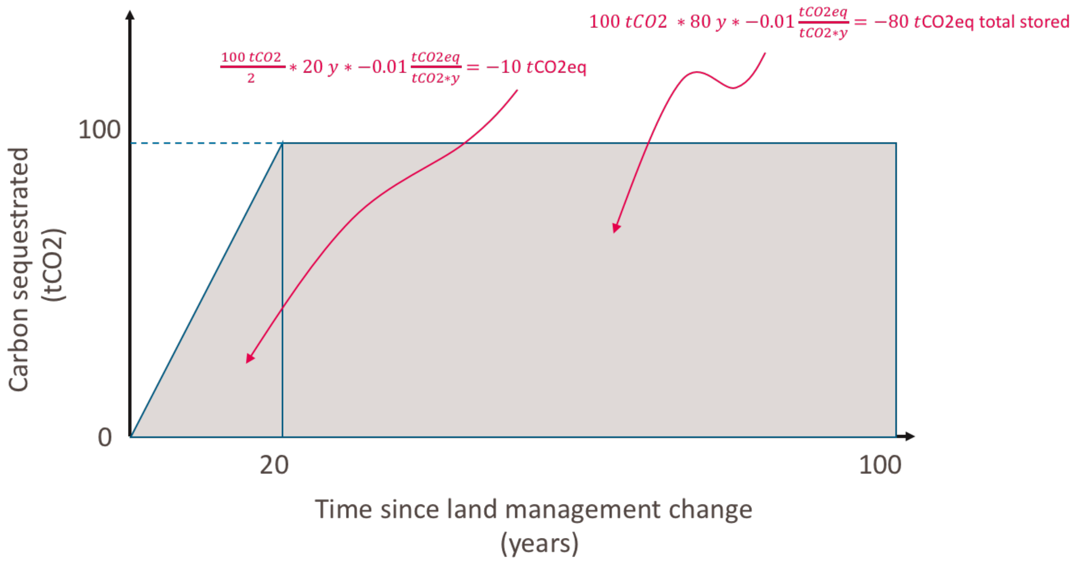

Figure 1. hypothetical example showing inventoried sequestered carbon over a time period and its characterization (in red text).

Step 4. The responsibility window is a value choice that must be decided with greater stakeholder engagement. The responsibility window is important because it sets the time period for which the practitioner can account for past changes in carbon and over which time period the entity takes responsibility for these changes. In Land Use Change accounting this responsibility window is set to 20 years. The final per year benefit or impact is influenced by the choice of the responsibility window. Three responsibility windows are proposed for public review 100 years (1% per year), 50 years (2% per year), or 20 years (5% per year).

Discussion

Through the development of this conceptual proposal it became clear that a key issue is aligning a GWP 100 characterization framework with carbon crediting and accounting outside of LCA which may have implicit assumptions of permanence, as well as the accounting of biogenic emissions. If sequestered carbon is assumed permanent, the assessment year could receive credit for future storage. In practice this would result in applying a CF of -1 kg CO2eq/kg CO2 stored permanently. This characterization is typical of many carbon crediting markets. Different than a typical LCA approach, carbon crediting markets may apply a risk, buffer, or safety factor to account for impermanence e.g. due to natural events such as forest fires, floods etc. In the case of assuming permanency in LCA or GHG reporting, there are several key questions such as: What needs to be true to assume a management change is permanent? What monitoring rules would be required? Furthermore, would there be a penalty for changes that are not permanent e.g. through characterization biogenic CO2 releases as 1 kg CO2eq / 1 kg CO2 biogenic which is not common practice. If the characterization of biogenic CO2 changes, then there are also questions on updating existing LCI and LCIA methods to consistently account for land management practices that do not sequester carbon (e.g. convention practices).

In addition to carbon accounting, there is also a need to understand the implications of practice. For example, the influences of management practices on other ecological and economic aspects of the agricultural system such as yield and agrochemical use. This conceptual proposal does not cover these aspects and it is the responsibility of the practitioner to consider these aspects when performing an assessment and guiding decision making.

Conclusion

The conceptual proposal for the default method is to inventory the cumulative net carbon sequestered or lost in terms of stoichiometric CO2 in relation to the reference state set before a land management or land use change or at the beginning of a responsibility window, and apply characterization factors of -0.01 kg CO2eq/kg CO2 stored/year and 1 kg CO2eq/kg CO2 emitted/year. This proposal provides credit to the assessment year for keeping CO2 removed from the atmosphere during that year, including CO2 that was sequestered in years past due to the land management or land use change. Responsibility windows of 20, 50, and 100 years are suggested which would influence the past time period that can be considered and the per year accounting that carries the responsibility for lost and gained carbon sequestered. The methods proposed are to encourage reducing the amount of atmospheric CO2 through changes and on-going management.

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Environmental impacts of the German food basket with a special focus on water use and water scarcity

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Abstract

Purpose It is well known that food consumption and dietary patterns are directly related to environmental burdens, such as greenhouse gas emissions, water scarcity and land use. This study aims to assess the mentioned environmental impacts of the German food basket.
Methods Based on German consumption, production and supply statistics the German food basket has been evaluated. Using international trade data, the main export countries for each product have been identified. To assess the environmental impacts a Life Cycle Assessment in accordance with ISO 14040 has been carried out. The included life cycle phases were: agriculture, animal husbandry, processing, retail and wholesale as well as consumption, including storing, cooking and shopping trips. Impacts on climate change have been assessed as well as water and land use, and the scarcity-adjusted water use, using crop-specific factors.
Results and discussion The German food basket results in the emission of 2.8 tons CO_2eq per year and capita. A total of 2366 m² of land was used for cultivation, and 35 m³ of water are necessary to fill the basket. This results in a water scarcity index of 1502 m³. The results show that there are clear differences between the environmental impacts of each product and product group. Meat and other animal products cause over 70% of the greenhouse gas emissions (47% and 25% respectively) and about 80% of land use. Regarding water scarcity, a few products make up most of the water scarcity footprint. Oranges from Spain and almonds from the USA alone account for 44%.
Conclusions Meat and other animal products result in immense greenhouse gas emissions and land use in relation to their share in food consumption. The same applies to some plant-based foods and their water scarcity footprint. In order to reduce the environmental impacts of German food consumption, it is necessary to consider all relevant environmental impacts and not just greenhouse gas emissions which are prominently discussed.

Keywords: *German food basket, water scarcity, water use, environmental impacts*

Introduction

Food consumption has a high share in environmental burdens (e.g. Rockström et al., 2020; Eberle&Fels, 2016; Meier 2017). In particular due to the changes in dietary patterns environmental burdens connected to food consumption will rise further in the future (Willet et al., 2019, Eberle, 2014). The aim of this study is to assess the environmental burden of German food consumption and thus updating previous studies (Eberle & Fels, 2016, Meier & Christen 2013). However, a particular focus of this study is laid on water use, water scarcity, and land use.

Material and methods

The analysis is carried out according to the ISO 14040 series for Life Cycle Assessment (LCA). It follows the approach described in Eberle & Fels (2016): the study analyses the material flows necessary to fill the German food basket, starting from consumption and going back to the production of agricultural and fishery commodities. This includes storing and cooking in households, the shopping trip, retail and wholesale, food processing, agricultural production, animal husbandry as well as all kinds of transports and wastes/losses along the product life cycles. First, the composition of the German food basket has been taken from statistical data such as German consumption, production and supply statistics (BMEL 2017, 2018, 2019). Trade statistics of FAOSTAT were used to assess the imports of products. In order to reduce the annual variations, a mean value was calculated on the basis of the years 2015, 2016 and 2017. The resulting composition was then used as an input for the LCA-study.

In the LCA-study greenhouse gas emissions, land and water use as well as the water scarcity footprint have been considered. Land and water use was considered at the level of agricultural cultivation only. The crop-specific blue water use is based on Mekonnen & Hoekstra (2010).

The impact assessment for climate change has been carried out using the baseline model of 100 years of the IPCC, using characterization factors of IPCC (2013), including direct Land Use Change (dLUC) and Land Use (LU) emissions. Water scarcity was assessed using the impact assessment model Available WAter REmaining (AWARE) (UNEP 2016) and the crop-specific AWARE factors (Boulay et al., 2019).

Results

The German food basket contains 617 kg of food consumed by one person in one year. Of these foods, 32.1% are of plant origin and 67.9% are of animal origin. Of the plant products, 35% are vegetables (including starchy vegetables), 25.7% cereals, 24.9% fruit, 6.9% sugar and 5.2% added vegetable fats. The rest are nuts, pulses and cocoa. Almost two thirds of the animal products consumed are milk and milk products (62.3%), one quarter (27.9%) meat and sausages, 6.5% eggs and 3.3% fish. This food basket amounts to 2780 kcal per day.

LCA results show that most environmental impacts of food consumption with respect to the analyzed impact categories are caused during agricultural production. Impacts of further steps along the chain are much lower. In total, 2.8 t of CO_2-equivalents are emitted per person and year in Germany for food consumption, 2366 m² of land have been occupied, and 35 m³ of water have been used amounting to 1502 m³scarcity-adjusted water use.

With regard to greenhouse gas emissions, it can be seen that most emissions (72%) are caused by animal products such as dairy products (25%) and meat and meat products (47%). Plant foods only cause 28% of greenhouse gas emissions, but account for more than two thirds of the food consumed (68%). In contrast, meat and meat products, which are responsible for almost half of the greenhouse gas emissions, only have a share of 10% in the German food basket. Most greenhouse gases are emitted in agriculture (54%) and animal husbandry (23%), followed by the consumption phase (14%). Processing (7%) and retail (3%) account only for a small share.

Regarding water use in agriculture most water (69%) is consumed for plant products. The scarcity-adjusted water use for plant products is even higher (91%). Water consumption of animal husbandry was not included, so that water use is slightly underestimated here. Most water for German food consumption is used in Spain (11.3 m³/a), followed by France (5.8 m³/a), the United States (3.8 m³/a), Italy (3.3 m³/a), the Ukraine (2.9 m³/a) and Germany (2.4 m³/a). The other countries are responsible for the remaining 5.5 m³/a (table 1).

Table 1: Water use and water scarcity impacts for German food consumption per person and year

Countrycode [ISO 3166-1 alpha-2]	**Water use [m³]**	**Share of water use [%]**	**Water scarcity [m³ worldeq.]**	**Share of water scarcity [%]**
ES	11.29	32.12%	863.15	56.85%
FR	5.78	16.46%	46.77	3.08%
US	3.81	10.83%	189.44	12.48%
IT	3.31	9.43%	155.88	10.27%
UA	2.92	8.31%	71.30	4.70%
DE	2.42	6.88%	5.08	0.33%
IN	0.64	1.82%	17.75	1.17%
TN	0.62	1.77%	49.19	3.24%
TR	0.53	1.50%	27.79	1.83%
EC	0.51	1.45%	2.89	0.19%
CR	0.45	1.28%	1.14	0.08%
ZA	0.37	1.04%	18.59	1.22%
GR	0.34	0.97%	25.18	1.66%
PL	0.32	0.92%	0.68	0.04%
KH	0.30	0.85%	3.53	0.23%
CL	0.28	0.81%	24.44	1.61%
TH	0.19	0.54%	1.25	0.08%
CO	0.16	0.45%	0.18	0.01%
AR	0.15	0.43%	0.34	0.02%
MM	0.14	0.40%	0.88	0.06%
NL	0.12	0.35%	0.20	0.01%
HU	0.12	0.35%	0.16	0.01%
PK	0.10	0.28%	5.59	0.37%
IR	0.09	0.25%	5.05	0.33%
BR	0.06	0.18%	0.09	0.01%
VN	0.03	0.09%	0.42	0.03%
CZ	0.02	0.07%	0.05	0.00%
BE	0.02	0.05%	0.04	0.00%
NZ	0.01	0.04%	0.20	0.01%
BG	0.01	0.03%	0.31	0.02%
EG	0.01	0.02%	0.69	0.05%
Others	9.3E-3	0.03%	83.6E-3	0.01%
Total	**35.15**	**100.00%**	**1518.33**	**100.00%**

Regarding water scarcity, it is interesting to note that it is not always the countries with the lowest water use that have the lowest scarcity adjusted water use, or vice versa (table 1). For example, France has the second highest water use (16.5%) for German food consumption but only a share of 3% in water scarcity impacts. In contrast, in the US water use is 1.5 times less than in France, but the scarcity-adjusted water use is more than four times higher (12.5%). In Spain, where one third of the water required for German food consumption (32.1%) is used, the scarcity-adjusted water use even accounts for more than half (56.9%).

Almost half of the scarcity-adjusted water use (44%) is caused by just two foods: oranges from Spain

and almonds from the US. These foods correspond to 5% of the German food basket. In contrast, potato cultivation and potato starch, for instance, which together have a share of 6.6% in the German food basket, is only responsible for 0.5% of the scarcity-adjusted water use. Rice, on the other hand, causes 6.7% of the water scarcity impacts but has only a share of 0.9% in food consumption.
As far as land use is concerned, about half of the land required for the production of the food consumed in Germany is used in Germany itself (1164 m^2*a) followed by Poland (173 m^2*a), the United States (172 m^2*a), Brazil (154 m^2*a) and France (113 m^2*a). Most land is used for the production of meat (56%), followed by other animal products (24%). The three crops with the highest shares are: corn (27%), wheat (15%) and soybeans (14%). All three crops are mainly used for feed.

Discussion & Conclusions

The results regarding greenhouse gas emissions for German food consumption are consistent with other studies conducted on this topic (Eberle & Fels, 2016; Meier & Christen, 2013). What is new, however, are the results on water scarcity, especially the country-specific view on these impacts. It is interesting to note that 80% of the water scarcity impact is caused by food imported from just three countries: Spain, USA and Italy. This shows that food that is known to be climate-friendly, such as fruit, can be worse in terms of its impact on water scarcity. These results clearly show how important it is to base strategies for a more environmentally friendly nutrition and food production not only on the results for greenhouse gas emissions.
Furthermore, it is shown that the caloric intake in German food consumption is on average 11.2% too high with regard to recommendations for healthy eating (Willet et al., 2019). Thus, a reduction in caloric intake towards a healthier diet could also reduce the environmental impact of German food consumption.
The results of the study help to better classify and evaluate the ecological relevance of certain products, product groups and production steps along the life cycle. The results can thus be used by politicians for regulations and framework measures, by companies for reducing environmental impacts and by non-governmental organizations for campaigns.

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Modelling foreground and background land use impacts in agricultural systems: the dilemma of highly detailed or universally applicable

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Abstract

Purpose A major challenge in LCA is to perform a detailed and specific assessment for the foreground system, even though the information in the background system is limited; we need a method, that is globally applicable. This paper presents a strategy for addressing this issue by combining a detailed method for assessing the effects of foreground (i.e. on-farm) processes with a general, but universally applicable, method for the background system.
Methods The conceptual work is based on the following methods:
Soil quality
Foreground: SALCA soil quality model (SALCA-SQ) developed by Oberholzer *et al.* (2012).
Background: LANCA® (LANd use indicator value CAlculation) proposed by Bos *et al.* 2016.
Biodiversity
Foreground: SALCA biodiversity model (SALCA-BD) developed by Jeanneret *et al.* (2014)
Background: Global Biodiversity loss model by Chaudhary and Brooks (2018)
Visual landscape quality
Foreground/background: normalised composite landscape indicator (Schüpbach *et al.* (2020).
Results and discussion
Biodiversity and soil quality: The study illustrates that it is feasible to use models of different complexity, spatial resolution and data requirements for assessing the biodiversity and soil quality of the foreground and background system.
The methodical design of the suggested models applied to the foreground and background system differ significantly. Nevertheless, overlapping components of the two models allow to build submodels.
We face the challenge that the reference situation clearly differs between the foreground and background system, but harmonisation is possible for certain research questions.
Visual landscape quality: Preliminary results from initial applications show that the contribution from land occupied by the background system can substantially influence the land use impacts of a farm.
Conclusions
Biodiversity and soil quality: For the impact of agricultural activities on biodiversity and soil quality that, the models applied to the (local) foreground and to the (global) background system share certain conceptual similarities, which allows impacts calculated by the two models to be combined.
Visual landscape quality: The indicator for landscape visual landscape quality can simply be expanded to account for both foreground and background land use.

Keywords: *soil quality, biodiversity, landscape quality, LCA, background system*

Introduction

Production of food is one of the major determinants of environmental degradation at global scale and a driver of land use impacts. Assessment of land use impacts in agricultural LCA is challenging for several reasons. One is that a detailed knowledge on management practices on a field or farm (foreground system) and a specific assessment method are needed to assess the impacts. Another is that the impacts are strongly dependent on pedo-climatic conditions and spatial context. When a farm purchases inputs, we also need to assess the impacts of the upstream processes, which are in the background system. Collection of detailed and specific inventories of the foreground system (e.g. a farm) is feasible, whereas data on the background system (purchased inputs) are of generic nature, much less specific and detailed. There is thus a trade-off between the level of detail in the method and its universal applicability. It is unrealistic to expect a single method to be both specific and detailed, and at the same time globally applicable and work with generic data. A more promising solution is to combine two assessment methods, a detailed method for the foreground system and a generic method for the background system.

This paper discusses some of the challenges encountered when trying to include impact assessment methods that consider background processes and combine them with methods suited for the foreground processes for biodiversity, soil quality and landscape quality in LCA.

Material and methods

Soil quality: The impact of on-farm management activities on soil quality can be estimated using the SALCA soil quality model (SALCA-SQ) developed by Oberholzer *et al.* (2012), which contains nine soil quality indicators for physical, chemical and biological soil properties. SALCA-SQ assesses changes in these indicator values at the field level due to specific agricultural management activities.

LANCA® (LANd use indicator value CAlculation) is a method specifically developed for soil quality assessment within LCA (Bos *et al.* 2016). In order to assess the impact of land use on soil quality, LANCA calculates the following five soil functions at the midpoint level: (i) erosion resistance, (ii) physicochemical filtration, (iii) mechanical filtration, (iv) groundwater recharge and (v) biotic production. In LANCA agricultural soil management is condensed into a few agricultural land use classes.

Biodiversity: The SALCA biodiversity model (SALCA-BD) developed by Jeanneret *et al.* (2014) allows to compute the potential impact of management activities at plot and farm level on 11 indicator species groups (ISG). The model computes a score for each ISG, which can be aggregated to a single score per crop and per farm. The model allows computation of the so-called biodiversity deficit, as it provides a maximum score for each crop assuming "best possible" management.

The Chaudhary and Brooks (2018) model (CHBR) permits accurate determination of spatially explicit biodiversity loss at global level depending on the type and intensity of land occupation and transformation. CHBR computes the effects of land use changes on five indicator species groups (mammals, birds, reptiles, amphibians, vascular plants), leading to specific regional characterisation factors (CFs). This method is applicable worldwide, but it does not cover the effect of individual farm management practices such as tillage, fertilization or harvesting. CHBR is a further development of the method recommended by the UNEP-SETAC for estimating impacts on biodiversity related to land use in LCA.

Visual landscape quality: The normalised composite landscape indicator (CLI) for a farm can be estimated by the method of Schüpbach *et al.* (2020), which accounts for seasonal diversity and the farm's contribution to perceived naturalness. CLI consists of the arithmetic mean of

two sub-indicators. The first sub-indicator, area-weighted preference value (AWPV), essentially captures the aesthetic value of the landscape, while the second, aggregated diversity index (ADI), mainly considers landscape diversity.
Land use in the background system is computed with the commercially available LCA software tool *SimaPro*, using the ecoinvent database as a background database.

Results and Discussion
For reasons of higher explanatory power, it is reasonable to use different models for the foreground and background impacts of agricultural activities, since the framework conditions of processes in the foreground (i.e. on-farm processes) are known in much more detail than those of background processes. For instance, it is crucial that the effects of on-farm soil management activities such as tillage, crop establishment, fertiliser application, field traffic and harvesting on biodiversity and soil quality are accurately recorded and assessed. Furthermore, the foreground system is the primary field of action, where the management can be improved. However, the origin and production conditions for e.g. imported concentrate feedstuffs are often not well known. To assess background effects, it is therefore appropriate to use a model which does not need a detailed description of on-farm agricultural activities but rather acts on a more generic level, based on geographical and pedo-climatic site conditions.
In a pre-evaluation of biodiversity models, we found that SALCA-BD is ideally suited for assessing the impacts of agricultural activities on biodiversity in the foreground system, while the global model CHBR is optimal for accounting for the additional impact induced by upstream processes that take place in the background system. For evaluation of soil quality, including upstream processes, our model selection step revealed that on-farm soil quality (foreground system) can be accurately simulated by SALCA-SQ and the background system by LANCA. This distinction makes it possible to account for differing levels of knowledge regarding management practices, production conditions, soil conditions and production location.
Below, we illustrate and discuss some conceptual challenges arising when linking the foreground model with the background model. We focus on two main aspects: (i) Selection of the reference situation, and (ii) differences in methodological design between the foreground and background models.

Selection of the reference situation
Land occupation and/or transformation impacts caused by land use activities are quantified in relation to a land quality difference between two states, which thus requires a reference situation (RS) against which the actual state is compared. Numerous studies have shown that the definition used for the RS strongly influences the LCA results (Milà i Canals *et al.* 2007; Koellner *et al.* 2013). The following three options for RS are recommended by Koellner *et al.* (2013):

1) Potential natural vegetation (PNV): vegetation that would develop if all human influences ceased.
2) (Quasi-)natural land cover (NLC) in each biome/ecoregion.
3) Current land use mix (CLM): current composition of land-use types within each biome. For biodiversity, CLM can be expressed as current mean number of species (Köllner & Scholz, 2008).

Comparison of the methods selected to assess the effects of foreground and background systems on soil quality revealed that the RS definition in the two selected models differs. SALCA-SQ estimates effects of current soil management activities on soil quality by comparing them to a RS assuming site-specific sustainable agricultural land use according to "good agricultural practices". In LANCA, the user can decide which land-use type to use as the RS in a specific study. In an LCA study, we need to combine impacts of the foreground system with those of the background system to assess the full life cycle. This is not possible, if the reference states differ between the models. We therefore have to adapt one method to match the reference state of the other, i.e. we need to choose one of the three above options for both methods. Otherwise, it is not possible to aggregate all impacts and we can only perform a separate assessment for the foreground and background systems.

The two methods selected here for calculating the impact of land use and agricultural activities on biodiversity have fundamentally different RS. SALCA-BD uses the most positive management for each culture as its RS, whereas CHBR compares biodiversity damage per taxa against the natural undisturbed habitat (NLC), as its RS. Thus the biodiversity impact of an intervention, quantified as the difference between the quality of the land resulting from agricultural use and the RS, differs strongly between SALCA-BD and CHBR.

Conceptual design

Some of the indicators in SALCA-SQ and LANCA are closely linked, suggesting that the main conclusions of the two models may be similar for a specific study. For example, the soil function "erosion resistance" specifies the ability of the soil to resist erosion exceeding the naturally occurring level. The LANCA procedure for determining "erosion resistance" is based on the same methodological framework as the SALCA-SQ indicator "rooting depth", as both are linked to the risk of soil erosion. On the other hand, the LANCA indicators "mechanical filtration capacity", "physicochemical filtration capacity" and "groundwater recharge" rely on algorithms depending strongly on soil and site data (closely resembling pedotransfer functions) and considering only one or a few management impact factors. For the foreground system, SALCA uses actual soil management inventory data and an expert model approach to consider anthropogenic impacts in a differentiated way.

The methodical design of SALCA-BD and CHBR also differs substantially. However, there are also certain similarities between the two methods which can help to derive one single, final composite biodiversity deficit score covering both the foreground and background systems. Both methods calculate changes in the number of certain species and three of the five taxa considered in CHBR (mammals, birds, reptiles, amphibians, vascular plants) are among the indicator species groups assessed in SALCA-BD (mammals, birds, amphibians). The same applies to land use types: SALCA-BD differentiates between arable crops, grassland and semi-natural habitats (SNHs) (e.g. extensively managed and low-input meadows, wild-flower strips, hedges), which partly match three of the six land use types suggested in CHBR (annual crops, permanent crops, pasture). Another feature shared by SALCA-BD and CHBR is that they both account for vulnerability of a taxon (or species group) in a certain ecoregion (or farmland type). In summary, despite crucial methodological differences between the SALCA-BD and CHBR approaches, through model simplification and adaption it should be possible to build "submodels" containing overlapping model components that can be directly compared.

Calculation of the indicator CLI differs from calculation of biodiversity and soil quality, since the required input data for CLI comprise solely the areas occupied by different land-use types (crops, grassland and semi-natural habitats). The foreground CLI can easily be computed using farm survey data. Assuming the same preference values for the foreground and background system, computation of the background CLI only requires data on the land area occupied by upstream chains, as retrieved from the background database ecoinvent.

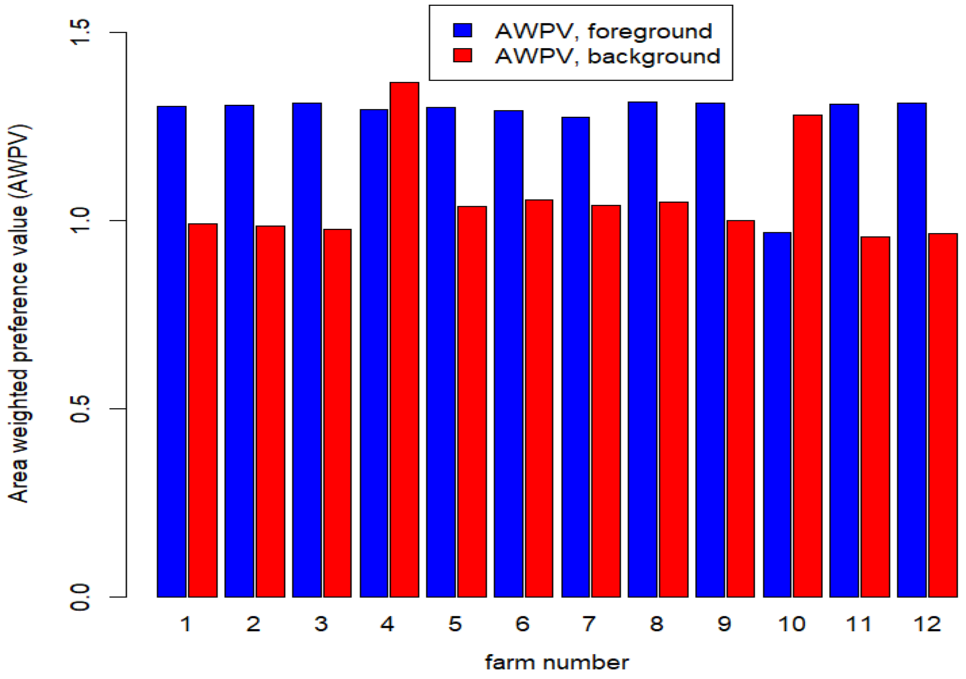

Figure 1. Area-weighted preference value (AWPV) for both the foreground and background system, based on data from 12 dairy farms analysed in the project 'Hohenrain 2' (Zumwald *et al.* 2018).

This method was applied to data retrieved in the project Hohenrain II (Zumwald *et al.* 2018), which compared three production systems: full-time grazing with reduced concentrate supplementation and partial grazing with reduced/ increased concentrate supplementation. The background processes included all land occupied for off-farm feed production, but excluded land required for production of machinery and energy, since no preference values are available for built-up areas.

The sub-indicator AWPV for both the foreground and background systems is shown in Figure 1. As can be seen, the on-farm AWPV is generally significantly higher ($p=0.0002$) than the AWPV for upstream processes. This derives from the fact that purchased (concentrate) feed often consists of crops that are generally assigned lower preference values than (extensive) grassland and semi-natural habitats.

Further development is needed to make the modelling system fully operational, e.g. to fully combine the two assessment approaches into a single impact indicator. This is critical for comparison of farms regarding all three impacts (landscape quality, biodiversity, soil quality) in line with LCA principles.

Conclusions

We present a framework that can be used in LCA to explore land use impacts on biodiversity and soil quality by treating the foreground and background systems in different ways. For reasons of improved interpretability and higher informative value, we suggest assessing foreground processes using a detailed model that accounts for the impacts of agricultural activities on biodiversity and soil quality, and assessing background processes using average or more generic data. Successful combination of the two models for evaluating background and foreground processes requires detailed analysis of differences in their general design. Our evaluation shows that, despite major differences, these models share also conceptual similarities, which allows impact assessments computed by the two models to be linked.

Concerning visual landscape quality, the same method can be applied to both the foreground and background systems, assuming that preference values are independent of country.

Preliminary results from an initial application showed that the contribution from land occupied by the background system may be substantial.
Further development is needed to make the modelling system fully operational also for soil quality and biodiversity. This is an essential precondition for comparison of farms concerning all their environmental impacts, in line with LCA principles.

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Abstract code: 92

Empirical knowledge to improve terrestrial ecotoxicity characterisation of trace elements with USEtox

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Abstract

USEtox is the consensus model for toxicity in LCA, yet it does not provide characterisation for terrestrial ecotoxicity. Owsianiak et al. (2013) suggested a new framework able to account for soil physical-chemical properties to characterise terrestrial ecotoxicity for trace elements. The performance of this USEtox-based Owsianiak framework was herein tested in the context of soil contamination by copper (Cu) and zinc (Zn) following the application of livestock faeces. To do so, one French soil sample exhibiting properties representative of the main average properties of European soils was incubated under laboratory controlled conditions alone or with the application of 31 swine or poultry faeces collected from experimental pens where livestocks was fed with different rate of Cu and Zn complements. The main endpoints of Cu and Zn availability in soils calculated in the Owsianiak framework were determined analytically on each of the 32 experimental treatments, namely: i) reactive Cu and Zn extracted with 0.43 M HNO_3, ii) total Cu and Zn in extracted soil solutions, and iii) free ionic Cu and Zn in extracted soil solutions. The single value for the intermediate endpoints (i.e. fate, accessibility, bioavailability, and effect factors) and the comparative toxicity characterisation factor calculated with the Owsianiak framework for Cu using the initial soil properties were within the range of values computed by Owsianiak et al. for a variety of global soils, thereby validating the hypothesis about the representativeness of the chosen soil. From an experimental point of view, the application of swine and broiler faeces to the soil induced substantial changes in soil pH and dissolved organic carbon concentration compared to the non-amended control soil. These chemical alterations of soil solution chemistry in faeces-amended soils induced a significant decrease of Cu^{2+} activity for 19 out of 31 faeces compared to the non-amended soil. These observed variations suggests consequently that intermediated endpoints determined for each experimental treatment will likely show some discrepancies with those determined theoretically with the Owsianiak framework, thereby opening the discussion to suggest some potential improvements.

Keywords: bioavailability; exposure; fate; speciation; trace metals

Introduction

Organic waste (OW) is increasingly being used as a source of nutrients for crops and organic matter for soils, via agricultural recycling. OW-borne contaminants, including trace elements (TE), are transferred to soils when OW is spread. Once in the soil, the fate of TE depends on several factors, which include its original chemical forms (i.e. speciation) in OW which itself depends on the treatment (e.g. composting, anaerobic digestion, storage) OW may undergo before spreading and the soil physical-chemical properties (e.g. pH).

USEtox is the consensus model for toxicity in LCA, yet it does not provide characterisation for terrestrial ecotoxicity, due to the complexities of its modelling, the paucity of terrestrial toxicity data, and other constraints (e.g. the concentration threshold for considering a TE as a contaminant or as a micronutrient). USEtox research has contributed evolving models for the estimation of terrestrial ecotoxicity (e.g. Owsianiak et al. 2013; Plouffe et al. 2016).

In such context, the SUMINAPP project (https://www.suminapp.eu/) produced empirical research on the fate and bioavailability (two key elements for the characterisation of trace elements in USEtox), and integrated the results within the Owsianiak et al. (2013) approach to i) validate it and reduce the uncertainty of its results by comparison with experimental characterisations, and ii) identify neglected mechanisms that should be integrated in a future terrestrial ecotoxicity framework.

Material and methods

Two strategies were followed. First, the USEtox-based Owsianiak et al. (2013) framework (comparative toxicity = fate x exposure[= accessibility x bioavailability] x effect) was applied to measured data from a specific soil from the French Qualiagro experimental site (Noirot-Cosson et al. 2016), which physical-chemical properties compatible with those of the "standard" USEtox soil.

Second, the predicted constituencies of the comparative toxicity characterisation factor were contrasted with results from laboratory tests on the Qualiagro soil. The soil was incubated for 26 d under laboratory controlled conditions alone (i.e. the non-amended soil) or with 31 animal faeces (see Tella et al. (2016) for experimental details). The faeces consisted of swine (8 and 11 from pigs and piglets, respectively) or broiler (7) faeces sampled from experimental pens where alternative dietary (i.e. Cu and Zn feed complements) treatments and an aging process (with or without) were tested.

The main endpoints of Cu and Zn availability in soils calculated in the Owsianiak framework were determined analytically on each of the 32 experimental treatments, namely: i) reactive Cu and Zn extracted with 0.43 M HNO_3, ii) total Cu and Zn in extracted soil solutions, and iii) free ionic Cu and Zn in extracted soil solutions as measured for Cu with an ion selective electrodes or estimated for Zn by modelling using WHAM (Tipping et al. 2011) and chemical properties measured in soil solutions.

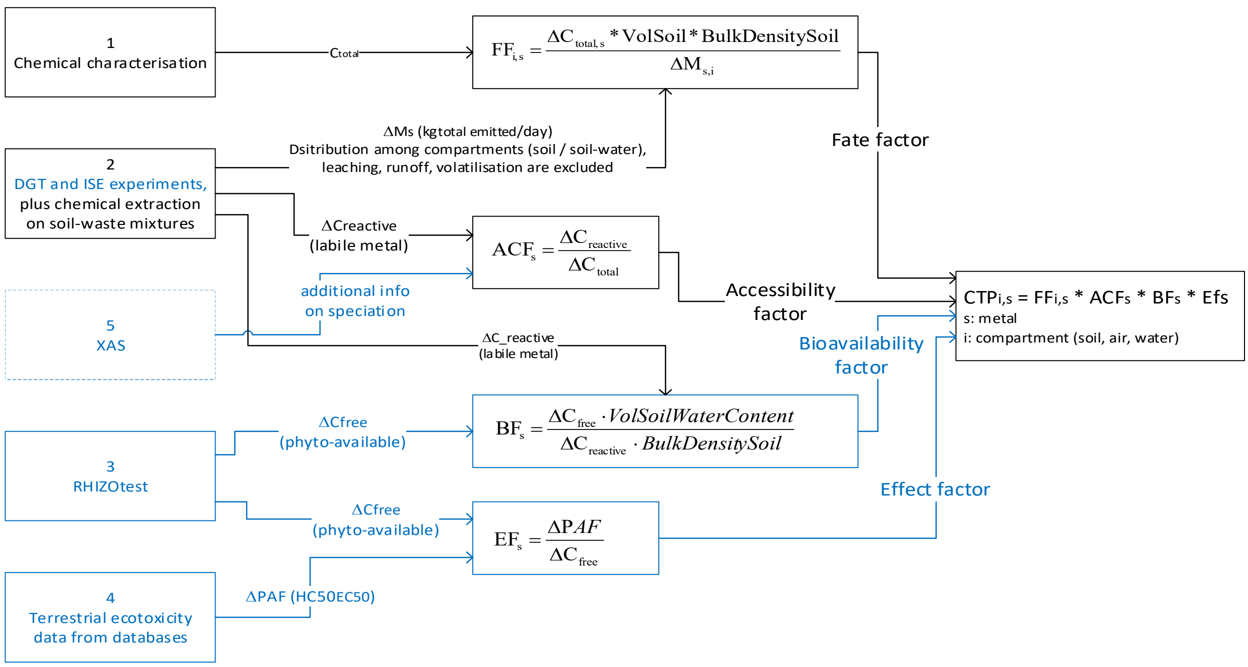

Fig. 1. Data sources to inform terrestrial ecotoxicity of trace elements with USEtox (elements in blue represent work in progress)

Consequently, the intermediate endpoints (i.e. fate, accessibility, bioavailability, and effect factors) and the comparative toxicity characterisation factor calculated with the Owsianiak framework for Cu and Zn using the initial and fixed soil properties was compared to those determined on each of the 32 experimental treatments. Fig. 1 summarises the different ecotoxicity determination elements.

We implemented the Owsianiak approach in Excel, and were able to compute predicted values for the comparative toxicity characterisation factors for Cu and Zn using Qualiagro soil characteristics.

Results and discussion

The application of swine and broiler faeces to the Qualiagro soil induced substantial changes in the solution chemistry and Cu and Zn availability of soils compared to the non-amended soil (Fig. 2). Soil pH tended to either increase or decrease with the application of 13 out of 31 faeces, with a significant increase observed for three aged pig faeces (Fig. 2a). Soil DOC increased significantly for all faeces applications compared to the non-amended soil and up to four-fold with some piglet faeces applications (Fig. 2b). These chemical alterations of soil solution chemistry in faeces-amended soils induced a significant decrease of Cu^{2+} activity for 19 out of 31 faeces compared to the non-amended soil. All these modifications of chemistry and Cu speciation in the solution of faeces-amended soils were in agreement with recent results obtained under realistic field conditions (Laurent et al. 2020). Accordingly, this experiment seems adequate to evaluate the robustness of the USEtox-based Owsianiak framework in the context of OW-amended soils.

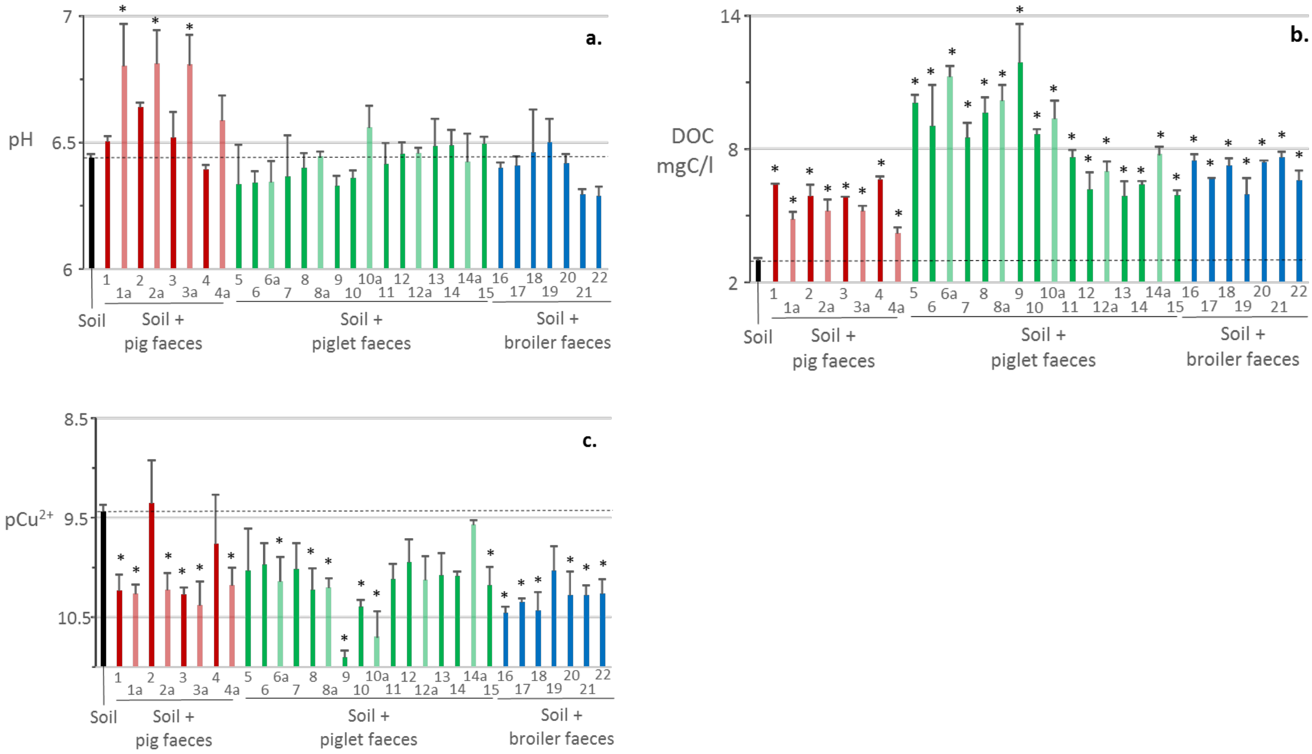

Fig. 2. Acidity (pH, a.), dissolved organic carbon (DOC) concentration (b.), and free ionic copper activity (pCu^{2+}, c.) measured in the non-amended soil (soil) and in the soil amended with 31 swine or poultry faeces. Some faeces were aged (a). Dashed lines correspond to the mean value measured in the control. Stars correspond to faeces applications that had a significant effect (ANOVA with Fisher, then HSD Tuckey tests; $p \leq 0.05$) on pH, DOC, and pCu^{2+} compared to the control soil

The characterisation factors computed with the Owsianiak approach by using the initial and fixed soil properties are within the range of values computed by Owsianiak et al. for a variety of soils all around the world (Fig. 3). These results consequently support the hypothesis about the representativeness of the chosen soil as compared to the world soil database considered by Owsianiak et al. (2013) when implementing its new USEtox framework.

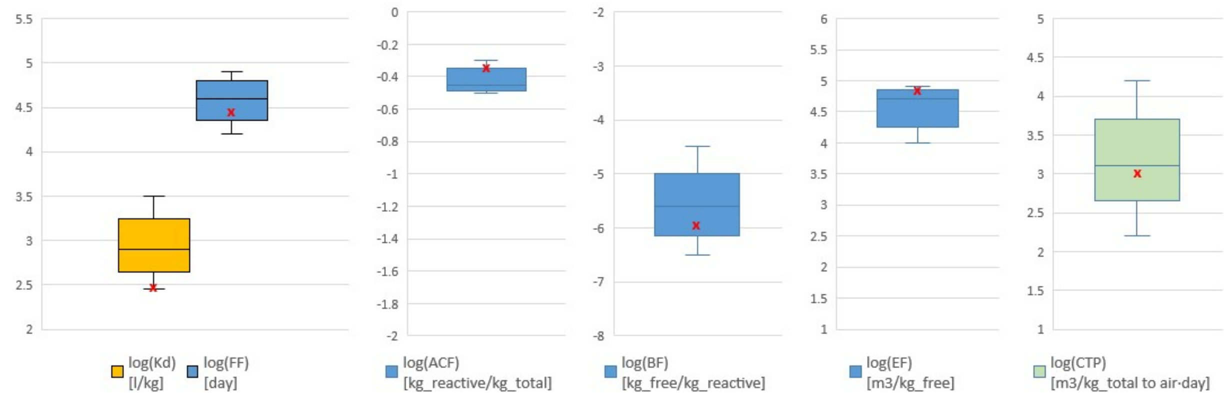

Fig. 3. Range of results obtained by Owsianiak et al. (2013) vs. our computed values (x) for Cu using the Qualiagro soil (no reference results were available for Zn)

Perspectives

Due to COVID19-related delays, the final part of the dataset on soil Cu and Zn availability has not to date been statistically treated. However, the results already treated showed that the application of livestock faeces to soil induced substantial changes in the chemistry and Cu speciation of soil solutions compared to the non-amended soil. These variations thus suggests that fate, accessibility, and bioavailability factors determined for each experimental treatment will likely show some discrepancies with those determined theoretically with the Owsianiak framework. Once the last experimental data will be treated, the whole dataset will be used to compare the CTP of the default Owsianiak framework results with the 32 CTPs based on measured values of total Cu and Zn concentration in soil solution as the main parameter used to compute the fate factor, of reactive Cu and Zn concentration in soil as the parameter used to compute the accessibility factor, and of Cu^{2+} and Zn^{2+} activity as the main parameter used to compute the bioavailability factor. Such results would enable us to open the discussion for suggesting some potential improvements of the Owsianiak framework.

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Poster Presentations

Topic 1:

Planetary Boundaries:

Biodiversity and Ecosystem Services

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Continuous CO_2 emissions from soil can have a major role in climate impact of diet and its mitigation

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Abstract

LCA-based scientific research has shown that global dietary change towards highly plant-based diet plays a major role in turning our lifestyle to climate friendlier and more sustainable. The IPCC report on climate change and land (2019) highlighted, in addition to the balanced diet and global reduction of greenhouse gas emissions, policies that support sustainable land management to keep carbon in the ground, as well as to ensure the supply of food. By now, sustainable land management is not sufficiently covered in food LCA. With regard to climate change, particular attention should be paid to changes in soil carbon stocks, and their associated carbon dioxide (CO_2) emissions, since they affect both atmospheric emissions and removals. Its impact potential is largely territorial and dependent on agricultural practices. In this study, soil carbon issue was integrated to the comparative climate impact assessment of the current Finnish diet and modified diets which were targeted to comply with the Finnish national nutritional recommendations. Alternative diets considered were: 1) halving meat, 2) reducing meat to a third, 3) fish and 4) vegan diet.

The climate impact and nutritional quality of diets were evaluated using the Food Minimum diet model built in the project. The model is based on product group level climate impact estimations and nutrient composition for foods, and consumption of product groups divided by gender and eight age groups. Data on climate impact estimations were from Luke's previous research on Finnish food products as well as literature. Nutrient composition of foods was from Finnish food composition database and food

consumption in the current diet was mainly from the food consumption survey. The CO_2 emissions from the change in the carbon stock of Finnish arable land were added separately as they are not included in the life cycle assessments of the products. It was assessed on a basis on agricultural land area needed to cover the consumption of the product groups as well as soil types and their unit emissions. Because of considerable uncertainty involved in estimating changes in carbon stocks, two different approaches was applied: the results of long term soil monitoring and modelling results of the method used in the National Greenhouse Gas Inventory. Consumers' food waste was was also included based on product group level data from previous empirical studies in Finland, as well as rough estimation for energy consumption of food preparation. Scenarios that assumed soil carbon balance to be achieved 1) in bovine production chain or 2) in cultivation of mineral soils, or 3) both were used to evaluate how potential reduction in the carbon flow from soil could affect the comparative climate impacts of the diets.

According to the results, soil CO_2 emissions due to decomposition of soil organic matter in Finnish agricultural land accounts for 18 – 23 % of the climate impact of diets. This share is significant, and it has to be taken into account when climate actions are designed. The result is in accordance with the National Greenhouse Gas Inventory. Results from carbon scenarios shows that balancing carbon stock reduces the climate impact of diets containing animal products far more than the climate impact of vegan diet. This is because a large part of cattle-based production is on organic soils, and in Finland most soil carbon emissions are caused by cultivation of organic soils. By balancing the soil carbon stocks, the climate impacts of ‘meat to third’ and ‘fish’ (with milk products) diets are quite close to that of vegan diet. On the other hand, the effects of agriculture based on solely or mainly plant cultivation on carbon stocks of agricultural soils in Finland are largely unknown, and thus they should be profoundly studied as dietary change seems to be necessary.

The study was carried out in The FoodMinimum Project, which was funded by the Finnish Government Office.

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Environmental impact of European Food Basket

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Abstract

Problem

Consumers are one of the key actors to achieve a sustainable food system. Most of them could actively choose between different food alternatives. Considering that, different initiatives are trying to promote more sustainable consumption patterns. However, to create confident and efficient communication, current patterns and best alternatives should be clearly defined.

For that purpose, we have measure and explore environmental impact linked to the European Food Basket (EFB).

Methods

Data for the European food consumption where taken from the FAOSTAT dataset. Food categories covering 90 % of the total food consumed in the Europe were selected. A representative product for each food category was identified to build the inventory. For selected products the following assumption where considered:

- **Primary production** inventory data was selected from Ecoinvent and Agrifootprint datasets.
- **Food processing** data was obtained from literature data [1, 2] representing most common processing steps for each product category.
- Different **packaging solutions** per product type were selected [III].
- **International distribution** of the imported products was defined based on the import-export data from EUROSTAT dataset.

- **Retailing stage** inventory data was obtained from the OEF screening report [IV] based on the occupation, storage temperature and time of each product at the supermarket [IV]
- The inventory data for the **consumption stage** was defined based on the OEF screening report [IV] and considers transport, storage and cooking of the food products at home
- Finally, biowaste and packaging **end-of-life** was considered. For the biowaste generation, ratio published by OEF retail was assumed [IV]

Results

In the table 1 summary of the environmental impact of the European food basket per person and year is presented.

Table 1 Environmental impact of EFB.

Impact category	Unit	Value
Climate change	kg CO2 eq	9,70E+01
Ozone depletion	kg CFC-11 eq	6,92E-06
Human toxicity, non-cancer effects	CTUh	4,19E+00
Human toxicity, cancer effects	CTUh	5,72E-01
Particulate matter	kg PM2.5 eq	1,12E-05
Ionizing radiation HH	kBq U235 eq	1,96E+00
Photochemical ozone formation	kg NMVOC eq	7,12E-01
Acidification	molc H+ eq	7,83E+00
Terrestrial eutrophication	molc N eq	8,56E+03
Freshwater eutrophication	kg P eq	2,84E+01
Marine eutrophication	kg N eq	7,39E+02
Freshwater ecotoxicity	CTUe	1,43E-04

Interpretation

As expected, animal products such have the highest environmental impact. Besides, following barriers have been also identified among others:

- International distribution have more significance for vegetable and fruits.
- For animal origin products primary production practices are more relevance
- Food production has high water consumption, thus production of water demanding crops in high water-stressed countries should be avoided,
- End of life and cooking requirements, are significant for products requiring water or oil for the preparation or with high biowaste production

Those specific concerns has been worked out to define effective recommendation for consumers.

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Biodiversity footprints from EE-MRIO

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Abstract

Environmentally-extended multi-regional input-output (EE-MRIO) analysis is an increasingly accessible option to establish country-level environmental consumption footprints to inform policy. A new tool hosted by the UNEP Lifecycle Initiative called Sustainable Consumption and Production Hotspots Analysis Tool (SCP-HAT) makes such footprints easily accessible for 171 countries. For the period 1990-2015 it covers a range of different pressures, such as land use, and impacts, such as biodiversity loss.

For impact characterization, the tool follows the recommendations made by the UNEP Lifecycle Initiative where possible. For biodiversity, the recommendation is to use characterization factors (CFs) derived by Chaudhary et al. (2015). The challenge is to develop an approach that is scientifically robust and consistent for all countries, and allows for the use of these CFs.

Land use time series are required for six categories: Annual crops, Permanent crops, Pasture, Urban, Extensive forestry and Intensive forestry. Data were derived from the FAO Land Use database, OECD built-up area data, and the FAO Forest Resource Assessment. For forestry, combinations of different use categories were made to match Extensive and Intensive forestry (Piñero et al. 2019). The country-level land use data were correlated with the areas derived from high-accuracy spatial mapping (Hoskins et al. 2016), yielding correlation coefficients of 0.98 and 0.97 for crop land and pasture land, respectively.

SCP-HAT uses the EORA input-output model, with 26 disaggregated sectors. While MRIO models cover formal economic activities only, the land use data also cover informal economic activities such as subsistence farming or firewood collection. Therefore, a fraction of land use is allocated directly to households. The allocation factors have been derived at country level from the Spatial Production

Allocation Model version 2010 (SPAM) for agricultural land, and for forestry from the UN Energy Statistics Database and Furukawa et al. (2015).

Global land use for agriculture (cropping and pasture) is roughly constant at 4.8 GHa (67% of total land use) with an associated biodiversity impact of slightly over 80 milli-PDF*yr (77% of total global biodiversity impact). Globally, 30% of biodiversity loss from crop land and 28% of biodiversity loss from pasture land is allocated directly to households. For individual countries, the allocation to households may be as high as 99% (Namibia) for annual crops. For permanent crops, the allocation to households is typically lower because many developing countries produce high-value crops such as cocoa and coffee that are exported.

Currently, SCP-HAT only discerns one sector for agriculture, which means crops and livestock products cannot yet be distinguished in the trade flows and footprints. Further work is planned to evaluate options to increase sectoral resolution as well as to add impact categories.

The tool is freely available online and will provide invaluable information to countries around the globe to develop effective SCP policies. It is essential to have biodiversity loss as one of the metrics, to ensure that this important issue is included in those policies.

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Assessing environmental and social impacts for current and future food consumption – challenges in scenario construction and LCA methods

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Abstract

Rationale Legumes for sustainable food system and healthy life- project establishes a food-system wide basis for transition from current practises, including primary production and dietary habits, towards climate-neutrality with increased utilisation of legumes. The project concentrates on grain legumes feasible to be cultivated in Finnish climate and assess their increased utilisation throughout the food system from primary production to raw material processing for feed and food industry, food services and to consumers, taking into account non-food legume side streams and food waste, and the overall impact on sustainability. The project creates scenarios (from 2020 to 2035) with increased legume production and consumption in Finnish food system and determines the regarding sustainability impacts.

Methods Approach includes baseline scenario with business-as-usual food system and alternative scenarios for the food system which are under impact of different environmental, social, economic and policy drivers. Utilized information in constructing these scenarios includes statistical and research data for production and consumption of food stuffs with inclusion of import and export statistics of Finland. For the future scenarios the drivers are considered through local and global pressures and constraints from environment, society and policy. These drivers include changing climate conditions, attitudes of consumers, well-being and economy of the production chain and also drivers from changing policy.

Environmental Life Cycle Assessment (eLCA) is conducted according to IPCC and ILCD (JRC 2010) guidelines for selected impact categories (GWP, eutrophication and land use). Assessments are done in several levels, i.e. for primary production of legumes and raw milk and increased utilization of legumes in national scale healthy diets, constructed based on the future scenarios. The Social Life Cycle Assessment (sLCA) methodology is implemented to compare social impacts of a current typical Finnish dairy production system to a system where the technological innovations are developed for primary production to increase legume production. sLCA focuses on the assessment of selected social impacts and is conducted following the basic framework and guidelines developed by UNEP/SETAC (2009 and 2013). This study is utilizing the Product Social Impact Life Cycle Assessment database, PSILCA (Greendelta 2017) which enables detecting the low and high risk values as hot spots for different social impact categories in the production chains based on country specific general level information. In addition, the possible lacking data is revealed and the production chain stakeholders are interviewed to gather sufficient data from the social impacts and supplement the analyses. The health impacts are built on estimations based on the literature, interviews and project outputs.

Results The scenarios for future food consumption includes variable drivers from environment, society and policy. While the scenario construction is kept as realistic as possible, the challenge in assessing the environmental and social impacts of the scenarios was found in resolution of the currently available methods. By combining available eLCA, sLCA with qualitative methods, potentially feasible resolution can be found. For sLCA more detailed methods for regional assessments are needed. sLCA would also benefit from development and inclusion of new impact categories, e.g. the welfare of the animals.

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Using of Biodiversity Loss Indicators for Life Cycle Assessment (LCA) in assessment of feedstock to production of biofuels in Brazil

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Abstract

Abstract

Problem and aim

Biofuels are energy substances produced from renewable biomass, such as biodiesel and ethanol. As a world pioneer in the use of biofuels, Brazil is the second largest producer of ethanol, from sugarcane, and the second largest biodiesel in the world, mainly, from soybeans (ANP, 2020). It is recognized the benefits from the replacement of fossil fuels for biofuels. However, the need for fertile areas for the production of feedstock can be a problem for it sustainability, due to.the expansion of agricultural areas and the intensification in the consumption of food, fibrous and energy. Biofuels have been questioned about their environmental impacts, mainly those related to the land use change, and the biodiversity loss and its ecosystem services. Life Cycle Assessment (LCA), as a methodology determines and attributes environmental impacts directly from products (Hellweg & Mila i Canals, 2014), can be used for

assessing the impacts from both biofuel production and its feedstock. Thus, LCA has received efforts to include biodiversity impacts in its assessments (Curran et al., 2016). The UNEP/SETAC Life Cycle Initiative have created a guide on biodiversity impact assessment, also provided a definition of the next steps to develop it, as the production of feedstock needs an effective assessment of their impacts on biodiversity. Therefore, the aim of this study is to assess the impact of the production of feedstock - soybeans and sugarcane - on the biodiversity in Brazilian biomes, for the production of biofuels.

Methods

The potential global damage to biodiversity (BD_{Global}) was determined according to Chaudhary and Books (2018). Characterization Factors (CF) for determining BDs can be applied by taxonomic groups (taxa) or being in aggregate values. For this study it was considered for taxa – mammals, birds, reptiles, amphibians and plants. Impact assessment was carried out for soybean and sugarcane crops for the six ecoregions present in Brazil – Amazon, Atlantic forest, Caatinga, Cerrado, Pampas and Pantanal.

Results

For soybean production, the most impacted ecoregions were Atlantic Forest, Cerrado the Amazon. The damages suffered are mainly observed at the taxa of plants, amphibians and mammals. For sugarcane production the highest damage was caused in the same ecoregions and taxa as soybean. However, the highest damage to Amazon and Cerrado came from soybean cultivation, while to the Atlantic Forest came from sugarcane cultivation, Fig. 1.

Discussion/Interpretation

The three most damaged ecoregions – Atlantic forest, Cerrado and Amazon – presented the most extensive cropland and highest CFs. As. In addition, some ideas to work with biodiversity are suggested: evaluating alternatives for reduction the damaged to change the intensity of the crop, providing a better use of the areas with the inclusion and interaction of other crops.

Key-words: Biodiesel; Ethanol; Environmental impact; Global potential damage.

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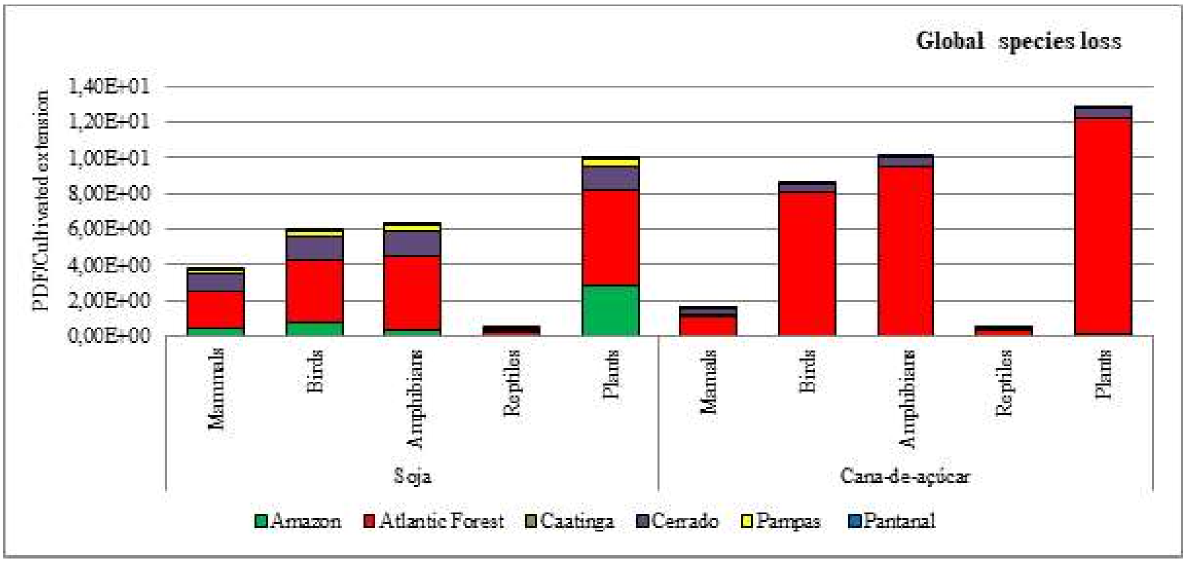
Figure 1. Potential loss of species (m^2) in the Brazilian ecoregions (Amazon, Atlantic forest, Caatinga, Cerrado, Pampas and Pantanal) by biofuel feedstock production in its territory (Soybean and Sugarcane)



Topic 2:

Livestock Production:

Beef and Dairy

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PROTECT: Managing climate change scenarios and its implication in the dairy sector under a life cycle perspective

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Abstract

Problem and aim:

Climate change leads to temperature rise, changes in water availability, and rainfall patterns, amongst other significant effects, impacting the agriculture production and dairy sector, two systems closely connected. Although being a global phenomenon, the effects are not expected to be regionally uniform [1]. Besides being very susceptible to climate change, at the same time the dairy sector is a significant contributor to this global threat. The whole dairy supply chain is prone to climate change effects, but it is clear that the primary production phase represents the largest share [2]. This study aims to analyze the bidirectional interlink (effect-impact) of climate change and dairy sector. A multi-region approach is considered to address the climate variability among regions. Also, taking snapshots with the use of scenarios will provide us a better picture of the future interdependence.

Methods:

A literature review was carried out to investigate the system dynamics and the interlink of climate change and the dairy sector. Then, the Representative Concentration Pathways (RCP) scenarios by the Intergovernmental Panel on Climate Change (IPCC) were consulted to define the time horizon. These

scenarios allow a long-term assessment to 2050 due to its long-term projections [3]. Additionally, a hybrid of product and multi-regional Input-Output (IO) LCA aid to estimate the impact (carbon footprint and water footprint) on climate change.

Results:

A new step-by-step methodology to model this interlink is proposed. Firstly, regions are defined giving the expected effects of climate change on the dairy sector. Secondly, a definition of the time horizon depending on the climate scenarios used. Then, direct and indirect effects are estimated, thus crop availability and regions prone to heat stress are located. The fourth step aims to quantify the current impact of the dairy sector, a life cycle inventory is built up with a hybrid approach, i.e. combining product and IO LCA. Special focus is going to be paid to avoid double counting. Lastly, in the fifth step, the future environmental impact to 2050 is modeled considering the effects of climate change previously estimated (figure 1).

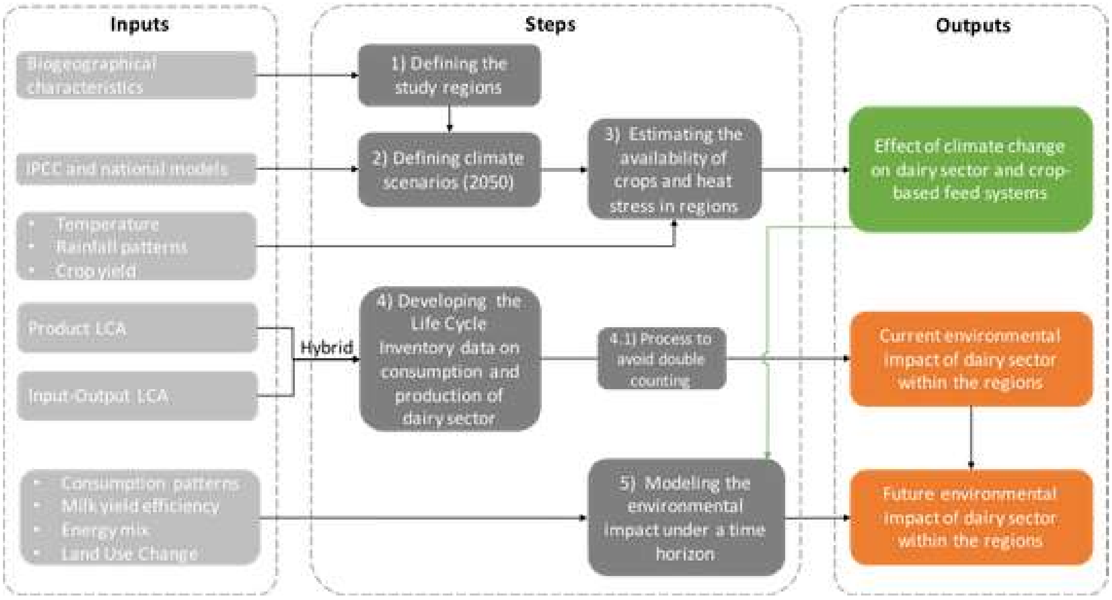

Figure 1. Steps proposed to assess the interlink.

Discussion:

The outcome of this research is expected to aid the dairy sector in two views, i) to create measures to address the impact of the dairy sector on climate change with the adoption of sustainable practices, and ii) to create strategies to address the effects of climate change on the dairy sector. Regarding the latest, climate change might contribute to increase the safety food risks due to the exposure of spoilage organisms and pathogens. There is an urgency to address food safety while reducing the environmental impacts of dairy products and dealing with the microbial risk due to temperature increase [4]. Within the WP5 of PROTECT (http://www.protect-itn.eu) our activities are dedicated on the combination of the Risk Assessment and LCA to improve the environmental sustainability of the dairy products value chains.

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A framework for comparative evaluation of sustainability of livestock products

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Abstract

Livestock products are a substantial source of global climate and environmental pressures. They represent a large part of the environmental burden of food, especially in developed countries. Over-consumption of livestock products has also adverse health implications. Because of these disadvantages there is considerable pressure to reduce the consumption and production of livestock products in developed countries and try to keep their growth moderate in developing countries. On the other hand, livestock products are rich in essential nutrients, some of which are of animal origin only. Livestock products are also an essential part of Western food culture and of current agricultural and food production systems. However, the role of animal products in diets and agricultural systems vary between Western countries. For example, in Finland as the most northern agricultural country in the world, livestock production currently is a basis for the agricultural and food production as a profitable

business, as well as for food security due to limitations in crop production. Pressure to reduce livestock production is perceived as a threat to domestic food production and self-sufficiency. Livestock production practices, such as feeding, also differ from country to country, which can lead to differences in the environmental impacts of livestock products. In Finland, for example, sustainability of domestic livestock production has been systematically developed, but has not yet been comprehensively verified. There is a clear need for an assessment approach that takes the country-specific overall sustainability into account. In this study, we applied a systemic approach to assessing the sustainability of livestock products. We provide a framework, criteria and indicators for assessing the overall sustainability of livestock products. The approach also allows comparison of products from different countries. The framework is based on FAO's definition on sustainable food and agriculture, and sustainable diet. The criteria and indicators cover aspects in products (e.g. LCA), production (e.g. biodiversity, vitality of rural livelihoods) as well as consumption (e.g. nutritionally adequate diet). The criteria and indicators are currently being developed in multidisciplinary way and in cooperation with Finnish stakeholders. By using finalized approach, the country specific food system and its sustainability can be taken into account in the sustainability assessment of livestock products. The approach will be applied to the comparative assessment of Finnish livestock products and imported products from the main importing countries.

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Evaluation of environmental impact of livestock production and products in selected EU countries

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Abstract

Intensification of European farming systems during last decades has increased productivity, but consequently led to increased pressure on the environment. Assessment tools such as agri-environmental indicators and life cycle assessments (LCA) are widely used for the evaluation and quantification of the environmental impact of livestock production. However, results are likely to be depended on assessment method, selected impact category and which functional unit is used. Assessment methods based on agri-environmental indicators yield results that show extensive farming systems more environmentally favourable options, whereas product based LCA often shows lower

impacts from intensive systems mainly due to higher yields. In addition, environmental pressure of livestock production varies across different regions in Europe due to different agricultural management practices and climate conditions. Countries differ in number, density and distribution of the domestic animal species. We will pool both the environmental and production data in a literature survey that use different frameworks for evaluating environmental impact of the agriculture and more specifically livestock production. We aim to 1) compare environmental impact of livestock production and products and 2) compare results of agricultural indicators with LCA results at a country level. The specific aim is to compare environmental impact of Finnish livestock production to selected EU countries. The study indicates that a combination of agri-environmental indicator based assessment methods and LCA together could provide more reliable information about the environmental sustainability of farming than LCA alone.

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Effect of beta-casein variant on milk quality and environmental impact of milk production

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Abstract

Problem and aim: In the last twenty years great interest has been directed for polymorphic milk casein for their nutritive and technological possible benefits in particular for beta-casein and its 13 protein

variants. The most common variants in Holstein–Friesian cattle are A1 and A2, others are rare. Many studies aims to verify if the A1/A2 polymorphism has a relationship with milk performance traits. Ng-Kwai-Hang et al (1990), Olenski et al (2010) found that the allele coding the A2 protein variant increases breeding values for milk and protein yield while no variation was observed for fat yield. In LCA studies on milk production, international rules (IDF, 2010) recommended as functional unit (FU) milk fat and protein content (FPCM). Recently some authors (Rice et al., 2019) suggested a FU based on milk quality payment that combine nutritive, hygienic and economic values of milk, valorising the farmers work and dairy processor interest. The aims of this study were to verify the environmental advantage of producing milk with different beta-casein variants. Moreover two FU units were tested to underlain the global value of milk.

Methods: Milk quality traits of 30 dairy cows bred in the same dairy farms were considering as inventory data for environmental impact evaluation of milk production, using LCA approach. Milk beta-casein content showed the following variants A1A1, A1A2, A2A2. Starting from primary data collected in the farm a simulation of three different herds with 100 dairy cows for each variants were considered. Two functional units were tested: FPCM and BPAM, base-price adjusted milk (Rice et al., 2019). Dairy farm gas emissions, from manure, were calculated using IPCC (2009) and EEA (2009) equations, for enteric methane emission Moraes et al. (2014). Global Warming Potential (GWP) were evaluated using CML-IA baseline V3.01 / EU25.

Results: Different beta-casein variants affected milk production traits. Herd with A2A2 had higher milk yield (+0.64% kg /head), fat (+4,2%) and protein (+1.14%) percentage compared to A1A1. Total bacterial count was lower in A1A2 then A2A2 milk (25119 vs 35481 CFU/ml) while lowest value of somatic cell count was obtained in A2A2 milk (95246 n/ml).

GWP values express with the two different FU (FPCM and BPAM) are in figure 1. The higher milk quality and quantity of A2A2 respect to A1A1 milk gave a lower environmental impact: -2,85% for GWP as FPCM. When BPAM is considered, the difference among the two homozygous milk type was reduced: -1.35% due to small difference on total bacterial count.

Discussion: As expected total milk production is the main driver of environmental impact so breed with the high milk productivity showed the best performance. The use of the two function units gives the possibility to underlain the total quality of milk not only nutritive value but also hygienic characteristics that are closed link to the farm management ability of farmers.

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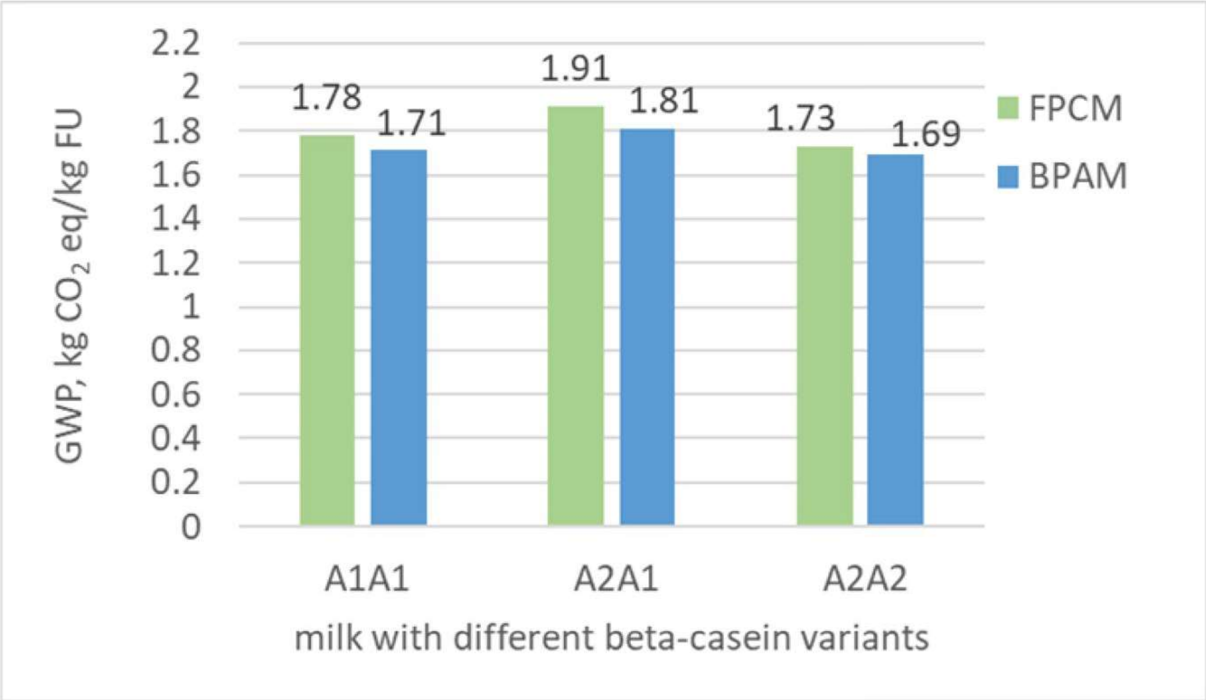
GWP, kg CO_2 eq/kg FU
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.78
1.71
1.91
1.81
1.73
1.69
FPCM
BPAM
A1A1
A2A1
A2A2
milk with different beta-casein variants

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PROTECT: Looking at improving the environmental sustainability of the dairy products value chains by the combined use of LCA and RA

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Abstract

The global population is increasing significantly and consumption patterns are moving towards western diets, intensifying the dairy products demand. Climate change is a critical threat that has direct and indirect repercussions on the dairy sector. Besides, it might contribute to increase the risk for food safety due to the exposure of spoilage organisms and bacteria such as *Escherichia coli* [1].

Hence, there is a clear need to understand the uncertainties of the present and future challenges to ensure food safety while addressing the contribution to and the effects of climate change with sustainable practices. This need is behind activities such as PROTECT a MSC-ITN recently started (http://www.protect-itn.eu). Within PROTECT, its WP5 is dedicated to improving the environmental sustainability of the dairy products value chains by the combined use of Life Cycle Assessment (LCA) and Risk Assessment (RA) methodologies. With a time horizon of three years, an integrated method that will effectively help and support the dairy sector in adapting to climate change effects, while also reducing its contribution to global warming, will be defined, developed and validated.

As a first step within this project, a literature review was carried out to understand the current situation of the sector and provide a better picture of its environmental impacts as well as its susceptibility to

climate change. 31 peer-reviewed papers (2002-2019) covering different dairy products and scopes were selected and analyzed.

An important number of LCAs have been performed, but all studies agree that primary production stands for the largest environmental impact. The whole dairy supply chain is prone to the effect of climate change, but the primary production phase is the most vulnerable. Global Warming Potential, Eutrophication, and Water Footprint are the most frequent impact categories chosen. Regarding food safety, risk management of dairy products is influenced by temperature effect and pH. Assessing the sustainability of diets.

It is vital to assess the sustainability of diets while considering the environmental burden and the nutritional value of health effects.

The dairy sector is questioned due to its significant contribution to climate change but supporting it has also potential benefits such as ecological services and boost biodiversity. Cows stimulate the process of carbon sequestration, they consume vegetation that promotes plant growth and increases organic matter [2]. Dairy farming itself can be considered a circular economy based system and it is a key element in the nutrient cycle [3]. There is an urgency to address food security while reducing the environmental impacts of dairy products and dealing with the microbial risk due to temperature increase. The intensity and the effects of climate change will vary depending on the geographical region. The integration of LCA and RA might help to cover the gaps and face the challenge [4]. However, there is a lack of literature that includes both methodologies in the dairy context and therefore the PROTECT activities will try to fill that gap and increase the environmental intelligence and science-based knowledge that is required to reach resilience in this sector against challenges due to climate change.

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Carbon footprint of beef from dairy herd – impact of allocation methods

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Abstract

The carbon footprint of beef varies due to different production systems and is considered lower from integrated beef and dairy production systems than from beef cattle. However, in assessments of meat and dairy products also different allocation methods cause variation in the carbon footprints. Financial allocation has been the most widely used method assessing milk and beef production, whereas other allocation methods, such as system expansion or biological-, mass- or protein-based are less common. Dairy and beef production systems produce also several by-products such as fertilizers, bioenergy, hides, pet food, chemicals, etc. Particularly the allocation method of these different by-products affects the results of LCA. The aims of this study are to: i) explore the impacts of different allocation methods on the carbon footprints of milk and beef meat and ii) investigate the LCA practitioners' reasons of using specific allocation methods. Literature review is conducted to identify the impacts of different allocation methods on carbon footprint of milk and beef meat. The study is completed with interviews of researchers to explain the reasons of using certain allocation methods.

Literature:

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Milk production and circular economy: advantages of organic dairy product and comparison of organic dairy systems

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Abstract

Problem and aim

Organic farming systems are based on principles of circular economy with fewer inputs, but still require improvements in farm nutrient management to decrease losses and improve recycling. In France, organic dairy production has steadily increased over the last 10 years, reaching more than 3425 farms in 2019 spread all over the country.

We first analyse a large farm dataset to see if French dairy organic farms are more 'circular-based' than conventional ones. Next, by analyzing contrasting organic dairy production systems, we try to identify the drivers that affect the environmental sustainability of dairy organic farms.

Methods

A cradle to farm gate LCA approach was used to assess environmental performance (CAP2ER, Agribalyse2). Organic farming practices were observed for 75 farms located in the North, West, East and Center-South of France, and for 3125 conventional farms surveyed by the LifeCarbonDairy project (2018). Optimized environmental performance of organic farming system was assessed through five typical dairy case studies (Inosys 2010-2019, Optialibio 2017) compared for nine environmental impacts in the ACV BIO project, 2020. Indicators used were from ILCD 2013, excepted for land competition (CML-IA non-baseline 3.04), cumulated energy demand (v.1.10) and biodiversity loss (Knudsen at al. 2017).

Results and discussion

Organic milk was on average more circular-based than conventional milk, due to lower natural resource depletion for energy use (-29%) and similar or better environmental performances by decreased nitrogen pressure (-45 kg N min./ha, less eutrophication risk), climate change impact (-26%), and improved biodiversity (+64%).

The comparison of the typical case studies presenting a range of milk productivity and proportion of annual crops in the farm area showed that none of them had the best score for all impacts. Nevertheless, a grass-based system with low yield per cow but high grass yield had lowest values for most impacts. Each of the five case study results is useful to advise farmers within a specific context of soil fertility, summer drought and frost duration. It illustrates that a farming system that is adapted to its climate and soil context has different environmental strengths and weaknesses, as can be seen from the variability for each impact (table 1)

Table 1: Variations for environmental impacts of typical organic milk case studies (ACV BIO 2020).

	Climate change	Freshwater eutrophi-cation	Marine eutrophi-cation	Acidifi-cation	Freshwater eco-toxicity	Ressource depletion	Land competition	Cumulated demand in energy	Biodiversity loss
	kg CO2 eq	kg P eq	kg N eq	molc H+ eq	CTUe	kg Sb eq	m2a	MJ	PDF
CV^2 Per kg of milk	7%	30%	23%	13%	15%	17%	21%	13%	-25%
CV^2 Per ha	16%	29%	35%	14%	12%	16%	0%	11%	-20%

Literature

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Topic 4:
Food Waste Models
and Prevention Actions

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Improving manure management towards more carbon & nutrient efficient agriculture

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Abstract

Problem and aim

Plant production and animal husbandry have each independently intensified over the last century, which have brought about environmental challenges and economic pressure. The disjunction between nutrient and organic carbon flows within animal and crop production is one example, where livestock farmers lack nearby land on which to apply manure. This disjunction has resulted in excess manure, and hence nutrient accumulation, and in turn yielded several environmental problems, including eutrophication of water bodies. Other causes for the excess manure include improper manure management and lack of technological resources to treat the manure.

The LIFE Agriclose project aims to solve the current disconnection between livestock farms (pigs and cattle with slurry or digested manure) and agricultural farms (high yielding irrigated fruit trees and field crops) located in the same area in order to close the nutrient cycle. The treatment of the manure is one the most utilised strategy to solve the manure management problem in intensive farming areas. The project develops new technology to adapt the technology to the characteristics of the by-products and crops. Resultant by-products are sufficient to replace some of the applied conventional fertilizers. This study presents actions conducted as well as the corresponding environmental quantification to ensure the loops are closed in an environmentally efficient way.

Methods

In order to test and guarantee environmental feasibility of the technologies, a Life Cycle Assessment (LCA) was conducted, following the Environmental Footprint Guidelines (EC, 2017), for the following scenarios:

1) Slurry liquid fraction applied in fruit trees using as reference conventional mineral fertilizer

2) Application of digested manure in extensive crops.

3) Implementation of a composting system for the pig manure solid fraction.

Results

The project and its corresponding environmental quantification allows us to:

· Improve the management of more than 1 M m^3 of treated slurry in Catalonia (Spain).

· The possibility of reducing mineral fertilization needs of 64.000 ha of fruit trees in Catalonia through manure treatment products by decreasing the use of nitrogenous and potassium mineral fertilizers by 80% (equivalent to 100 kg N/ha and 96 kg K_2O/ha, respectively) in peach and nectarine orchards.

· To reduce the emissions of NH_3, CH_4 and N_2O, by 60, 50 and 30% respectively, during the storage of the acidified solid fraction (45, 134 and 0.5 t/year, respectively).

Discussion/Interpretation

On the one hand, the current study has contributed to ensuring positive environmental behaviour of proposed technologies, but on the other hand, also it contributes to highlighting the shortcomings of the LCA methodology applied. This could be summarized as:

1) Need of prospective assessment for experimental trials

2) Inclusion of soil quality indicators to judge improvement provided by organic fertilization

3) Local adjustment of emission factors

Literature

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LCA of an Invention to Reduce Perishability of Fresh Produce

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Abstract

Globally one-third to half of all food produced for consumption goes to waste.[1] Fresh fruits and vegetables have some of the highest food waste rates due to perishability.[2] The produce supply chain is designed to accommodate, and limited by, this fixed perishability. Existing solutions that extend the shelf life of produce, such as refrigeration, single-use plastics, and controlled atmosphere storage, have significant environmental impacts.[3]

Apeel Sciences, a late-stage startup and a World Economic Forum Technology Partner has developed a plant-derived coating for fresh produce that slows the rate of water loss and oxidation and can keep the produce fresh two to three times longer. Apeel's technology can enable more produce to reach markets in the absence of refrigeration and can reduce retail and consumer waste by providing more time to consume the produce at its ripe condition. By reducing loss and waste across the supply chain, the Apeel technology effectively increases yields and simultaneously reduces the embodied emissions and resource consumption associated with that otherwise wasted food.

In August 2020, Apeel completed an LCA study, with a critical review performed by Quantis, to measure the environmental impacts of incorporating its plant-derived coating into the supply chains of several produce categories: avocados, limes, apples, mandarins and oranges. Since all five of these Apeel products have already been brought to market, this LCA study was able to source product performance data directly from Apeel's retail customers in both the US and Europe. The scope of this study was cradle-to-grave, and the functional unit was 1kg Apeel Produce (i.e. produce treated with the Apeel product) consumed in a US or EU home. The analysis was conducted in OpenLCA using ecoinvent v3.5 background data and the ILCD 2.0 2018 midpoint LCIA methodology.

The results demonstrate that through waste reduction and supply chain efficiency gains, the lifecycle environmental impacts of Apeel Produce are 10% to 25% lower compared to those of baseline produce consumed in US and EU homes. The study also evaluated the trade-offs between the environmental impact reductions realized from reducing food waste and the additional impacts attributable to the Apeel product itself. To account for variation in baseline waste rates across supply chains, and in the waste reduction enabled by the Apeel product, this study included a sensitivity analysis for a number of different outcome scenarios. The environmental benefits of the Apeel-enabled waste reduction were greater than the additional impacts attributable to the Apeel product in all scenarios examined.

This poster presentation will include a brief overview of the Apeel product, which was recently named as one of the TIME Magazine's Best Inventions of 2019 in the Sustainability category. In addition to the aforementioned LCA study results, the poster will also briefly touch on how Apeel leverages LCA as an internal decision-making tool in order to maximize the environmental savings of this disruptive technology.

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The utilization of food waste and its contribution to mitigate Global Warming

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Abstract

Problem and aim

Residues from the food manufacturing industry such as press cakes, pomace or other losses have great potential for use in the biotechnology industry and are often available in large quantities in Europe. This kind of food waste or food residues is not primary focus of prevention measures which have highest priority in the waste hierarchy, but require management options with the "best overall environmental outcome" (European Commission, 2008). The identification of sustainable solutions depends however, on many influencing factors such as energy demand in the valorisation process, transport distance, and substituted products on the market.

This study shows the influencing factors on the overall greenhouse gas (GHG) emissions of the valorisation, recycling, recovery, or disposal of three specific food side-flows in the European Union; animal blood, apple pomace and brewers' spent grain. On top of the environmental relevance of processing this unavoidable food waste, this study also demonstrates the complexity of using superseded products in the LCA of food waste management by system expansion and pinpoints crucial factors in the assessment.

Methods

A footprint approach (attributional approach) was used to summarize all associated GHG emissions with the life cycle from cradle-to-factory gate of a product. Valorisation, recycling, and disposal options for food waste are compared within this study. These options, except for the latter, typically produce a valuable product; a secondary good (e.g. pectin, electricity, heat), which can be further used as a food ingredient or as an energy source. To solve multi-functionality at this end-of-life stage, system expansion with substitution was chosen. The actual superseded product is based on plausible scenarios. For example, several different comparison products, ideally with small, medium, and high carbon footprints

(e.g. Norway as the greenest electricity mix in Europe and Estonia as the least green electricity mix in Europe) compared to the primary good are considered.

Results and Discussion

In a direct comparison of all considered food side-flows, it is notable that valorisation does not always result in reduced environmental net impacts (GHG savings), which means that other options at lower levels of the waste hierarchy might be more beneficial to the environment. The further use of apple pomace or brewers' spent grain for the production of food ingredients is only advantageous if the processing emissions are smaller than the emissions from the substituted products. The measuring of circularity in the food sector is a challenge in itself due to the complexity of renewable materials. This study shall help to understand the interwoven influences of certain parameters to the results.

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LESSONS LEARNT FROM A REVISION OF LCA STUDIES ON PHA PRODUCTION FROM FOOD INDUSTRY WASTE STREAMS

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Abstract

PROBLEM AND AIM: Around 100 Mt of food waste and residues from the food processing industry are generated every year in EU [1]. Thanks to their high organic matter content, a potential pathway for its valorisation is the use as substrate to produce biodegradable polymers such as polyhydroxyalkanoates (PHAs). Following a circular economy strategy, their conversion into added values product avoids the use of dedicated raw materials that can compete with food production system. The aim of this work is to ascertain the environmental benefits and identify the main challenges of their production pathway, performing a review of LCA studies published so far on PHAs production.

METHODS: *Google Scholar* search engine was used for the selections of the documents, where the following keyword combinations were typed: LCA of PHA production, LCA of biobased polymers, sustainability of green plastics, mixed-culture PHA production assessment, review of LCA on PHA production. Twenty-four suitable studies were identified, among which six references consider waste stream as substrates rather than dedicated crops: agro-alimentary wastes as wastewater (WW) from food industry [2; 3], a by-product of cheese production as whey [4; 5], a by-product of the ethanol biorefineries as black syrup [6], and the organic fraction of municipal solid waste (MSW) [7].

RESULTS: The main results coming from the comparison are presented in the table 1.

Table 1 Main elements coming from the comparison of the LCA studies reviewed

SOURCE	FUNCTIONAL UNIT	SYSTEM BOUNDARIES[1]	IMPACT CATEGORIES[2]	MAIN RESULTS	OPEN ISSUES RAISED
[2]	1 kg COD in the feed	*Gate-to-gate*	GWP	Higher GWP than that of PHA production from dedicated crops	Technology optimization is still needed in order to have a competitive process from an environmental and economic point of view
[6]	1 kg PHA	*Gate-to-gate*	NREU GWP	Lower NREU but higher GWP than PHA production from dedicated corn and soybean oil	
[4]	1 kg PHA	*Cradle-to-gate*	Ecosystem quality Human health Supply of resources	Indicators comparable with those associated to PHA production from *ad-hoc* cultivated corn and lower than those of transgenic corn	
[7]	1 kg PHB	*Gate-to-gate*	Primary energy GWP, EP, AP, OFP	Producing PHB from dedicated corn requires around twice the primary energy and GWP than from organic fraction of MSW	
[5]	1 kg PHA	*Gate-to-gate*	Total ecological footprint[3]	The amount of industrial whey that exceeds the requirement for whey powder production can be used for producing PHA: this process has a lower ecological footprint compared to whey powder production one	
[3]	1 kg PHB	*Gate-to-gate*	NREU GWP	GWP in line with that of PHA production from dedicated crops while NREU is higher	

[1] *Cradle-to-gate* includes feedstock production, substrate pre-treatment, PHA production and extraction, while *Gate-to-gate* starts at substrate pre-treatment.
[2] GWP: global warming potential; NREU: no-renewable energy use; EP: eutrophication potential; AP: acidification potential; OFP: ozone formation potential.
[3] Assessment performed by using the sustainable process index (SPI).

DISCUSSION: In conclusion, even when there are still some challenges to scale-up PHAs production (such as the process energy optimization or the choice of an inexpensive substrate), the use of waste stream from food industry is interesting key point on which focusing the future research as valorisation of food processing by-products or waste stream represents not only an opportunity but also a necessity.

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LCA of an alternative solution for wine packaging : a reusable keg

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Abstract

Stainless steel keg is widespread in hotel/café/restaurant sector for beer but not for wine, as it does not keep the wine quality satisfactorily. But a new solution is today available and overcomes this limit : a plastic reusable keg with an airtight pouch inside. This packaging then provides the same service than a glass bottle, and could spread in hotel/café/restaurant of Switzerland where the glass bottle is nearly the only packaging for wine. On top of wine quality preservation, the reusable keg could reduce : volume and weight during transport, resources consumption for its production and wine waste during storage in hotel/café/restaurant. To assess the benefits of this packaging solution, an LCA has been done comparing 30L of wine distributed in reusable keg or in glass bottles. Primary data were collected as much as possible from the keg designer and retailer. PEFCR for wine default activity data were used

when difficult to measure (bottling and cooling). Six indicators of the ILCD 2011 Midpoint+ method were considered as relevant for this study : Climate change, Acidification, Marine eutrophication, Freshwater ecotoxicity, Water resource depletion and Mineral, fossil & renewable resources depletion. The results show an environmental benefit of the reusable keg to the glass bottle except for the Mineral, fossil and renewable resources depletion indicator. A shift from aluminium multilayer pouch to plastic multilayer pouch and from single use to washable pouch head could improve these results. Moreover, the gap between reusable keg results and glass bottle results decreases as the distance of transport increases, so it is important to consider different scenarios of logistics. However, this study highlights the difficulty to take into account the reduced volume of the reusable keg (about half the volume of glass bottles) in the LCI of the distribution stage.

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Circular bioeconomy life cycle approach to food waste management in the hotel sector

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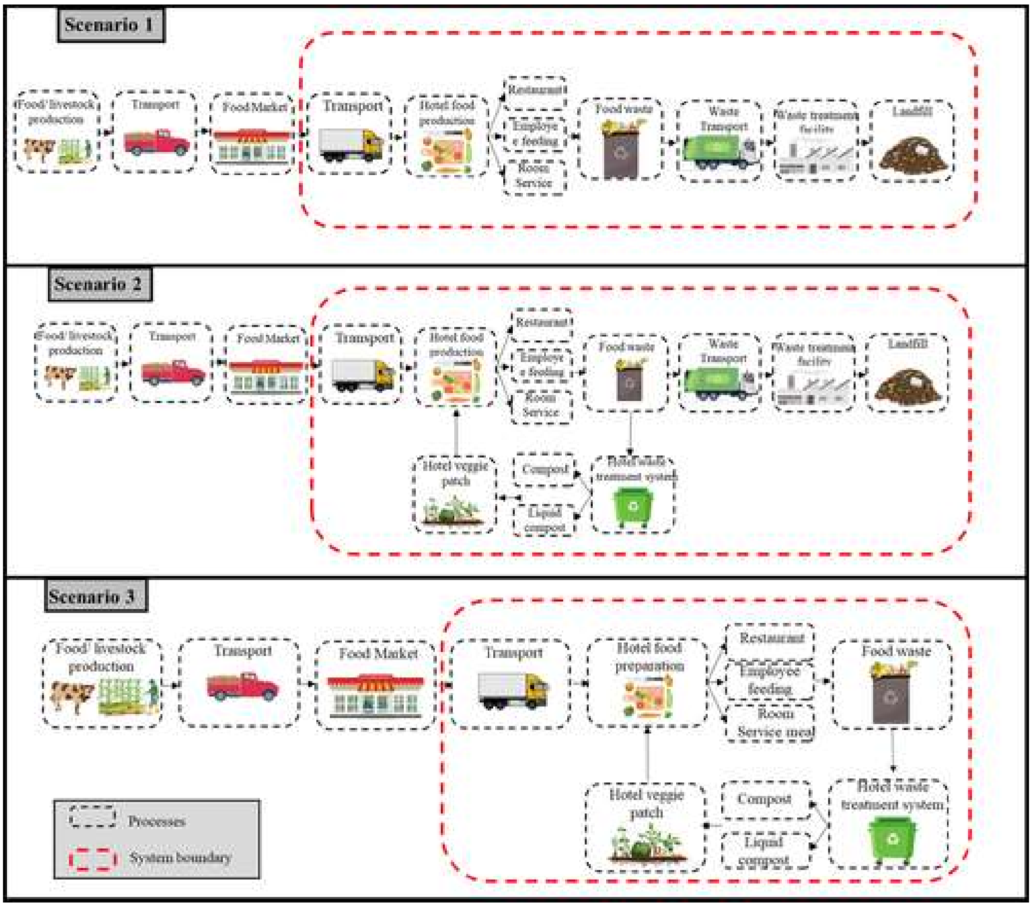
Abstract

Problem, aim and methods

Wasted food and food residue (WFFR) valorization is a challenge for achieving sustainable development (Zabaniotou and Kamaterou, 2019). According to World Resources Institute, by 2050 the world population will reach 9.6 billion people, consuming the equivalent of 1.6 times the planet's resources, and generating a proportional amount of waste. The most widely used approach to waste treatment in developing countries is landfilling (Dastjerdi et al., 2019), however, once food waste lies untreated on landfill sites, it leads to decomposition and generation of greenhouse gases (Gandhi et al., 2019). The study aimed to quantify the potential environmental impacts of a circular bioeconomy approach for WFFR management in a hotel located in on the northeast coast of Brazil. A life cycle assessment was

used to investigate three different management strategies including landfilling of the total amount of WFFR (Scenario 1), composting a partial amount of the generated WFFR combined with the landfill (Scenario 2) and composting of the entire amount of the generated WFFR (Scenario 3).

Interviews, direct observations, and documentation were used to collate the data. This study was conducted in accordance with existing standards (ISO 14040: 2006 and ISO 14044: 2006). The LCA model was created using the SimaPro 9.0.0.49 (SIMAPRO, 2019) Software for life cycle engineering. This LCA was based on primary data and secondary data from the ecoinvent database (Ecoinvent, 2015). The Functional Unit was the annual amount of WFFR generated in the hotel (kg WFFR) using data from the Hotel Waste Management Plan of 2018 and reported updates from 2019, taking the perspective of an end-of-pipe waste management problem rather than a valorization perspective. It was assumed that the system boundary for the study started with the transport of the food to the hotel to the final destination of the WFFR namely "gate-to-grave". The LCIA was based on the Centre of Environmental Science at Leiden (CML) (Guinée et al. 2002) impact assessment methodology as recommended by the International Reference Life Cycle Data System (ILCD) (ILCD 2011). The impact categories were selected based on their relevance for waste management: global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP).



Results and Discussion

The expected results include technological procedures such equipment, manpower and training required in the system; the quality of the compound; the quantified emissions generated in each of the three scenarios; the stage of the system providing an important contribution for the environmental impacts; the scenario with the lowest global warming, eutrophication and acidification impact and the downstream benefit including carbon abated, avoided mineral fertiliser (NPK) and contribution on the landfill lifespan.

The limitations observed in the implementation of the referred system, as well as recommendations to consolidate the optimal phase will be discussed. The study may corroborate with the circular bioeconomy approaches and support decision-makers to apply the WFFR management strategy with the best environmental performance.

Literature

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Topic 5:

LCA of Pigs and Pork Products

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Environmental life cycle assessment of Danish pork - focusing on mitigation options - by analyzing the development between 2005 and 2016

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Abstract

Problem and aim

Environmental mitigation options have to be identified in the pig production systems because of concerns related to the increasing world population causing increased pork consumption at global level. In order to avoid pollution swapping, mitigation options have to be assessed from a whole-system perspective.

Therefore, an environmental analysis was conducted by using a life cycle assessment (LCA) approach from cradle to slaughterhouse gate to estimate the environmental impact of Danish pork. By analyzing the development between 2005 and 2016 of Danish pork, successful mitigation options were identified.

Methods

The functional unit (FU) was 1 kg product used for human consumption. The system boundaries were from cradle to slaughterhouse. In the model we included the following impact categories: climate change, eutrophication potential, acidification potential, abiotic depletion, land occupation and biodiversity damage. Slaughterhouse data was collected on how the live weight of pigs end up in products for human consumption and other product.

Results

The number of pigs produced per sow per year was increased from 25.0 to 32.1 piglets per sow per year and in total from 22.7 to 29.5 finisher per sow per year. Total live weight gain per sow per year was increased by 39% from 2393 kg LW in 2005 to 3320 kg LW in 2016. The major feed use is for the slaughter pigs. Al together feed used per sow including pigs produced has increased 29% from 7205 kg to 9299 kg /sow/year.

The amount of the live pig that is used for human consumption has increased from 777 kg in 2005 to 841 kg out of 1000 kg LW in 2016

The environmental impact was calculated per kg LWG at farm gate. There was found a decrease in the period for all impact categories, though eutrophication was unchanged.

GWP has decreased from 2.8 to 2.3 kg CO_2/kg LWG and the use of land for feed production from decreased from 6.3 to 5.4 m^2.

Discussion

The identified mitigation options caused by the general changes in pig production from 2005 to 2016 are described in the following. In feed production, higher crops yield, less use of N per kg feed and more environmental friendly types of N fertilizer reduce the emissions. The higher feed efficiency e.g. less feed used per kg LWG also reduces the emissions. Other identified mitigation in stable were less amount of energy in stable, less N in manure/kg gain, other more environmental friendly types of housing, more use of biogas, and acidification and higher utilization of dead pigs for energy production.

At slaughterhouse, the higher proportion of LW used for meat for human reduce the emissions per kg LWG. More environmental friendly trucks for transport of pigs from farm to slaughterhouse, better use of by-products at slaughterhouse and finally less use of energy and other resources for slaughtering are other mitigation options.

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Life cycle assessment of pig slurry acidification for mitigating ammonia emissions in agriculture under Danish, Dutch and Spanish conditions

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Abstract

Problem & Aim

Efficient treatment and utilisation of farm manure is a challenging balance between financial, environmental and health aspects.

The aim of this study is to determine the environmental effects of in-storage pig slurry acidification for NH_3 emission mitigations under Danish (Jutland, DK), Dutch (South Holland, NL) and Spanish (Catalonia, ES) environmental and legal conditions compared to the handling of untreated slurry. Differences in performance and their potential causes are investigated to determine whether the introduction of acidification as a slurry treatment technology is recommendable under given conditions.

Methods

The LCA study complies with ILCD guidance (ILCD 2010). The software used for LCA modelling is openLCA v1.10.2 (GreenDelta 2019) and the EcoInvent database v3.6 (Ecoinvent 2018) was used for background processes. To determine emissions in the field, the soil-plant-atmosphere model Daisy v5.88 (Abrahamsen and Hansen 2000) is used.

The functional unit is 1000 kg slurry ex-housing from fattening pigs under prevailing conditions of each region. Emissions, resource consumption and effects are analysed from the moment the slurry is pumped into the outdoor storage until 100 years after field application.

The LCA includes environmental impacts associated with outdoor storage and field application, slurry treatment, transportation between life stages, utilization of electricity and chemicals.

Parameters, which are likely to be included in scenario and sensitivity analyses are slurry emission factors, phosphorus regulations, soil lime application, transport distances of slurry, crop species.

Preliminary Results & Discussion

The preliminary results presented only include slurry storage without Daisy simulations.

Compared to the baseline, acidification performs better in the impact categories for which this technology was initially introduced for, such as climate change (13-21 compared to 50-197 kg CO_2-eq; DK<NL<ES). This is due to decreased CH_4 and N_2O emissions (biogenic) which off-set increased emissions (fossil) related to acid (0.55 kg CO_2-eq. for the production of 6 kg H_2SO_4, assumed the same for all regions) and electricity (1-1.8 kg CO_2-eq. for the production of 3kWh for mixing acid and slurry: ES<NL<DK) production. The differences in potential impacts from slurry between countries result from slurry composition (highest dry matter content in NL with 9% compared to lowest in ES with 5.7%) and emission factors (highest CH_4 conversion factor in ES). Terrestrial eutrophication is also decreased due to acidification. Namely from 1.8-2.5 to 0.9-1.3 mol N-eq, respectively. This is due to decreased NH_3 emissions during storage. However, in most other categories, acidification results in higher environmental impacts, e.g. resource consumption and freshwater eutrophication due to acid production and energy requirements for mixing.

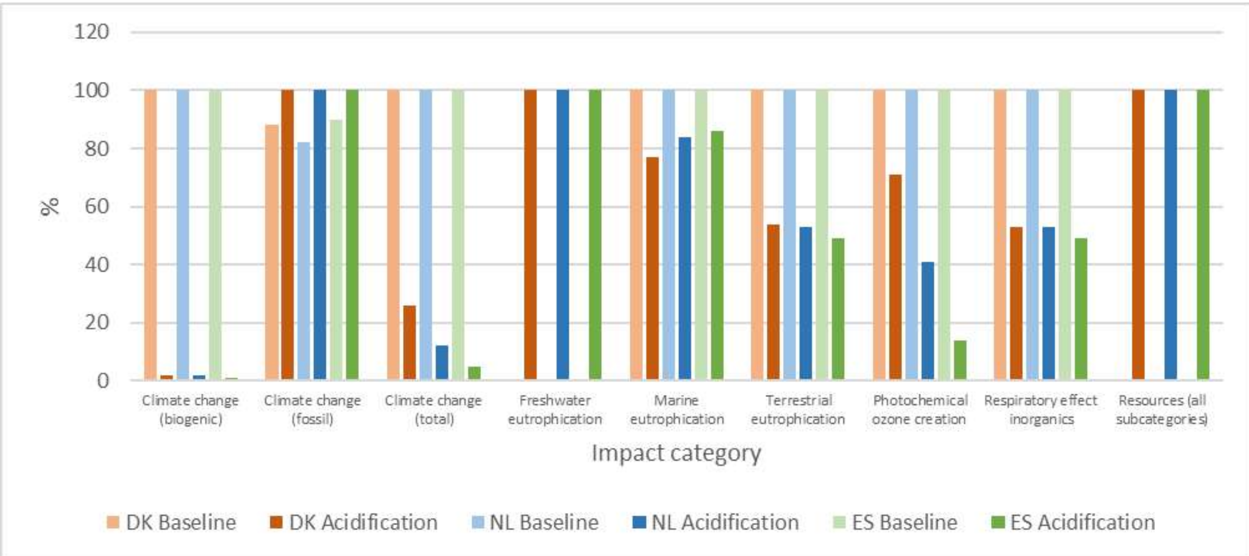

Figure 1: Relative indicator results per country after ILCD 2.0 2018 Midpoint. Untreated vs. acidified slurry in storage. DK: Denmark, NL: the Netherlands, ES: Spain

Result patterns show that impacts are mainly technology-specific and only to a small extent influenced by country-specific conditions (e.g. electricity mix, slurry composition). One technology is always favoured over the other independent of country. Continuing the study, it will be identified how factors such as variation in emissions related to field application and yield response influence performances.

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Effect of different cleaning protocols on freshwater use in the pork production chain

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Abstract

Water plays a crucial role in the pork production chain. Fresh water is used for feed production, and for drinking and cleaning purposes. Increasing emphasis on sustainable use of water resources highlights the need to quantify and characterize fresh water use along the pork production chain. To properly address water use, a distinction should be made between green and blue water, with the first referring to soil moisture available for plant growth, and the second to liquid water stored in water bodies. To quantify and reduce the blue water footprint of pork, detailed information about water used for drinking and cleaning purposes on pig farms is required.

Washing of pens between batches of pigs is a routine activity on pig farms as it helps to remove pathogens from the previous batch. This is particularly important for newly weaned pigs, which are extremely vulnerable to infectious diseases. The method of washing, however, varies between farms. The aim of this study was to quantify fresh water used during washing of weaner pens using different combinations of cleaning protocols to determine which procedure cleans most effectively with the least amount of water.

The cleaning protocols evaluated in this study were: P1: power washing only; P2: presoaking with water followed by power washing and disinfection; and P3: presoaking with water followed by detergent, power washing and disinfection. Detergent used was Kenosan, (0.5% dilution rate) and disinfectant was Hyperox (1% dilution rate).

We used three weaning rooms in this experiment. Each room had 10 pens (2.4 m × 2.6 m) with a capacity to hold up to 14 pigs each. Pigs remained in the weaner stage for seven weeks, weaned, and then pens were cleaned before the next batch of pigs moved in. Over three replicates, one of the three cleaning protocols was applied to each room between batches. To compare the efficacy of the protocols, swab samples were collected from the floor (n=2), wall (n=1) and feeder (n=1) from 3 randomly selected pens in each room, before and after cleaning. Each swab was tested for the presence of *Enterobacteriaceace, Staphylococcus* and total bacterial count (TBC). The volume of blue water used for power washing and presoaking was also measured, and the time it took to clean each pen.

Data were analyzed using the mixed models procedure in SAS v9.4. There was an effect of cleaning protocols on the time taken to clean a pen (P1 =15.69 ± 0.49, P2 = 13.36 ± 0.47, P3= 11.52 ±0.53) minutes. However, there was no difference in total water used for the cleaning protocol, (P1= 196.4 ± 18.76, P2=226.6 ± 18.16 and P3=215.4 ± 27.85 liters) (Figure 1). Neither was there an effect on water used per pig or water use per pigspace.

There was no effect of cleaning protocols, or interaction between protocols and sampling time on the bacterial counts. The *Staphylococcus* and TBC counts were lower after washing than before (P<0.001), but there was no effect of washing on *Enterobacteriaceae* counts. The location of sampling (floor, feeder or wall) had an effect on bacterial counts (P<0.001).

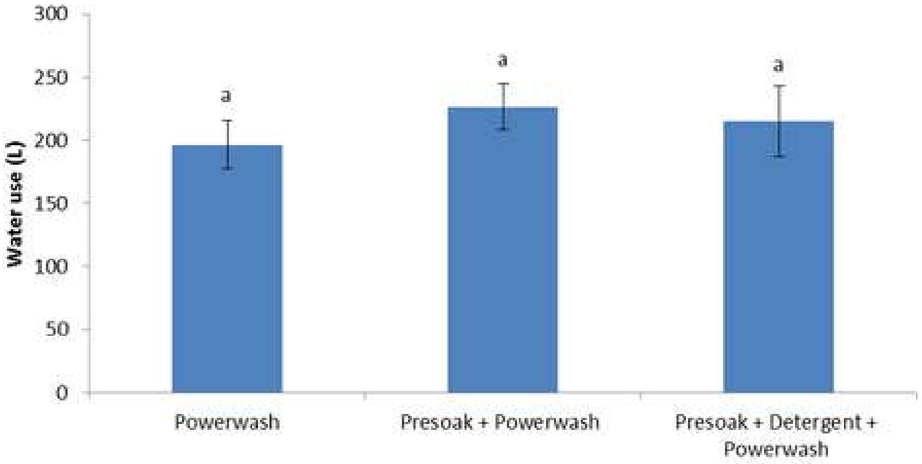

Figure 1. The effect of the different treatments on total water used to wash weaner pens. Similar letter on the bar indicates no significant difference between cleaning protocols.

In summary, different cleaning and disinfection protocols did not affect the water used, but there was a reduction in the time taken to do the power washing if presoaking was done and detergent was used. For the bacterial counts, no difference was found between the three protocols used but *Staphylococcus* counts and TBC reduced from prewash to post wash. Thus, the cleaning protocols used in this study had no effect on the blue water use of the pork production chain. Since there was no difference in both water use and bacterial load, power washing without presoaking detergent or seem to be the preferred option.

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Benefits of low dietary crude protein strategies on feed global warming potential in broiler and pig production systems: a case study.

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Abstract

Livestock production is facing numerous sustainability challenges such as the reduction of Global Warming Potential (GWP), Eutrophication (EU) and Acidification (AC). As feed is one of the main drivers of animal performance and nutrient efficiency it is a key parameter to consider in sustainability assessment. Feed is the major contributor to GWP with 60-75% and in a lesser extent to EU and to AC with 35-60% and <30%, respectively. Animal excretion or manure is an important contributor to EU and AC accounting to 20% and 60% of the total impact. Therefore, to efficiently evaluate feed strategies on sustainability parameters it is valuable to consider: the GWP at the feed level “feed gate” and the EU and AC at the farm level “farm gate”. Reducing crude protein (CP) of broiler and pig diets supplemented with feed-grade amino acids (AA) has shown benefits in reducing the utilization of soybean meal (SBM) and reducing nitrogen in the manure without altering animal performance. As this strategy affects both the feed and the manure, a Life Cycle Assessment (LCA) approach is advised. This study is the first step of the LCA and its objectives were to assess to which extent low CP diets in broiler and grower pig affect 1) the “feed gate” GWP and 2) broiler and grower pig performance.

Data from literature were gathered and compiled. They were selected according to the following criteria 1) to be published from 2017 onwards, with 2) performance and diet composition available, 3) constant dietary digestible lysine and 4) indispensable AA adequately supplied. The associated GWP (kg of CO_2 equivalent) was calculated using GFLI (2019) database. For ingredients not included in GFLI (2019),

EcoAlim (2014) database was used. SBM and oil were “RER”: average for all countries in Europe in GFLI (2019). Micro-ingredients such as premix, minerals and non-nutritional additives were not considered in the GWP evaluation as their impacts were negligible.

The database included 9 experiments from 8 papers published from 2017 to 2019. As starter, grower and finisher phases were considered independent, it resulted in a database of 15 trials (10 in broiler and 5 in pig) and 45 treatments. All CP reductions were performed by gradually replacing SBM and oil contents by cereals or other protein rich feedstuffs and feed-grade AA. Dependent variables included average daily feed intake (ADFI), average daily gain (ADG), feed conversion ratio (FCR), SBM level and GWP. For performance parameters, only broiler data were analyzed due to the low number of publications in pig. A general linear model was used “Trial” was set as random factor and “protein level” as covariable. For SBM and GWP data analysis, general linear mixed effect model was used “Trial” was set as random factor, “Species” as fixed factor, “Protein level” as covariable and the interaction “Protein level” and “Species” was tested. Minitab 2019 software was used.

According to linear regression equation, lowering CP significantly increased broiler ADFI (P=0.020) and increased ADG (P=0.059) but did not affect FCR (P=0.847). An interaction was found between “Protein level” and “Species” (P=0.088), reduction by 1%-point CP decreased SBM by 35 kg in broiler and 39 kg in swine per ton of feed (P<0.001, R^2=99.20). It also led to significant savings in CO2, a decrease of 1%-point CP reduced CO2 emissions by 101 kg and not affected by species (P<0.001, R^2=99.39).

This study indicated that low CP strategy in broiler and pig diets is an efficient tool reduce SBM utilization and to mitigate GWP without altering animal growth performance. It is thus an efficient solution to reduce the environmental impact of broiler and pig production. The next step will be to quantify EU and AC at the “farm gate” considering farm and manure. Combining these data will allow animal nutritionists to formulate feeds taking in consideration GWP, EU and AC and thus reduce livestock global emissions without reducing performance.

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Global warming potential associated with consumption of pork meat products in Serbia

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Abstract

Problem and aim

Within the food chains, meat as a type of food is associated with the highest environmental impact (Djekic and Tomasevic, 2018). It affects climate change visible by calculating global warming potential (GWP) as well as acidification and eutrophication potentials joint with consumption of resources (water / energy). Emission of greenhouse gases (GHG) is linked with farms resulting in GWP and climate change (IPCC 2013). However, by elevating the perspective we can observe the meat supply chain from the

farms to the consumers (Djekic et al. 2018). Limited number of research link dietary habits and climate change (Djekic et al. 2019) and this research connects data from pig farms and a consumption survey.

Methods

This research covered inventory data from 12 pig farms and consumption data from 806 pork meat consumers in Serbia. Pig farm stage covered all livestock activities. GWP was calculated using inventory data with the aid of ©CCaLC database. Consumption stage comprised of quantities of consumed pork meat products on a 7-day recall basis. Monte Carlo simulation was employed on both types of data – from farms and consumers. Figure 1 depicts the method employed.

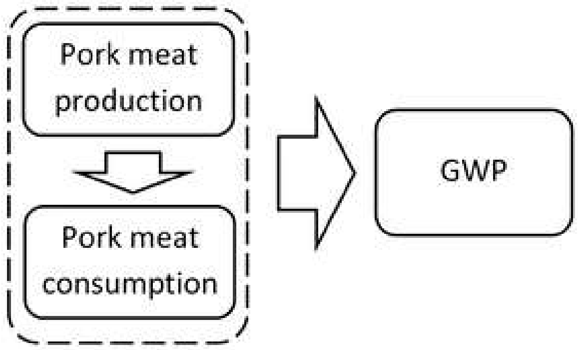

Figure 1. Modelling impact of meat consumption on GWP

Results

Based on the data from pig farms, CO_2 emission is within the range from 1.99 to 5.50 kg CO_{2e} / per 1 kg of live weight, with an average value of 3.50 kg CO_{2e}. Monte Carlo simulation revealed that every week an average Serbian pork meat consumer releases around 4 kg CO_{2e}. Deeper calculation per body weight of an average consumer show that 55.83 g CO_{2e} is accounted a week per every kg of body weight.

Discussion/Interpretation

Intention of the calculation was not to judge on pork meat consumers in any way since scientific models on connecting dietary habits and climate change are prevailing compared to studies on every-day food consumption. Switching to vegan/vegetarian cuisine is a big challenge since it requires major habitual changes (Rijsberman, 2017). Depending on type of food we replace with meat, reduction in meat consumption does not imply lower environmental impact (Hyland et al., 2017). Also, diets with lower environmental impacts may lead to nutrient deficits (Meier and Christen, 2012).

Opposed to rather aggressive campaigns against meat consumption, promotion of sustainable (climate change friendly) diets should consist of providing consumers with nutritional and GWP data for majority of food sold on the market and leaving the consumers a free choice.

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Environmental Assessment of traditional Iberian pig production in Spain with two different fattening systems

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Abstract

Alternative pig production systems have usually higher environmental impacts than conventional ones, due to older age at slaughter and higher consumption of compound feeds. However, few studies investigating outdoor traditional productions suggested that lower impacts may be achieved by such systems, given that they would strongly rely on the consumption of natural resources available on grasslands and woodlands. The traditional Iberian pig production is characterized by outdoor systems with animals fed with natural resources. The feed supply can be either null (montanera) or limited (cebo campo) in the fattening period. We hypothesized that traditional Iberian system with fattening in montanera present lower environmental impacts than systems like cebo campo which depend more on compound feeds. The aim of this study was to assess the environmental impacts of these systems through Life Cycle Assessment (LCA).

Environmental impacts were analysed per kilogram of live weight. The perimeter of the analysis included inputs and emissions for crop production, concentrate feed production at the feed factory, animal production unit, and manure storage. Emissions resulting from nutrient excretion consecutive to the consumption of natural resources were included as well. The systems evaluated are farrow-to-finish systems, which fatten all the piglets produced on the farm. Since the perimeter of the study is farm gate, we did not consider separately the relative products obtained from the different types of animals (fattened pigs and sows). Data were collected through questionnaires from 33 farms (27 farms with montanera fatteners and 6 farms with both montanera and cebo campo fatteners).

Table 1. Environmental impacts of pig production in the traditional Iberian system, obtained from the whole dataset (33 farms).

Impacts per kg of live pig at farm gate	**Farms with *montanera* *(27 farms)***	**Farms with *montanera and cebo campo* *(6 farms)***
Climate change (kg CO_2 eq)	3.40 ± 0.223	4.36 ± 0.428
Acidification (molc H+ eq)	0.091 ± 0.004	0.110 ± 0.010
Eutrophication (kg PO_4^{3-} eq)	0.046 ± 0.002	0.057 ± 0.005
Non-renewable Energy (MJ)	20.65 ± 1.698	28.57 ± 3.523
Land Occupation (m^2·year)	43.01 ± 22.807	31.60 ± 6.662

Iberian pig production in montanera had the lowest impacts for climate change (CC), acidification (AC), eutrophication (EU) and cumulative energy demand (CED) due to the strict use of natural resources (acorns and grass) during the fattening period (Table 1). Environmental impacts for CC, AC, EU and CED were 22, 17, 95 and 28% higher, respectively, with cebo campo compared with montanera. For land occupation (LO), however, cebo campo had lower impact (31.6 m^2·year) than montanera (43.0 m^2·year) system. Environmental impacts of Iberian pig production traditional systems are reduced just using montanera system for finishing (vs. cebo campo). Therefore, relying on the ability of Iberian pigs to consume acorns and to valorise them with compensatory growth allows mitigation of impacts that are close to those of conventional systems despite the lower growth potential of Iberian pigs.

To our knowledge, this study provides the first life cycle assessment of traditional Iberian pig production and includes for almost the first time the emissions associated to the consumption of natural resources available on pasture and open woodlands. The contribution of emissions derived from the consumption of natural resources to CC, AC and EU impacts reached about 10%. Therefore, they should be included in the LCA perimeter to avoid underestimation of the environmental impacts for systems in which natural resources are used.

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Comparative life cycle assessment of ham products using different packaging materials with consideration of consumer behavior

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Abstract

Problem and aim

Food loss can theoretically be reduced by extending the expiration dates, which is now possible due to the improved maintenance of food quality packaging. Fewer leftovers imply reduced environmental loads in the life cycle. In contrast, highly functional packaging and small-volume packaging tend to place a heavier load per unit weight of the content compared to conventional packaging. Here, we assess the total impacts of food by considering the two contrasted environmental loads with reference to changes in consumer behavior, which we consider a key concept for the assessment of food consumption.

Methods

In this study, with a focus on ham, LCA was performed on individual hams to which the three types of containers and packaging were applied. The functional unit is “providing one ham product”. The entire life cycle through the fattening of pigs, raw meat production, ham production, transportation, sales, consumption, and waste disposal / recycling treatment including used containers and packaging and discarded contents was defined as a boundary.

A skin pack using a barrier film (packaging A) was used as the high functional packaging, and two types of packaging materials were used for the conventional packaging products. Those were a PSP tray covered with PE wrap film (packaging B) and paper-like slices of film made of pine (packaging C).

In regard to the expiration interval after packaging, the unopened, functional packaging A was set to 21 days, packaging B to five days, and packaging C to two days.

The leftovers after the expiration date were treated as food loss. When food loss is counted, the consumer purchases an additional amount corresponding to the loss and consumes 12 pieces of ham, equivalent to one functional unit.

Results

1. For packaging B and packaging C, which were mainstream before the prevalence of high functional packaging, it was estimated that the food loss rate at the time was lower than the current packaging.

Regarding the LC-CO2 of ham to which packaging B and packaging C were applied at that time, although there was a difference in environmental load due to the packaging, the load over the entire life cycle was almost the same, and there was not much difference from the current packaging A.

2. For the current consumption scenario, the consumption time and loss rate after purchasing packaging A obtained from the consumer questionnaire were used.

Assuming that packaging B and C maintain the same consumption period as packaging A, LC-CO2 was calculated by applying the scenario to packaging B and C, while taking into account the amount of food loss generated after the expiration date.

Packaging A showed the lowest LC-CO2, as it had the longest shelf life and no losses were generated.

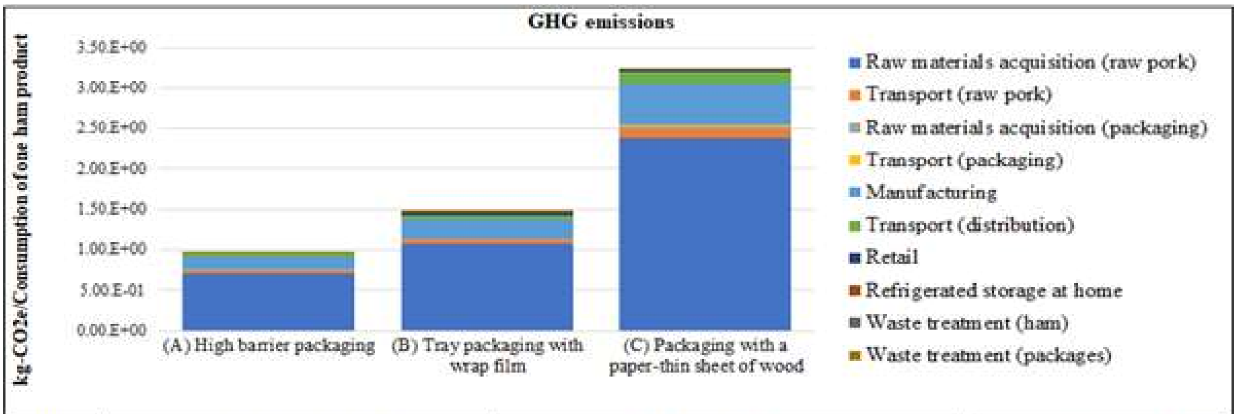
In contrast, the environmental load of packaging B and packaging C were roughly 1.5 times and 3.3 times higher than that of packaging A, respectively, as a result of the additional accounting for environmental load due to food loss (Fig. 1).

Discussion/Interpretation

The food protection performance of packaging C was not much higher than that of packaging A and B because the content food had a short shelf life. For this reason, consumers tended to significantly suppress food loss by purchasing only the necessary amount for consumption every time they went shopping, and by consuming any leftovers by cooking.

However, in the case where the current consumer consumption scenario was applied to packaging B and C, the additional purchase to compensate for the high loss contributed to an increase in the environmental load.

In the era when packaging B and packaging C were mainstream, the loads on those packaging types were not significantly different from the current packaging A. However, at present, when lifestyles related to consumer diets (such as reduction of purchase time and purchase frequency) have changed dramatically, packaging A has greatly contributed to the reduction of environmental load.



ID	Packaging for ham	Current scenario	Scenario before 1980s
A	High barrier packaging	Most common	(Not available)
B	Tray packaging with wrap film	Common (well sealed)	Common
C	Packaging with a paper-thin sheet of wood	Almost disappeared	Most common
	Functional unit	Providing one ham product	Providing one ham product
	Consumption timing	Timing based on current consumption behavior	Avarage timing in those days
	Food loss rate	Rates based on current consumption behavior	Avarage rates in those days

Figure 1: LC-CO2 calculation results for current consumer consumption scenerio

Topic 6:

Aquatic Models and LCAs

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Substituting fish oil with microalgal meal as a step towards sustainable aquaculture: A life cycle perspective

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Abstract

Problem and Aim

Growing demand for aquatic foods globally has raised the concerns regarding sustainability of aquaculture. The current demand for aquatic food is about ~150 million tonnes and it is estimated that by 2030 the demand would rise by 23 million tonnes. Aquaculture largely depends on fish meal and fish oil for feeding as source of protein and lipids and expansion of aquaculture would require alternatives to fish meal and fish oil ingredients. Plant seed based meal and oils have been tested as alternative, however, lower levels of essential amino acids and poly unsaturated fatty acids limits the use of these ingredients. In this regard, marine microalgae has gained attention as an alternative because of their nutritional profile. This research aims at analysing the sustainability of aquaculture with replacement of fish oil with microalgal meal. Polyunsaturated fatty acids can be produced by microalgae either via photoautotrophic or heterotrophic modes of nutrition. Hence, life cycle assessment of microalgal biomass production via photoautotrophic and heterotrophic routes for use as aquatic feed was conducted

Method

Goal and Scope: The goal of the study was to analyze the life cycle energy requirements and environmental impact of microalgae based biodiesel. System boundary and functional unit considered was Cradle to Gate and 1 tonne of microalgal biomass production, respectively. The inventories in the "cradle-to-gate" LCA for microalgae include cultivation in a raceway pond, fermenter, harvesting by flocculation, Centrifugation, and dewatering using spray drying (SP). The inventories in the "cradle-to-gate" LCA for fish oil production include fish feed production, cold storage, grinding, cooking, oil separation, and purification

Life cycle inventory: The inventory inputs, processes and entire emissions involved in algal biodiesel production were acquired from the Professional database (Ecoinvent, Peter Eyerer, European Life Cycle

Database and Plastics Europe) available with GaBi software package. The data relevant to Indian scenario were used. The inventory data regarding the feed composition was obtained from Sarker et al., 2016. The data regarding preparation of corn meal, soya meal and wheat flour is obtained from Pelletier and Tyedmers, 2007. The inventory data regarding cultivation of microalgae was obtained from Sarat Chandra et al., 2017 and Barr and Landis, 2018.

Life cycle impact assessment: GaBi was used as platform for performing LCA. The environmental impacts were evaluated by using the Traci 2.1 method. The parameters such as primary energy demand and the environmental impacts such as global warming potential, eutrophication potential and acidification potential are assessed.

Results and Discussion

Five different feed compositions were analysed with varying amounts of microalgal biomass (0, 25%, 50%, 75% and 100% replacement). The life cycle analysis results indicated that microalgal biomass could be substituted as an alternative to fish oil in the aquatic feed. Production of microalgal biomass by photoautotrophic mode requires lower energy compared to the heterotrophic modes of nutrition. This is due to the use of centrifugation as harvesting option in heterotrophic mode. Sensitivity analysis indicated that increase and biomass productivity will decrease the primary energy demand and lower environmental impacts.

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Climate impact and nutrition density of seafoods

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Abstract

Seafood is a crucial source of micronutrients, fatty acids, and protein for many populations worldwide, especially those more nutritionally unsecure. The term seafood encompasses thousands of species of fish, crustaceans, molluscs and seaweeds from oceans as well as freshwater streams. Large variability in both nutritional content and environmental sustainability between seafood products point to the need for diet recommendations that include both health and environmental aspects. In the present study, the combined nutrient density and climate impact of 41 of the globally most produced species of seafoods is analyzed. Climate impact or greenhouse gas emissions was chosen as an indicator that can be quantified across seafood products and systems and serves as a rough indicator of overall environmental sustainability. The nutrient score used relates nutritional content to the recommended intake for around 20 nutrients relevant for seafood. It gives equal weight to all nutrients up to the recommended intake level. Nutrient data was taken from four major seafood nutrition databases. Greenhouse gas emissions for the products were taken from seafood LCA studies or studies of energy use in fisheries and harmonized in terms of methodological choices in order to make the data comparable across species. When combining the two dimensions nutrition and climate, by using the nutritional score as the basis of

assessment instead of mass, species can be grouped as those having high nutrition and low greenhouse gas emissions which should be promoted for increased consumption. Results show that several species among salmons, herrings and mackerels belong to this group. These species are at present consumed in modest volumes, which limits their current contribution to human nutrition as compared to less nutritious seafoods consumed in larger volumes e.g. many whitefishes such as carps. Species with a low nutrition score and high greenhouse gas emissions should instead not be promoted. For the remaining two groups, conflicts exist between nutrition and climate and for those having both high nutrition score and greenhouse gas emissions, efforts are needed to reduce emissions, e.g. by shifting to less intensive production technologies. Nutrition is harder to influence (the fourth group is low in nutrition and in greenhouse gas emissions), but can to some extent be controlled for fed species from aquaculture through feed composition. Any modifications need to take into account both the nutritional requirements of the species, the nutritional properties of the seafood product and its climate impact, which often is highly dependent on the feed. Except for broader measures of environmental sustainability and incorporating measures of nutrient bioavailability (rather than the mere content as done here), knowledge is also lacking on the spatial and temporal variability in nutritional content in different species. For fish, often only nutrition data for the fillet is available, despite indications that the nutritional value of by-products is high. As a conclusion, this study shows that as a first step towards seafood dietary recommendations based on both health and sustainability goals, combining climate and nutritional quality can provide a useful starting point to guide future seafood consumption. **The presentation will explain the methods used to synthesize nutrition and climate data, results, how these can be used in policy and industry and what further research is needed in this field.**

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Effective implementation of the Product Environmental Footprint in the Mediterranean aquaculture sector

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Abstract

Problem and aim

Aquaculture is key sector in meeting rising demand for fishery products [I]. However, it is also responsible for diverse environmental impacts [II]. One of the main initiatives to promote sustainable products is the European Product Environmental Footprint, developed by the EC. However, there are a lot of challenge for real implementation.

Within this framework, main objective of AQUAPEF project (LIFE17 ENV/ES/000193) is to promote the implementation of the PEF initiative into Mediterranean aquaculture sector by developing an integrative methodology to facilitate data collection, footprint calculation, verification and B2B and B2C communication.

Methods

In order to achieve the objective, first of all, a standardized and integrated protocol to obtain traceable, consistent and comparable inventory data have been developed. In line with the Marine Fish PEF, we have developed a questionnaire to simplify data collection in all stages of the aquaculture life cycle. Moreover, all the European PEF compliant dataset have been reviewed to select and categorize those that are valuable for aquaculture production systems.

Moreover, an integrative evaluation-tool to facilitate the evaluation and certification of aquaculture product environmental impact have been developed. The tool (administrator + web application) has been developed using Visual Studio .NET, on Visual Studio 2017 and the database is centralized in a SQL

Server 2017. Adobe Illustrator CC2018, Adobe Photoshop C2018 and Sketch 2019 have been used for designing.

Currently 3 aquaculture companies are using the tool to evaluate their environmental footprint and by mid-2020 it will be validated.

Results

The core of the project is to develop an innovative tool for the evaluation and certification of aquaculture product environmental impact specific for aquaculture sector following the Marine Fish Product Environmental Footprint methodology.

The web-tool allows aquaculture companies to know their environmental impact and their contribution to the final product's environmental impact. Depending on the type of actor (feed producer, hatchery, growing farm or preparation) the user could fill the questionnaires with production data and evaluate the environmental impacts following the PEF methodology. Moreover, linked to this web-based tool, an administrator tool has also developed to allow managers to define questionnaires or include additional impact methodologies.

Discussion

Several challenges have been, and are expected to be, faced when developing this kind of solutions. Among others:

- Emissions to the environment: One of the main environmental concerns of open-net aquaculture production is the N and P leaching to the environment [III] . However, unlike livestock, there is no official model to estimate the emission to the ocean of those components. We are working to develop a tier 1 or tier 2 method to estimate those nutrient emission.
- Lack of specific environmental impact: There is no specific methodology to evaluate potential impacts on the marine environments due to escapees or antibiotics [IV].

It is expected to overcome all this challenges by mid 2020. In 2021, replication and transferability actions will be carried out to stablish a commercialization strategy for the tool.

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Building a pathway to the Blue Economy: a robust life cycle database for seafood sector in the European Atlantic region

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Abstract

Problem and aim

The European seafood and aquaculture sectors are facing important challenges in terms of environmental threats. Climate change can interact with fisheries in many different ways, mainly increasing rivers and sea surface water temperatures leading to population collapses [1]. On the other hand, marine debris is a global issue crossing country borders in which micro- and macro-plastics are the type of debris most found on the sea surface and sea floor due to an insufficient waste management, littering and consumption behaviour [2]. Finally, many of the world´s fisheries are showing a decline in the fishing yield due to the continuous depletion of the fish stock at a rate higher that the capability of the systems to replenish it, as a result of biological reproduction, fact that is intrinsically related to

climate change effects. In addition, fishing and aquaculture activities generate high amounts of waste streams that have classically been regarded as of limited value and potentially harmful, but now, there is an enhanced focus on valorising them. These issues are forcing all stakeholders, from policy-makers to citizens and industries, to move to more sustainable policies, practices and processes adopting a "nexus thinking", in which the action in one of the systems has impacts on the others. In this sense, the NEPTUNUS project aims to promote the sustainable development of the fish and seafood sector in the European Atlantic area by supplying a consistent methodology based on life cycle assessment (LCA) for products eco-labelling and defining eco-innovation strategies for production and consumption under a circular economy and nexus approach.

Methods

To reach this objective, LCA methodology is applied to the European fish and seafood sector to quantify main inputs and outputs of the product system in a life cycle inventory (LCI) according to European Life cycle Database (ELCD). The species were selected based on statistical data for catches by Atlantic fishing area and reported production from aquaculture for the same area. Regarding marine captures, this project is focused on: (i) Demersal fish: cod, hake, haddock; (ii) Pelagic fish: herring, sardine, anchovy, horse mackerel, Atlantic mackerel, tuna; (iii) Molluscs: octopus, squid, clams, shrimps/prawns. Regarding aquaculture the main species produced and object of this project are: (i) Diadromous: salmon, trout, turbot, sea bream; (ii) Molluscs: mussels, oysters, scallops. The coordination of 11 partners involved in NEPTUNUS project from 5 different countries, focusing their joint efforts in the collection of data, denotes a transnational approach and makes sure the development of a robust database for Atlantic area fish and seafood supply chains.

Results

NEPTUNUS project aims at creating a solid LCI database for fish and seafood in the Atlantic area which will be the basis to create a user-friendly tool for assisting seafood produced, municipalities, communities and regions of the Atlantic area to easily obtaining LCA results on seafood production and consumption. This should gather the needs and requirements of future users as far as possible, and allow users to make some changes in variable parameters.

Acknowledgements

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Environmental analysis of frozen seafood logistic operations in Galicia (NW Spain)

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Abstract

Food supply chain is very complex in a globalized and connected world. This is particularly relevant for seafood supply chain, where fishing grounds, processing plants and retailers are far away from one another and generally located in different continents. Currently, frozen seafood market is growing at a rate of 7.1% because consumers prefer frozen over fresh seafood due to price and food safety.

In this context, logistic centers play a key role within the frozen seafood supply chain. Additionally, frozen seafood logistic operations are commonly outsourced to specialized companies, providing services such as frozen storage, semi-processing facilities and customs warehousing for third-country goods. Therefore, logistic centers are also the liaison between the provider and the client inasmuch as they storage catchments or semi-processed seafood until subsequent stages: processing, wholesaling, etc. These centers can receive frozen seafood either by road or ship from different origin based on client, season or fishing ground. The storage time of products can vary considerably from weeks to months in accordance with client necessities or market fluctuations.

Frozen logistic operations are high energy intensive because of frozen chambers consumption, accounting up to 75% of global energy consumption —mainly electricity from the grid—, and transportation, which sometimes implies more than one kind of transportation: road, ocean or rail. In addition to this, frozen seafood logistic movements is featured by the seasonality throughout the year: fishing bans, market demands, etc.

The current study evaluates the logistic operations through Life Cycle Assessment (LCA) of a frozen seafood storage center in Galicia (NW Spain) during one year. Moreover, the study have been taken into account the temporal variation in order to shed light on fishing bans and market influence on final environmental impact: seasonal impact per specie.

The results obtained have shown that environmental impacts derived from logistic operation varied when implementing a seasonal approach, remarking the relevance of fishing campaigns and product rotation based on market fluctuations.

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Topic 7:
Novel Technologies
and Protein Production Systems

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Life cycle assessment of microbial protein

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Abstract

Problem and aim

Production of food for the world's growing population is one of the main contributors to environmental change. The food sector is responsible for about 26% of anthropogenic greenhouse gas (GHG) emissions. In addition, the agricultural sector is responsible for 92% of all fresh water usage with animal products having the highest water footprint per unit of product. Climate change is also causing challenges to global food security. As a response to these sustainability challenges, novel food production technologies are under constant development. Cellular agriculture is an example of an emerging field that aims at using cell-culturing technologies for producing food products. In this paper, we present the preliminary results of a life cycle assessment study (LCA) of an industrial scale production of microbial protein (MP).

The MP consists of single cell bacteria produced in a bioreactor that is supplied with hydrogen through onsite electrolysis and a supply of liquid carbon dioxide (CO_2). The hydrogen serves as a source of energy while CO_2 is needed as a carbon source. Other essential nutrients are fed to the bioreactor to enable bacterial growth. The idea of MP production was to disconnect food production from the conventional reliance on agricultural land and the consequential environmental problems. However, MP production is dependent on industrial electricity with the potential to use renewable energy sources.

Method

We used a LCA with a cradle-to-gate approach and focused on climate change, land use, water use, and eutrophication. Several of the inputs required for the production of MP, such as ammonia water, CO_2 and steam, could be produced onsite using renewable energy. In addition, wastewater could be recycled onsite rather than being send to the municipal wastewater treatment plant. We therefore created three scenarios in which we vary the dependency on solar energy and recycling of water. Business-as-usual (BAU) in which the Finnish electricity mix is used and no recycling of wastewater is assumed. Renewable electricity (RE) in which electricity consumption and steam is generated with PV cells and water is recycled. Fully renewable (FR) in which, additionally to the RE scenario, the above-mentioned inputs are produced onsite using PV cells. We measured water use by the state-of-the-art AWARE method. For other impact categories, we used ReCiPe 2016 Midpoint (H) method. We carried out the assessment using SimaPro 8.5.2 software.

Results

Preliminary results of the LCA per kg of MP.

	BAU	RE	FR	Beef
Global warming potential (kg CO_2-eq)	18.7	11.0	6.4	45 – 209*
Freshwater eutrophication (kg P eq)	0.0047	0.0066	0.0052	-
Marine eutrophication (kg N eq)	0.00074	0.00077	0.00049	-
Land use (m^2a crop)	1.96	0.23	0.14	75 – 165*
AWARE (m^3)	4.58	4.86	4.17	883[#]

Discussion/Interpretation

The preliminary results suggest that MP could have lower environmental impacts compared with other sources of protein. However, as the industrial energy requirements in MP production are relatively high, the level of GHG emissions depend on the source of energy. The scenarios that consist of higher share of solar energy, had lower environmental impacts with the exception of eutrophication potential. This was explained by the fact that solar panel production causes higher eutrophication potential than the production of current Finnish electricity mix.

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Carbon footprint of protein from organic multispecies mixtures processed in a biorefinery

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Abstract

Problem and Aim

Reducing the climate impact of agriculture is one of the main challenges and soil carbon sequestration holds a mitigation potential. Including more grass lays in the crop rotations has the potential to increase soil carbon sequestration (Cong et al. 2018a) and at the same time increase biodiversity on the arable land (Knudsen et al. 2019). It furthermore has a potential to reduce the pressure of certain weeds and increase productivity (Cong et al. 2018b), which is especially beneficial in organic crop rotations. Increasing the diversity in the grass lays will potentially benefit biodiversity (pollinators) even more depending on the number of cuts per year (Dupont 2019).The biomass from these multispecies mixtures can be used in a biorefinery to produce a protein concentrate and a residual fibre fraction. The protein concentrate can be used for feeding monogastrics to replace imported soybean, while the fibre fraction can be used as cattle feed. Thus, producing protein from multispecies mixtures has a potential climate benefit which can be investigated by using life cycle assessment (LCA).

The main aim of the study was to asses the climate impact of using organic multispecies mixtures for protein production in a biorefinery.

Methods

Three different multispecies mixtures and two cutting regimes (two or four cuts per year) was evaluated. The biomass were refined to protein concentrate for monogastrics, while the fibre fraction was used for ruminant feed. The climate impact of the mixtures at field gate and the protein concentrate at biorefinery gate was evaluated using life cycle assessment. Soil carbon sequestration in a 100-year perspective was included in the carbon footprint based on Petersen et al. (2013).

Results

The carbon footprints per kg DM of the multispecies mixtures at field gate were in the same range for all three mixtures. The hotspots in the agricultural production was the nitrous oxide emissions and the soil carbon changes. The climate impact of protein concentrates from the multispecies mixtures depends on the energy use in the biorefinery and the transport. If it is assumed that the energy from the residual juice is utilized via a biogas plant that supplies energy for the process, the energy from the residual juice can in theory cover the energy demand in the process, thereby reducing the carbon footprint considerably. The hotspot in the production of the protein concentrates was the agricultural production, transport and energy use.

Discussion

The carbon footprint of protein from the grass mixtures is highly dependent on harvest yield, transport mode and distances, and last but not least, the setup and energy utilization in the biorefinery process.

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Applying LCA for comparative study of FOX mobile apple juice production system and standard industrial apple juice production system

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Abstract

Problem and aim

Fruit and vegetable (F&V) sector is an indispensable sector in the EU, characterized by 21% of total agricultural output with only 3% of the EU cultivated land used, high proportion of farms and SMEs (>90%), high segmentation and highest reported waste per year (up to 50%) that originates mainly from stages of food production and retailing. Increasing global competitiveness in F&V sector coupled with unfair practices along supply chain worsened positions of farmers and SMEs, making it clear that changes in the EU F&V system are necessary. EU funded FOX project (Food Processing in a Box) is tackling the mentioned challenges through shifting the production in the sector from cost effective to value-added and from large-scale to small-scale (by innovative down-scaled processing technologies) simultaneously empowering SMEs and decreasing the environmental impact.

One case study of this project explores possibility of applying down-scaled mobile juice processing unit that can operate on farm level for increased fruit utilization and a shortened supply chain. Using novel fruit processing technologies for low oxygen juice extraction and mild preservation (vacuum press and pulsed electric field (PEF)), this unit enables production of juices with premium quality.

Aim of this study was to evaluate environmental impact of two different apple juice production systems, system boundaries shown in *Figure 1*, one based on FOX approach and the other considered standard larger-scale industrial system.

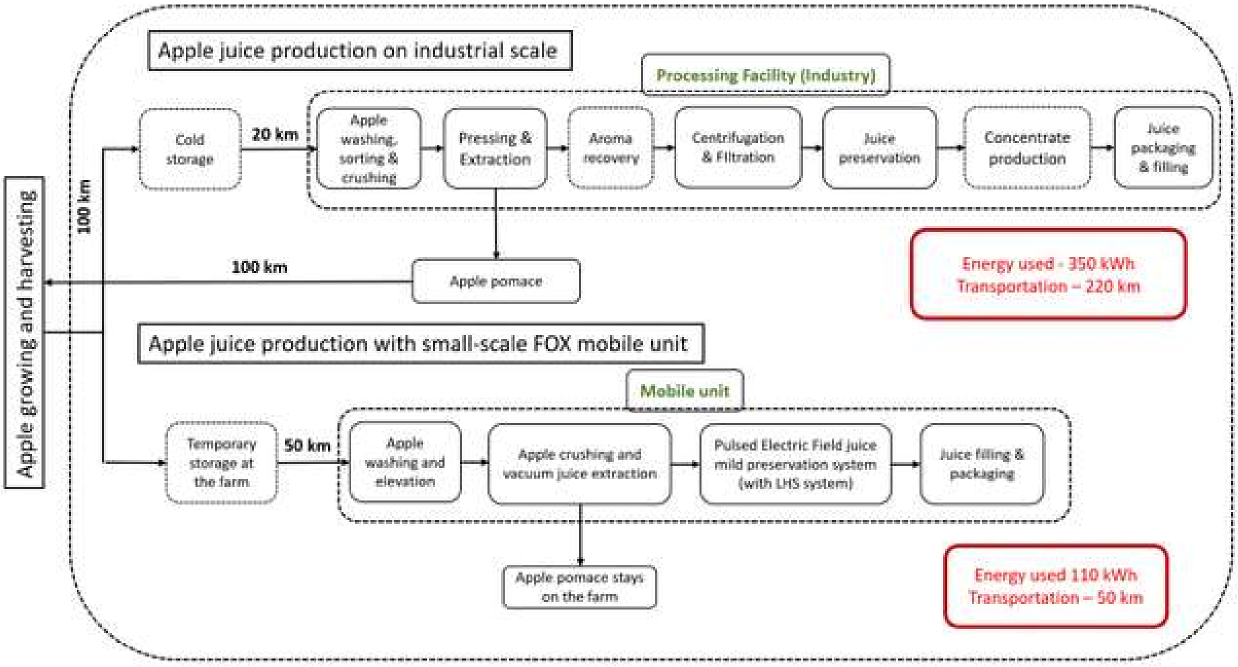

Figure 1. Comparative scheme of FOX approach apple juice production system and standard industrial apple juice production system ("farm to gate") with overall estimation of energy consumption for manufacturing and transportation of 1 ton of apples

Methods

The study relied on attributional LCA, ReCiPe2016 midpoint(H)V1.02 methodology. Defining the project goal as the assessment of environmental impact of two different apple juice production systems as a service, processing one ton of apples with either of the technologies was taken as a functional unit. The considered parameters were electricity (kWh) and transportation (tkm). System was evaluated from farm transportation till juice packaging ("farm to gate").

Results

First results showed that for processing one ton of apples into juice with FOX mobile unit 110 kWh is being used, while "standard" industry consumes 350 kWh energy. For transportation it was assumed that potentially apples from farmers would have to be transported to the mobile unit, settled in the region for up to 50 km by euro 3 trucks. For standard industry it was assumed that for transportation of apples to processing facility 120 km is needed and that for return of pomace (feed), if needed to be returned to farm, another 100 km transportation is needed by lorry truck. Overall, taking these two parameters (energy and transport) into consideration for processing 1 tons of apples with FOX mobile unit 45,7 kg of CO_2 equivalent along with 8,9 m^3 of water and 0,8 m^2 of arable land are being used.

Standard industry for processing of 1 tons of apples uses 82,3 kg of CO_2 equivalent, 7,67 m^3 of water and 1,73 m^2 of arable land.

Discussion

From obtained first results it can be concluded that for processing the same amounts of apples under defined system boundaries and assumed conditions, FOX mobile units require less energy, less arable land and somewhat more water usage. Emission of carbon-dioxide is lower in case of FOX mobile unit approach than in case of standard juice processing system. Further studies that would include more parameters and more potential scenarios are necessary to examine in more detail FOX mobile unit environmental impact.

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Life cycle assessment of cultured meat –current state of the art, new findings and future research needs

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Abstract

Livestock production for food is one of the main contributors to global environmental change. As a response to the challenge to reduce livestock production, researchers have started to develop novel technologies for producing meat by using tissue engineering and cell culturing technologies familiar from medical industry. The aim is to produce identical products with livestock meat, so that consumers would not need to change their dietary preferences. Cultured meat is produced by multiplying and growing livestock cells in a bioreactor in nutrition medium[1]. This technology requires substantially less animals for meat production, as animals are only needed for donating cells. The initial cells can be obtained from the muscle tissue of a living animal by using fine needle biopsy. Satellite cells extracted from the biopsy are multiplied in a bioreactor in nutrition medium consisting of essential macro- and micronutrients. Once the desired number of cells have been obtained, the cells are differentiated to muscle cells. After differentiation, the cells start to fuse together to form muscle tissue. Other cell types, such as fat, can be co-cultured in the process to improve the taste and texture of the product.

A few studies have estimated the environmental impacts of cultured meat produced in large scale bioreactors[1,2,3,4,5] and show high variation in the estimates. The aim of this paper is to i) discuss the current state of the art of understanding the environmental impacts of cultured meat and reasons for the varying environmental impact estimates, ii) present some new insights in the environmental impacts of cultured meat based on an ongoing project, iii) discuss what research would be needed to improve the estimates of environmental impacts of cultured meat.

Literature review yielded only two original LCA studies of cultured meat published in peer-reviewed journals[1,2] and one conference publication[3] presenting preliminary results. In addition, two papers[4,5] used data from previous studies and changed data for some processes and/or used different impact assessment methods. The main reasons for the variations in the results of the existing studies

were due to different assumptions regarding the nutrition medium components or production methods, differences in the bioreactor system design, source of energy and impact assessment methods used.

Lynch et al.[5] assessed the climate warming impact by using 1000 year timeframe instead of the 100 years global warming potential that is commonly used in LCA studies. They found that after 100 years some of the cultured meat production systems had higher warming impact than some beef production systems. This was explained by the fact that the greenhouse gas emissions from cultured meat production are mainly carbon dioxide whereas beef production emits substantial amounts of methane. Methane has an atmospheric lifespan of only around 12 years whereas carbon dioxide accumulates in the atmosphere and stays there, unless it has been captured by vegetation.

The new insight from the ongoing LCA study highlights the significance of the cell-yields and growth medium use efficiency on the environmental impacts of cultured meat production. The study also illustrates how different process design options can have a major impact on the energy use and GHG emissions.

In order to understand better the potential environmental impacts of cultured meat production, more LCA studies with different system designs are needed. In addition, consequential LCA approach would be required to estimate the environmental impacts of producing co-products from livestock production.

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Life cycle assessment of cultured plant cells

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Abstract

Problem and Aim:

World's growing population in this climate era makes food security as one of the most critical issues to be tackled. Conventional food production systems appear vulnerable to the unpredictably fluctuating climate that has been evidently experienced all over the world in recent years. Therefore, climate-proof food production technologies such as plant cell culture will likely play a crucial role in the near future. Plant cell culture can be applied for broad range of applications and for many different types of plants. However, this novel technology can be energy intensive, which could lead to intensify and accelerate the climate change depending on the source of energy used. To secure food production while minimizing adverse consequences, the environmental impacts of novel food production systems need to be holistically assessed before implementation.

Method:

Here, we apply life cycle assessment to assess global warming potential (GWP) associated with cultured plant cells and compare it with conventional production systems. Different types of cell cultures, i.e., cloudberry, lingon and tobacco (BY-2), are studied and their impacts are analyzed. In addition, hot-spot analysis is conducted to identify opportunities for impact reduction.

Results and Discussion:

The contribution of electricity demand to the overall GWP is expected to be high for all the cell cultures considered in this study. As such, potential impact reduction by using renewable energy source is investigated. Also, significant magnitude of environmental impact difference among different cell lines due to the varied yields is projected. Advantages and disadvantages of application of plant cell culture for each plant species are determined and the role of plant cell culture in the future food production is discussed.

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Life Cycle Assessment of Cell-Cultured Chicken Ovalbumin

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Abstract

The global food systems are increasingly challenged by the population growth, climate change, animal welfare and change of land use. More food needs to be produced in declining cultivation conditions

while market demand and ethical considerations set stricter societal preconditions for the livestock production in the future. Life cycle assessment (LCA) studies about cellular agriculture, defined as utilization of cell-culturing technologies for food production, have indicated promising results regarding water and land use whereas impacts of energy usage remain somewhat controversial due to the energy intensive cell-culturing processes. Cellular agriculture as a production sector provide cellular products made of cells such as cultured meat and acellular products made by cells such as proteins provided by microbes. One of the acellular product innovation is the cell-cultured chicken ovalbumin produced by *Trichoderma reesei* developed by the VTT technical research centre of Finland ltd (VTT). Ovalbumin produced by fungus is purified and concentrated before drying to a powder. The objective of this study is to estimate the greenhouse gas emissions, energy use and land use for industrial scale production of cell-cultured chicken ovalbumin powder. Based on the previous LCA-studies on cellular agriculture, the working hypothesis was that cell-cultured ovalbumin is more energy efficient and have less greenhouse gas emissions compared with the conventional egg powder production. The environmental impacts were modelled by using life cycle assessment. The preliminary results indicate lower greenhouse gas emissions compared with traditionally produced dried egg white powder. Novel foods like chicken ovalbumin produced by *T.reesei* can be one answer to food challenges we are facing, but legislations and consumer acceptance are crucial.

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The Potential of Anaerobic Digestion for Sustainable Food Production

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Abstract

Problem and aim

Protected cultivation, i.e. growing food in greenhouses, has significant potential for increased sustainability and resource efficiency. In 2015, the total area under protected cultivation in the EU was approximately 17,500 hectares and it is continuing to increase [1]. "*Digeponics*" has been proposed as a method of sustainable food production by integrating anaerobic digestion (AD) with protected cultivation, similar to existing aquaponic and hydroponic growing systems [2]. The aim of this study is to determine the sustainability of optimising all outputs from AD systems for use in protected cultivation.

Method

Consequential life cycle assessment will be used to assess the environmental impacts of implementing this circular system of food production. The geographic scope of the study is Dublin, Ireland, where approximately two-thirds of protected cultivation takes place nationally [3]. Fruit and vegetables have the highest wastage rates of any food; in Europe it is estimated that 20% are wasted at the farm level [4]. Growers can also have significant amounts of waste in the form of peelings from processing in packhouses. In digeponics, fruit and vegetable waste can produce biogas and digestate which can then be used as renewable resources in protected cultivation.

(Expected) Results

Currently, protected cultivation is resource-intensive. Artificial lighting and heating used in greenhouses require a substantial amount of energy which is usually supplied by fossil fuels. The AD process can provide both heat and electricity for greenhouses via a CHP, as well as carbon dioxide for the CO_2

supply. Frequently there is low demand for the heat output from AD systems, so this integration ensures that heat is not wasted. For growing media, peat is the main constituent in the EU [5]. Peat is a limited resource and its extraction has negative environmental impacts. The digestate that is produced by AD can be used as an alternative growing medium to substitute peat. The results of this study will show the net environmental change of replacing resource-intensive inputs in this novel system.

Discussion/Interpretation

Consequential life cycle assessment is appropriate for this study as it reflects the physical causalities in the system and is useful for decision support. Combining protected cultivation with biogas production could become a sustainable alternative food production system.

Literature

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Life Cycle Assessment of Sustainable Broiler Production Systems: Low-Protein Diet and Litter Incineration

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Abstract

Problem and aim

Animal products has large impacts on the environment as indicated by various research results and reports (for example, Poore & Nemecek 2018). It is increasingly required to produce animal products in the more sustainable way, and thus sustainable animal production system needs to be designed. The aims of this study are to evaluate environmental impacts of conventional broiler chicken production in Japan (CN) using life cycle assessment (LCA) method and to compare them with those of broiler production with mitigation options: low-protein diet supplemented with synthetic amino acids (LP), incineration of broiler litter (IC), and combination of LP and IC (LP+IC).

Methods

A broiler LCA model was developed assuming an average productivity and feeding strategy in Japan as well as based on literature and LCA databases. The functional unit was defined as 1kg-liveweight of broiler chicken. For CN, it was determined that broiler chicken is slaughtered at 52 days of age with liveweight of 3.06 kg as an average productivity (Ogino *et al.* 2017). Broiler manure (litter) is treated by composting without forced aeration. Regarding LP, the diet was formulated with lower crude protein (CP) level by 1.3 point than in CN and supplemented with synthetic amino acids so that the contents of methionine + cystine, lysine, threonine, and tryptophan were the same as in the diet for CN according to the results of a feeding study. Other conditions of LP are the same as those of CN. For IC, broiler litter is incinerated instead of treated by composting. The heat generated from litter incineration is utilized for heating broiler house especially during the chick stage, and the reduction rate of fuel consumption for heating was determined to be 80%.

Results

The environmental impacts of CN were 1.71 kgCO_2e for climate change, 51.5 gSO_2e for acidification, 18.0 gPO_4e for eutrophication, and 18.4 MJ for energy consumption. Since broiler manure management has lower emission factors of nitrous oxide (N_2O), the effect of low-protein diet on greenhouse gas (GHG) emissions were very limited. However, a large amount of ammonia (NH_3) is emitted from composting of broiler litter and the low-protein diet reduced nitrogen excretion and consequent NH_3 emission, and thus LP had lower acidification and eutrophication potentials than CN. The IC system reduces fuel consumption by utilizing the heat generated from litter incineration for broiler house heating and thus had lower GHG emissions and energy consumption. Furthermore, IC reduces NH_3 emission from the waste treatment process by incineration and thus had lower acidification and eutrophication potentials even if NOx generation by litter incineration was taken into account. The LP+IC system, combination of LP and IC, had 16%, 50%, 25%, and 17% lower environmental impacts than CN for climate change, acidification, eutrophication, and energy consumption, respectively.

Discussion

Broiler chicken has relatively small environmental impacts among animal production systems. Nevertheless, the results of this study suggest that there are still mitigation opportunities for broiler chicken, and thus the broiler production system with mitigation options helps animal products are produced and consumed in a sustainable society.

Literature

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Social life cycle assessment of autonomous slaughterhouse cell systems

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Abstract

Problem and aim

This paper presents the structure of a social life cycle assessment (S-LCA) for autonomous slaughterhouse cell systems, in the context of the new Horizon 2020 project RoButcher (grant no 871631). Robotised slaughter systems will have social impacts, most significantly related to the work situation of slaughter house workers and their local communities. When developing such technology, it is therefore important to assess also the social consequences. S-LCA is a structured approach to such assessment. An important potential social consequence is the reduction of employment opportunities in the sector, or the perception of such insecurities. However, previous studies from semi-automotized systems (Valente et al., 2019) have shown innovative abattoir system can create job opportunities for engineers and technicians that can push towards professional development, as well as more opportunities for women due to lighter work generating equal opportunities in a sector dominated by man as working force. The Meat Factory Cell (MFC) concept might generate local jobs, decreasing the migration rate and potentially also the social risks related to social dumping. However, the Valente et al. (2019) study confirms that even if the job situation might become more stable for some stakeholders, the total number of jobs created will be reduced, potentially affecting the local communities as a stakeholder to MFC. Other social impacts can also be a consequence of MFC.

The aim of the study presented here is to outline a S-LCA analysis and end user engagement via focus groups for comparing the social performance of pre-pilot autonomous cell systems against post-pilot autonomous cell systems. The goals are to understand the end user effects of the MFC concept and to increase the S-LCA knowledge in the European meat sector.

Methods

S-LCA is applied to a pre-pilot and post-pilot case study for MFC. The focus group on the end users is utilized for establishing a discussion among individual workers and organizations regarding social aspects in the deployment of the MFC concept. The needs of the workforces are evaluated by the focus group studies, through the engagement of meat sector expert and other end users. The data collection is done by direct engagement (e.g. interviews, focus groups and questionnaire) and indirectly by using hotspot database as the Product Social Impact Life Cycle Assessment database (PSILCA) for the European meat sector.

Results

Previous results for the semi-automatized system (Valente et al.,2019) indicate that the social impact of the innovative concept might be lower than the conventional abattoir with respect to lower risk of injuries and incidents, less physically demanding work and request of higher competence leading to higher salary. On the other hand, this may lead to loss of jobs especially for lower qualified workers.

Since this study is in the starting phase, preliminary results will regard the combination of literature studies, the results from the PSILCA database and the results from the interviews and questionnaire to the pre-pilot scale of the MFC concept.

Discussions and interpretation

In the paper, we will discuss the preliminary results, especially regarding the challenges of using S-LCA to evaluate the social performance of novel technology products. Challenges are related to the lack of data on the new technologies, the absence of harmonization in accounting social impacts and the combination of primary, database and proxy data.

Literature

Valente, C.; Møller, A.; Johnsen, F.M.; Saxegård, S.; Brunsdon, E.R.; Alvseike, O.A.2019 Life Cycle Sustainability Assessment of a novel slaughter concept. Submitted to Journal of Cleaner Production, under review.

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Environmental performance of insect protein for fish feed

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Abstract

Problem and aim

Europe is experiencing a protein deficit for animal feed and is forced to import substantial amounts of protein. EU aims at increasing protein self-sufficiency, and protein from insects is one of the alternatives which could be used to fill the gap. The environmental performance of insect production is sparsely reported in literature and studies of insect protein show large variations in results and methodologies applied, making it difficult to compare between studies. Hence, this is an attempt to reproduce results, combining the inventories published in peer-reviewed papers with background data from only one database, making a consistent life cycle assessment (LCA) based on the PEF methodology.

Methods

LCA according to ISO 14040 has been used together with information from the product environmental footprint category rules (PEFCR) for feed for food-producing animals (FEFAC 2018), resulting in using six environmental indicators. In this abstract, however, only climate change results are shown. The study is based on attributional LCA and ecoinvent has been used as database for background processes.

The functional unit is 1 kg of protein delivered at Averøy, on the west coast of Norway.

Life cycle inventory data have been extracted from studies using original data only. Mealworm *(Tenebrio molitor)*, black soldier fly larvae *(Hermetia illucens)* and housefly larvae *(Musca domestica)* are the three species for which most data are available. Hence, focus has been on these three insect types.

Some studies were excluded because they were literature studies and did not contain original data, others because their focus was waste of animal origin; using a diet for insects that can be used directly as fish feed seems to be a waste of resources. This left us with eight scenarios with a mix of insect species and diets.

Results

According to literature, the most important parameters affecting the environmental footprint when rearing insects are insect species, feed and location/temperature. Even though our study does not have enough cases to make any statistical conclusions regarding species and location, it is quite obvious that the feed is dominating the results. Hence, we have grouped the results into the following three diet categories:

- Vegetable feed with high economic value (mixes of grains, flour, bran, vegetables and beer yeast)

- Vegetable feed with low economic value (distiller's dried grains with solubles, spent grains, cookie remains)

- Pig manure

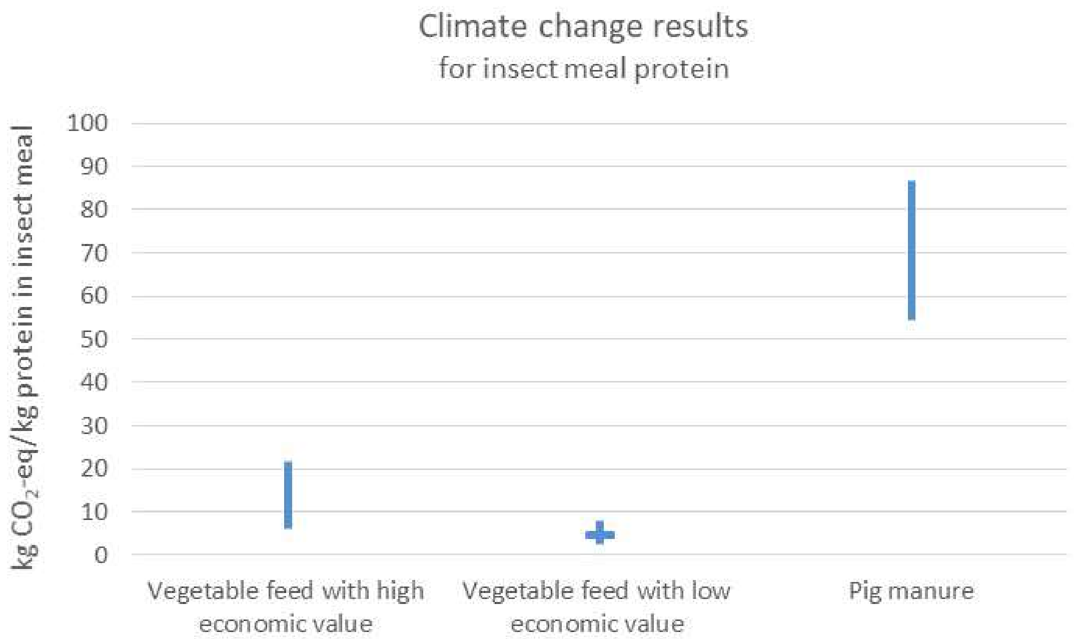

Figure 1 Climate change results for insect meal protein, divided into different insect diets

Discussion

In our study, the pig manure cases (housefly larvae) are clearly most burdensome. The burdens are mainly connected with use of energy for rearing and processing, and the insect diet (includes milk powder). The original study was constructed for removal of pig manure, hence it had more than one output. In our reproduction of this study, however, all burdens have been allocated the insect meal. Hence, the pig manure cases are very dependent on allocation principle, and the results given are conservative.

For the 'high economic value feed' cases the feed contributes the most (over 65%). When the diet is changed to low value resources, the climate change results are substantially decreased, becoming more dependent on energy use for rearing and processing into insect meal.

The results show that using frass (insect manure) to substitute mineral fertilizer reduce the climate change results by 12%. Transport from Europe to the Norwegian west coast contributes only marginally to the climate change results. Direct gas emissions from insects and substrate is not very important, either.

Literature

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Climate impact of house cricket (Acheta domesticus) production for human consumption

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Abstract

Problem and aim

Edible insects provide a new protein source and thus can help increase protein self-sufficiency. They also potentially are associated with a lower environmental burden compared to traditional livestock products. However, very few studies exist on the environmental sustainability of commercial insect production. The goal of this study was to assess the climate impact of small scale house cricket production in North European conditions.

Methods

The climate impact of house cricket production is assessed using attributional Life Cycle Assessment (LCA) taking into account the greenhouse gases CO_2, CH_4 and N_2O. The system boundary included all material and energy inputs from cradle-to-gate, including transport (Figure 1). The functional unit was 1 kg of house cricket (edible weight).

The feeding was based on mixed grains and side flow lettuce biomass from greenhouse production. House cricket excreta were further used for biogas production and the climate impact was allocated to the outputs (house crickets for human consumption, excreta nutrients) based on their relative economic value.

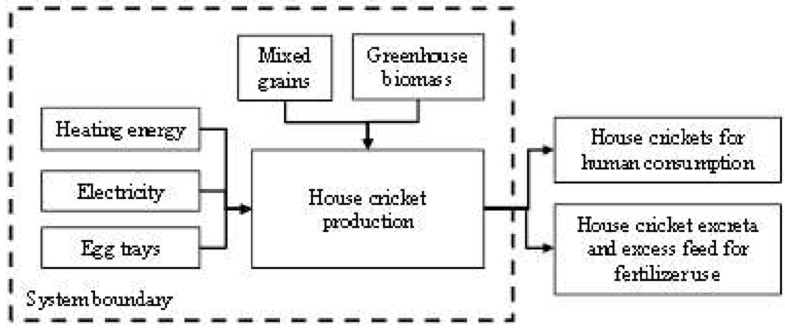

Figure 1. Simplified flowchart of the system boundary of house cricket production from cradle-to-gate. Transport of soybean meal (included in mixed grain feed) to Europe is included.

Results

Direct energy use and production of the mixed grain feed caused the majority of the environmental impacts of house cricket production. The climate impact of house crickets varied from 3,15 to 4,95 kg CO2 eq/kg depending on feeding level and energy use option.

Discussion

The results are greater than what was reported by Halloran et al. (2017) for field cricket and house cricket production in Thailand (1,7-2,6 kg CO2 eq/kg), which can be explained by greater energy need in the north European conditions. The GWP was approximately at the same level that of many traditional protein sources (Hartikainen & Pulkkinen 2016) when compared when compared based on the protein content of the products (Figure 2). Optimising direct energy use and finding suitable side flow based feed ingredients are the most important ways to reduce the environmental impacts of the cricket production in the future.

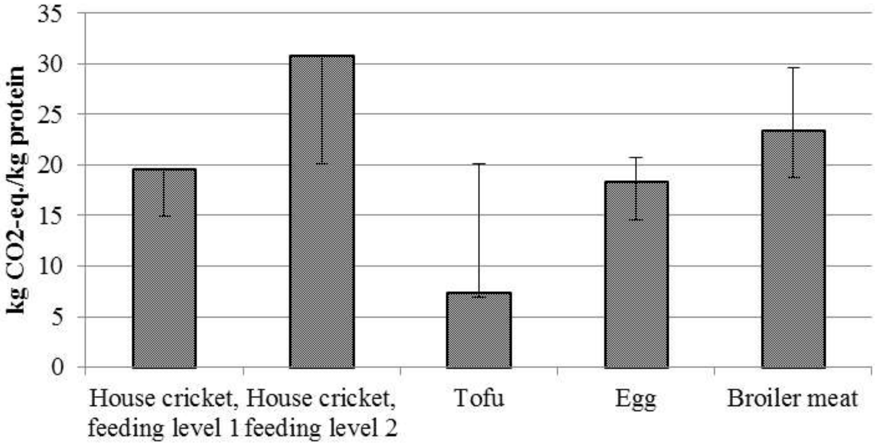

Figure 2. Climate impact results compared to alternative protein sources, based on Hartikainen & Pulkkinen 2016.

Literature

Halloran A, Hanboonsong Y, Roos N, Bruun S (2017) Life cycle assessment of cricket farming in north-eastern Thailand. J Clean Prod 156:83-94

Hartikainen H, Pulkkinen H (2016) Summary of the chosen methodologies and practices to produce GHGE-estimates for an average European diet. Natural Resources Institute Finland, Helsinki, Finland

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Environmental performance of protein from wood compared to other protein sources

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Abstract

Problem and aim

Europe is experiencing a protein deficit, which largely is filled by importing protein products, especially from the US and South America. For fish feed, the protein deficit will likely increase in the coming years, due to restrictions on the use of fishmeal from wild caught fish. Both increased soybean production on the American continent and increased production of fishmeal from wild caught fish are known to lead to detrimental environmental impacts. There is therefore a need to find alternative and more environmentally sustainable protein sources.

So-called single cell protein (SCP), i.e. protein made from microorganisms, may provide a solution to close the protein gap while imposing relatively low environmental impacts. This paper investigates the environmental performance of a SCP made from wood and compares it to the environmental performance of other protein sources.

Methods

The main method used to study the environmental performance of the protein sources has been life cycle assessment (LCA), whereas a systematic literature review was used in order to select the other protein sources to study.

The selection of other protein sources to study was based on four criteria, including that the protein source: 1) is produced in, or imported to, Europe in large amounts; or 2) is described as a future important protein source in Europe; and 3) is relevant to substitute in production of fish feed; and 4) has existing data for life cycle assessment.

An LCA for SCP from wood was made in parallel with the selection of protein sources. The product environmental footprint category rules (PEFCR) for "Feed for food-producing animals" (FEFAC, 2018) was used as basis for the LCA method choices. This choice enables the results to be compared to future studies of feed ingredients under the PEF regime, although the choice of datasets is different from those approved to be used by the PEFCR.

Determining allocation keys and selecting environmental impact categories were two important choices steered by the PEFCR. Allocation is performed according to mass in transportation stages and according to economy in connection to handling by-products. The selected environmental impact categories are: 1) climate change; 2) land use; 3) water scarcity; 4) respiratory inorganics; 5) acidification; and 6) eutrophication. These were specified as especially relevant for feed production chains. Some categories use methods that have not been widely applied in previous LCAs.

Data was compiled through engineering documents and specific sources for the SCP from wood. All LCI data for the other production chains was found in journal articles and databases and several different sources were crosschecked. All LCI data for all production chains was translated into datasets from the ecoinvent database V. 3.4. Analyses were performed with SimaPro V. 8.5, including the PEF method as adjusted to the software.

Results

The first result was the actual selection of protein sources. The protein sources that ranked highest on the four criteria were: 1) insect meal; 2) proteins from soybeans; 3) fish meal; 4) rape seed meal; and 5) other single cell proteins – bacterial protein meal (BPM) and yeast protein concentrate (YPC) made from other resources than wood.

The second result was the environmental performance of the different protein sources. Absolute values will be presented in the final paper, while the figure below shows the relative contribution of each protein source compared to the worst performing protein source in each environmental impact category.

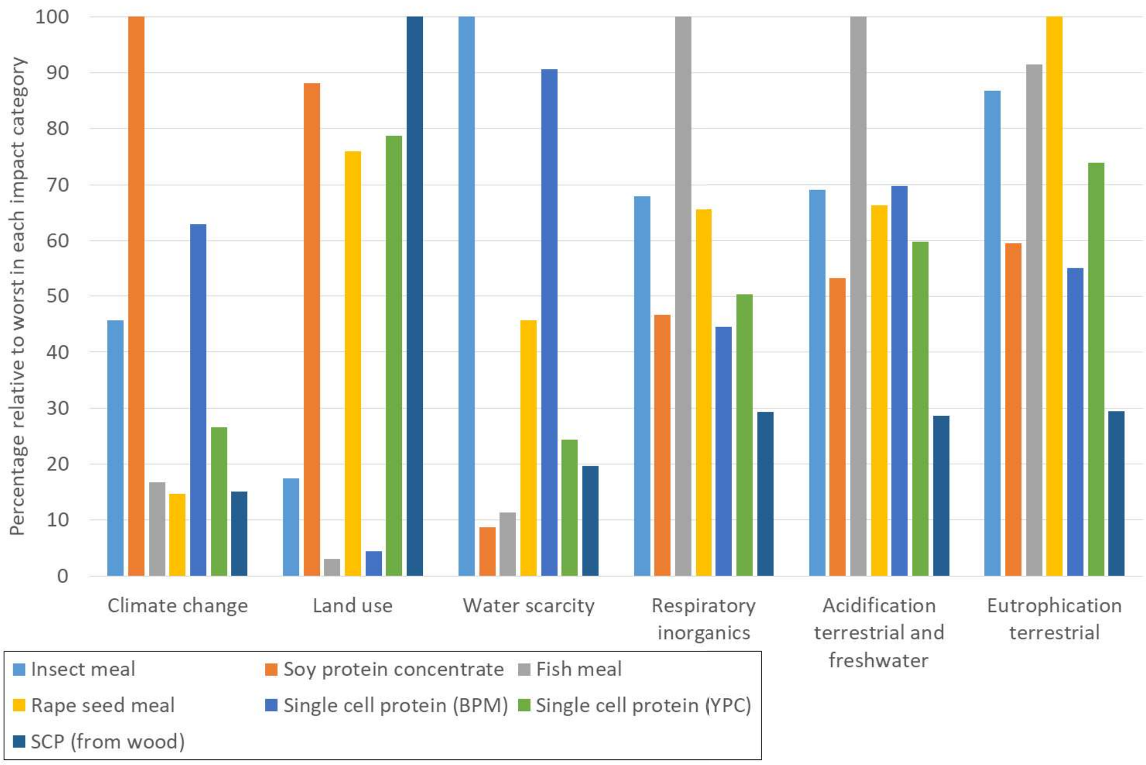

Figure 1 The relative contribution to the environmental impact categories from the various protein sourcees.

There is no protein source with better or worse environmental performance than all the others in every impact category.

Discussions/Interpretation

Further investigation is needed to rank them according to overall environmental performance, and this is included in the final paper.

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Reducing the resource use of the food production system by incorporating milder fractionation techniques

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Abstract

Food crops are currently fractionated into more or less pure ingredients such as proteins and starch isolates or concentrates, which are subsequently mixed again in the formulation process of consumer foods. The procedure to fully fractionate crops requires a lot of resources (e.g. energy, water, and chemicals), and leads to significant losses of the targeted component, while the side streams often have been degraded (van der Goot et al., 2015). Therefore, a shift towards functionality driven fractionation is proposed (Geerts et al., 2018): the creation of fractions targeted at the right functionality rather than at molecular purity.

To achieve this, gentle or mild, processing techniques have been developed, which use significantly less energy, water, and chemicals to produce less purified ingredients with promising functionalities. At the same time, the yield of the targeted components is increased and the degradation of side streams reduced (Berghout, Pelgrom, Schutyser, Boom, & Van Der Goot, 2015). To optimize the use of all fractions, the functional fractions can be used individually or blended to produce intermediates that adhere to the product requirements (Figure 1). However, as the mildly fractionated fractions are complex and therefore not straightforward to use in food products; it still must be conclusively shown that the production of these functional ingredients results in a reduction of resource use in the overall food production system.

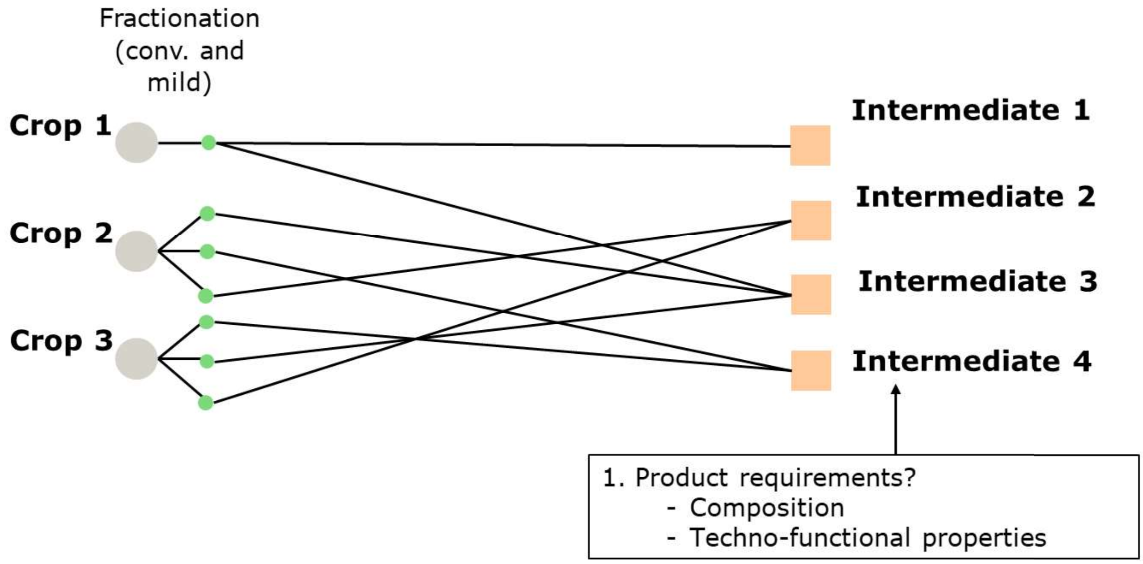

Figure 1. Schematic overview of the intermediate production from conventional and mild fractionation processes.

A multicriteria approach has been proposed to select the optimal conventional and mild fractionation pathways and intermediates to create versatile ingredients that fulfil the compositional requirements of the food assembly industry (Jonkman, 2018). However, this model aimed to optimize the energy and water consumption of *only* the fractionation processes. As the footprint of the cultivation of the crops was not considered, this approach resulted in an undesired two-fold increase in by-product volumes. Therefore, we here assess the impact of incorporating mildly processed ingredients in de food ingredient industry on the resource use, including the footprint of both cultivation *and* fractionation.

This is illustrated using a case study in which yellow pea and lupine are fractionated through mild and conventional fractionation techniques and were matched to a food product portfolio. The carbon and water footprint from crop to intermediate was determined for all fractions through a Life Cycle Assessment using SimaPro 8. Subsequently, the set of intermediates with a minimal footprint was determined using Fico Xpress optimisation. The incorporation of the complete footprint of the fractions led to a significant decrease in the number and volume of by-products. In addition, it was found that the use of mildly processed intermediates decreased the water and carbon footprint of the food production industry compared to the current way of refining, provided that we include all aspects, from cultivation to intermediate.

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Environmental impact assessment of black soldier fly larvae production as a feed

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Abstract

While insects are increasingly valued for their suitability as a feed in livestock and aquaculture production [1], their environmental superiority to conventional feed counterparts remains largely unconfirmed. To be a viable alternative to conventional feed, insect production systems need to showcase equivalent nutrient outputs at competitive environmental costs. For this, black soldier fly (*Hermetia illucens*) larvae (BSFL) are recognized as a suitable candidate, particularly due to their efficiency in converting a broad range of low-opportunity-cost organic material into valuable protein [1]. However, few studies exist to date which investigate the environmental performance of BSFL feed production systems using primary data [2-4]—therefore their eco-efficiency remains poorly understood. This study addresses this deficiency by assessing the environmental impacts associated with a Swiss facility producing BSFL meal for use in fish and poultry feed.

To this end, production scenarios were defined and assessed via attributional (aLCA) and consequential life cycle assessments (cLCA). The BSFL production system was observed in four distinct stages: adult population maintenance and egg production, nursery, larvae grow-out and, lastly, harvesting and processing into the final product at facility-gate. Upstream processes included external production and sourcing of diet components, electricity and water. Infrastructure was excluded. For the cLCA, the BSFL system was expanded to account for indirect impacts of diverting organic materials away from biogas or compost production and into the BSFL diet. The functional unit was 1 kg defatted, milled BSFL (dry matter: 96%, protein: 59%). Primary data on BSFL meal production was provided by a research-pilot scale facility in Switzerland [5]. Fish and poultry performance trials with the BSFL feed confirmed its substitutability with fish and soybean meals, respectively. Regionalized secondary data from ecoinvent 3.6 described all upstream processes. Together, these datasets established the baseline.

Scenario analysis served the purpose of exploring the influence of BSFL production scale and location on environmental performance. Scenario development was guided by literature and experts and resulted in four scenarios: baseline at 0.7 t a^{-1} final product (b), production scaled to 20 t a^{-1} (b20) and the b20 scenario realized in both Mexico (b20M) and France (b20F). To assess potential impacts, IMPACT World+ was chosen due to its recently updated and spatially resolved methods and inclusion of additional substances [6]. All 18 midpoints were justified and used, and impact assessment calculations and sensitivity analyses were carried out using the open source LCA framework, Brightway2 [7].

Both aLCA and cLCA baseline results reveal higher impacts than literature values for fish and soybean meals. Electricity-use and direct emissions of larvae contribute the most to global warming potential (GWP). The increased production level in b20 made more efficient use of production equipment and thus absorbed a portion of impacts—yet not enough to deem BSFL meal superior. When empirically measured direct emissions were replaced with assumed values found in present BSF LCA studies [2-4], results generally agreed. GWP impacts approached competitive levels in b20M and b20F which can be attributed to less use of climate control units in Mexico and the nuclear-based energy mix in France.

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The life cycle assessment of nonthermal food extraction technologies

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Abstract

Food production system has a significant impact on the environment. Conventional thermal methods are mostly used in the food industry for their efficacy and safety. Such technologies are based on the indirect heat transference into the product by conduction and convection principles, using a heating medium generated by combustion of fossil fuels. This processing often demands some restrictions and energy inefficiencies that derive from slow heat conduction, heat losses through the equipment surfaces and thermal damage conducted by overheating. Not only that excessive heat treatment lead to a considerable consumption of natural resources, but also cause undesirable protein denaturation and loss of valuable bioactive compounds leading to degradation of food quality and accordingly reducing the efficiency of food chain [1]. Thermal preservation treatment has been highlighted as one of the most energy consuming stages in food processing sector [2]. With the aim of protecting and preserving the environment, scientists are finding new methods for food processing that are within principles of the sustainable development [3]. Novel nonthermal techniques use less energy and chemicals, reduce processing time, impact less on the environment (lower carbon footprint), produce less waste and have a potential for industrial scale-up. Also, conventionally used organic solvents for extraction are replaced by water or other environmentally acceptable green solvents. These nonthermal techniques include: pulsed electric fields (PEF), high-pressure processing (HPP), high-voltage electrical discharge (HVED), pulsed light (PL), irradiation (IRR), ultrasound (US) and ultraviolet light (UV) [4]. Our focus is directed towards the use of nonthermal technologies for "green" and sustainable extraction of natural compounds from various food sources, mostly plants. As usage of nonthermal technologies should have aim to achieve sustainable development and reduce impact on the environment, comparing with conventional extraction methods, our goal is to present their environmental impact. The life cycle assessment (LCA) is a promising tool for assessing the environmental impact associated with a product, process or activity [5]. LCA combines environmental accounting and management approach that considers all the aspects of resource use and environmental releases associated with an industrial system. Specifically, it is a holistic view of environmental interactions that cover a range of activities, from the extraction of raw materials and the production of energy, through the use, reuse, and final disposal of a product [6]. The goal is to implement LCA to nonthermal extractions and to measure the

environmental impact of the whole process, covering their life cycle from raw material extraction to waste treatment. The aim of the study is to identify potential improvements for each nonthermal technology and to provide an environmental assessment when selecting a technology for extractions. Results should present the potential of replacing thermal extraction methods with nonthermal one and measure the return of investment as an important investing factor for industries.

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Topic 8:

Agri-Food,

Dietary and Nutritional LCA

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Methodological challenges for combining qualitative future scenarios and LCA in the food and agricultural sector

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Abstract

Problem and aim

The scenario method is an established instrument in foresight and strategy development that supports the user with handling uncertainties. Scenarios explore the future and identify different future perspectives, thus provide a background for decision-making. Moreover, by unfolding scenarios, decision makers win awareness of the variety of future possibilities, uncertainties in surrounding environment and indicators of discontinuities. Since they are based on assumptions about future developments scenarios mostly include a wide range of qualitative descriptions and are presented as story lines about alternative futures. A life cycle assessment, however, is based on quantitative data as well as values and numbers related to the present, e.g. alternative options of products (studies unit versus reference unit). In this study a concept to combine future scenarios with a life cycle assessment will be developed. Scenarios of the future European food sector serve as a basis to test the conceptual framework of quantifying the qualitative descriptions and their subsequent combination with LCA.

Methods

Scenario method and LCA are in focus of the analysis. Qualitative information from scenarios will be transferred into quantitative data in the course of this study. That means that qualitatively described scenarios or aspects of these scenarios will be converted into variables in order to be incorporated into a LCA model.

Results

In the European research project Food processing in a box (FOX) that is a part of the Horizon 2020 Research and Innovation programme scenarios for the European food sector are developed. They serve as future framework conditions for innovative technologies, that are developed by other partners in this project. The focus here lies on mildly processed fruits and vegetables through innovative, small-scale technologies in flexible and mobile processing units to be used in regional food systems. This study will develop a concept of how to integrate the findings from the scenarios for the European food sector into LCA in order to future-proof the analysis of the lifecycle of products. This enables the technology developers to design their processes in a more robust, sustainable and market oriented way.

Discussion

The world is facing major global challenges with a high impact on food systems and food security. Climate change and digitalisation are examples for mega trends that have great impact on various stages of the food value chain. Consumer behaviour as well as the attitude towards sustainability in society are driving factors for the demand for diversified food. These aspects are discussed in scenarios within the project FOX. In this project scenario development as well as LCA is conducted for specific products and technologies. The consideration of qualitative aspects and alternative future developments in the LCA would set this quantitative method in a bigger context.

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Use of environmental indicators to improve agronomic practices

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Abstract

Problem and aim

The use of environmental indicators is a useful tool to know the environmental impact for the future sustainable agricultural management. A number of LCA tools are not including improvement practices or conversely, decision support tools are not based on environmental indicators. The LIFE AGROgestor and the associated websig platform contributed to a better management of agricultural fields based on

environmental indicators. This project proposes the collective management of various plots belonging to different farmers. With an environmental and economic profitability objectives, the aim is to improve the agronomic strategy of a collectivity, such farmers' cooperative. The platform will evaluate the initial planned agricultural management based on environmental and economic indicators and it will compared to new more sustainable itineraries. The aim of this study is to evaluate the environmental impact of the production of maize, wheat and barley based on LCA in a representative cooperative in Navarra.

Methods

Non-irrigated wheat and barley, and irrigated maize grain for feedstuff, have been assessed for 2018 production. All the agricultural activities from 283 wheat, 156 barley and 25 maize plots have been introduced to the AGROGESTOR platform, adding up to 464 hectares.

The following indicators have been assessed: yield (kg ha^{-1}), Carbon Footprint (CF) per tonne (kg CO_2 eq. t^{-1}) and per hectare (kg CO_2 eq. ha^{-1}), water consumption (W) (m^3 ha^{-1}), kilograms of nitrogen applied (N) (kg N ha^{-1}) and nitrogen profitability (NP) (euro kg^{-1} N). For the calculation of the CF, the specifications of the PAS 2050: 2011 and the IPCC 2013 method have been followed. The calculation of NP has been determined as follows, [(production price (€ kg^{-1}) * yield (kg ha^{-1}) – fertilizer Price (€) * fertilizer rate (kg ha^{-1})] / kilograms of N applied (kg N ha^{-1}).

Results

Table 1 shows that the most productive crop was maize with 11,723 kg ha^{-1} followed by wheat and barley with 5,828 and 4,928 kg ha^{-1} respectively. In terms of CF expressed per tonne, barley gave the highest values with 612 kg CO_2 t^{-1} compared to 578 kg CO_2 t^{-1} for maize and 511 kg CO_2 t^{-1} for wheat. The opposite result was obtained when expressing CF per hectare, since maize had a CF twice that of wheat and barley. In terms of N, application was 53 and 62% higher in maize than in wheat and barley respectively. Finally, the higher nitrogen profiability was obtained in maize.

Table 1. Results of the indicators for the three crops. The standard deviation is shown in brackets.

Crop	**Yield (kg ha^{-1})**	**CF (kg CO_2 t^{-1})**	**CF (kg CO_2 ha^{-1})**	**Water (m^3 ha^{-1})**	**N (kg N ha^{-1})**	**NP (€ kg^{-1} N)**
Wheat	5828 (372)	511 (90)	2998 (549)	0	180 (32)	5 (2)
Barley	4928 (672)	612 (99)	2995 (139)	0	170 (11)	4 (1)
Maize	11723 (1362)	578 (280)	6632 (3110)	4819 (544)	275 (0)	8 (1)

Discussion

With the difference in yield between crops, the carbon footprint of maize per tonne could be expected to be more downwardly differentiated from that of the other crops. This indicates that the increase in maize production based on higher electricity and nitrogen consumption has not offset the environmental impact, as evidenced by the result of the carbon footprint per hectare. Nevertheless, from an economic point of view there is a clear profitability of nitrogen in the case of maize due to the higher yield.

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"How much is the dish?" – Calculating External Climate Costs for Different Food Categories: A German Case Study

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Abstract

Although the agricultural sector is a main emitter of greenhouse gases globally, thorough economic analysis of its environmental and social externalities has not yet been conducted. Available research especially lacks differentiation between farming practices and various food categories. A method addressing this scientific gap is established in this paper and applied in the context of Germany. With LCA and meta-analytical approaches our methodology quantifies and prices the externalities of greenhouse gas emissions (GHG) arising during the production process of foodstuff. A differentiation is made between the categories of conventional and organic production as well as animal-, dairy, and plant-based products but also more narrow categories like beef (animal-based), milk (dairy), or cereal (plant-based). By doing so, a generalized method is presented, applicable for different country contexts.

The quantification includes the determination of food specific GHG emissions during the production process by usage of the material flow analysis tool GEMIS (Global Emission-model for Integrated Systems)[1] and follows a bottom-up approach. The hereby obtained emission data of conventional farming systems are translated to organic farming systems by applying meta-analytical methods to studies comparing the systems' GHG emissions directly to one another. Through monetization this emission data is translated into monetary values, which constitute the category specific external costs. For this we use the recommended cost rate of 180 €/tCO_2equivalent by the German Federal Environmental Agency (Umweltbundesamt)[2]. The ratio of external cost to the foodstuff's producer price represents the percentage surcharge which would have to be added on top of the current food price to internalize externalities from GHGs.

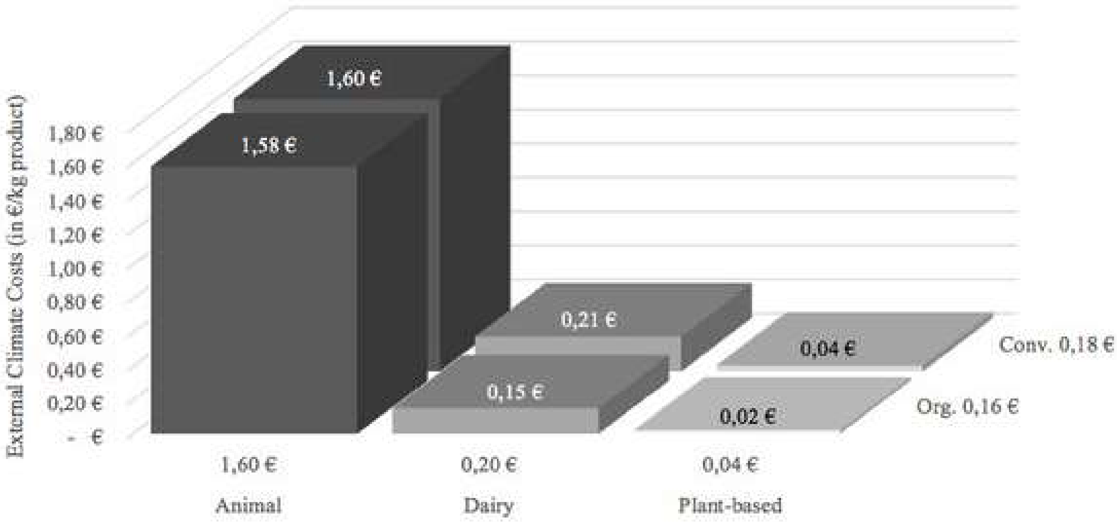

Figure 1: External climate costs for animal, dairy, and plant-based products from conventional and organic production systems

External climate costs of foodstuff show to be the highest for conventional animal products (1.60€/kg product; 97% surcharge on producer price level), followed by organic animal products (1.58€/kg; 46%), conventional dairy products (0.21€/kg product; 78%) and lowest for organic plant-based products (0.02€/kg product; 5%). In the case of animal products (conventional and organic), the level of external costs and surcharge costs can be explained in particular by the energy-intensive rearing of farm animals. This includes feed cultivation, heating and ventilation of the stables as well as the metabolism of the animals. These factors lead, among others, to significantly higher greenhouse gases emissions than for plant-based products. Comparing conventional and organic production practices, the absence of mineral nitrogen fertilizers in plant production and the reduced use of industrially produced feed in livestock production lead to lower external costs for organic products in all food categories studied.

The large difference of relative external climate costs between food categories and the absolute external climate costs of the agricultural sector suggest the urgency for policy measures that close the gap between current market prices and true costs of food. With our study we provide the quantitative basis for such measures.

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Sustainability of food consumption in the Ruhr Metropolis (Germany) under the One Health approach

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Abstract

Background

Moving towards healthier and more sustainable diets has become a global concern [1]. Food consumption generates 26% of anthropogenic greenhouse gas (GHG) emissions, 32% of terrestrial acidification, and 78% of eutrophication, globally [2]. Furthermore, potential sustainability tradeoffs may arise among environmental impacts, human health, and animal welfare. One Health (OH) is a new approach, which aims to bring together the health of humans, animals, and ecosystems to address complex health issues and sustainability [3]. Most Life Cycle Assessment (LCA) studies focus only on the environmental performance of food systems. We propose an LCA framework for quantifying impacts

from food consumption under the OH approach. We apply it to assess the sustainability of dietary patterns in the city of Essen in the Ruhr Metropolis (Germany) as an example of a Western diet in a densely populated area in Europe.

Method

We assess the impacts of the basket of food products representing the average diet in Essen. The functional unit (FU) is defined as the overall quantities of the most representative food items consumed per capita and year based on data from the German national nutrition survey (2008)[4]. The food basket includes 24 food items plus 8 beverages. Impacts are assessed from “farm-to-fork”, including agriculture (crop and livestock production), food processing, packaging, distribution, retail, and consumption (preparation and food losses), excluding final disposal and waste management. For the life cycle inventory, we rely on the Optimeal® dataset to quantify upstream and downstream impacts from food items by considering reference processes in the European context, e.g. global exports of raw materials for the European market [5]. System boundary and environmental impact category assumptions are based on the Product Environmental Footprint guidance [6]. Environmental impacts are estimated at both midpoint and endpoint levels according to the ReCiPe method [7]. For human health, we define quantitative indicators based on dietary risk factors attributed to the top three diet-related non-communicable-diseases in Germany, using epidemiological data [8]. For animal health, three animal welfare indicators are used [9], considering criteria from farm to slaughter (Figure 1).

Results-discussion

The food items that cause the most significant impacts of global warming, land use, acidification, eutrophication, and water consumption, are red meat (beef), sausages, dairy products, and coffee, all highly consumed in Essen. Animal welfare loss relates mostly to the consumption of eggs and seafood, due to a larger number of animals consumed per FU as compared to beef or pork. The dietary risk factors resulted from the food basket affect human health in descending order stroke > cardiovascular > diabetes, due to the high intake of meat products, and low intake of fruit and vegetables. We also identify the tradeoffs of the food basket among ecosystem damage and Disability-adjusted life years attributed to chronic disease. Increasing the intake of fruits and vegetables could improve the performance across the three OH dimensions. However, results should be regarded as work in progress. The indicators need further improvement for a more comprehensive tradeoff assessment under the OH approach.

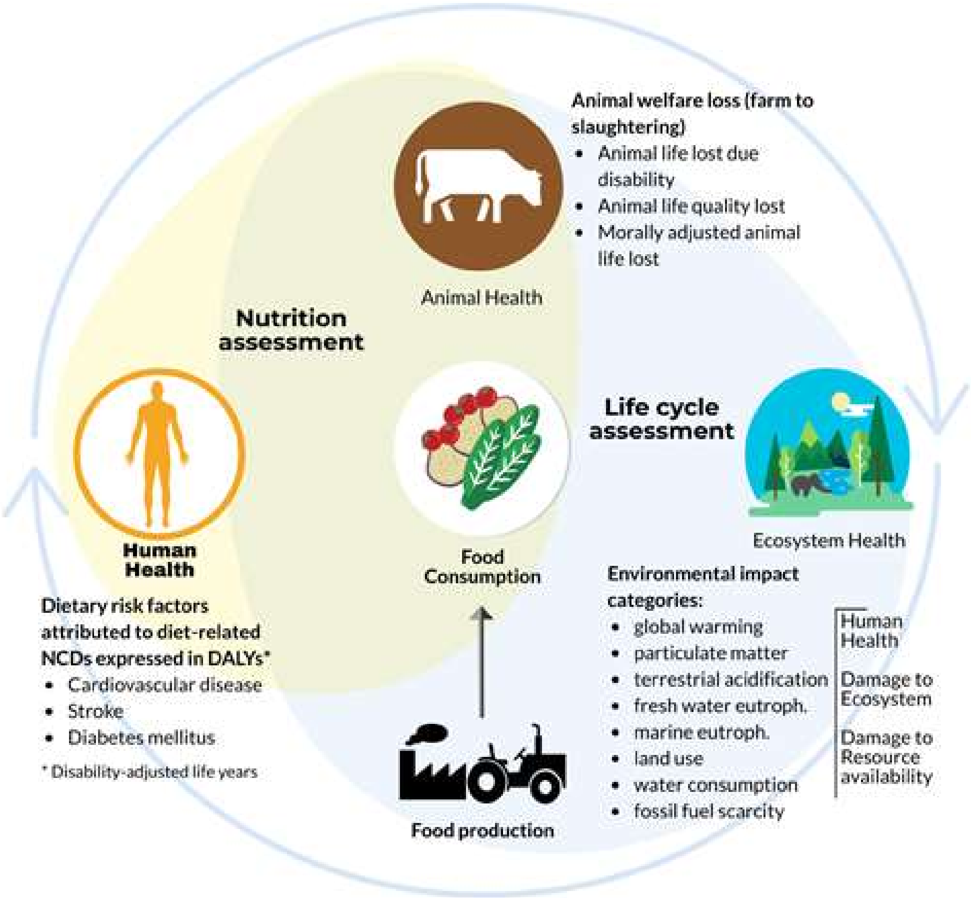

Figure 1: Integrated LCA under the OH approach

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Nutritional LCA improves the understanding of the environmental impacts of foods taking into account the diversity of recipes within a same food category: the case of pizzas

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Abstract

Problem & Aim

Life Cycle Assessments (LCA) of food products are generally calculated on mass basis, reducing the function of a food to its mass, which is an obvious limitation. Some authors have considered the nutritional intake of a product to be its main function and have included nutritional indexes into the Functional Unit (FU) [1, 2]. These works are still exploratory and conducted by comparing the impacts of

different categories of food. The subject is complex: linking daily nutritional requirements and the nutritional composition of food lead to contradictory recommendations for a product.

On another side, available LCA results on food products are most of time provided for “average products”, hiding the nutritional diversity of foods that can be found within a same product category.

This study aims to show the diversity of environmental impacts within the same food category with a wide variety of recipes, the pizza, and how a nutritional approach of LCA can improve the understanding of the links between food features and environmental impact.

Methods

The goal of this study was to evaluate the variability of environmental impact within 80 industrial pizzas, representative of the French market (OQALI database), depending on whether the reference flow is dimensioned by a mass a nutritional FU.

SimaPro (V9.0 PRé consultant) was used for the LCA modeling with the midpoint impact EF (adapted) characterization method.

Product labelling was used to calculate the recipes of the pizzas. Data collection was obtained from databases (mainly Ecoinvent and Agribalyse), literature (scientific and technical information from suppliers) and experimental measurements of packaging.

Different FU have been tested: a classical mass FU, a FU corresponding to a pizza portion, a kcal FU, a protein FU, a fibre FU and a combined protein and fibre FU, with values calculated from nutritional recommendations [1]. Complementary, negative nutritional impacts of the pizzas have been calculated using the intake of nutrients to limit according to nutritional recommendations.

Results & Discussion

Independently of the FU chosen, the diversity of pizza recipes induced a significant variability of environmental impacts associated to these pizzas, showing the limits of “average product” approaches, and consequently the necessity of specific results as much as possible for food products.

Nevertheless, in all cases ingredients caused the major part of the impacts, in accordance with the literature [3]. A potential underestimation of the other stages of the system (transformation, transports…) has been noticed because available data are less detailed compared to the agricultural stage.

In addition, our preliminary results showed significant differences following the FU chosen. For example, FU based on proteins stated that environmental impact of a beef pizza could be lower than a vegetarian pizza. On the contrary, if proteins and fibres were combined in the FU, the vegetarian pizza caused less environmental burdens than the beef pizza. The associated nutritional burdens could be used to better understand the links between environment and nutrition. A consolidation of the results is being carried out and will make it possible to propose in-depth interpretations of those links. Such an approach would be a first step towards robust assessment of diets on both environment and nutrition dimensions.

Literature

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Supermarkets as tractors of the environmental assessment of food products.

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Abstract

Problem and aim

The implementation of Product Environmental Footprint (PEF) methodology (COM 2013/179/CE) in food sector is difficult due to lack of specialized knowledge and high resource demand for data collection. Moreover, all the actors involved in a product chain must participate in the environmental assessment. For this reason, the aim of the EuskoPEF project (FEDER-IHOBE IE420/2018) is to facilitate retailers 1) to traction the assessment and reduction of environmental footprint of food products, 2) to integrate green purchasing through comparative assessments of PEF results for the same product category, and 3) to communicate the environmental impact of products to consumers.

Methods

For that purpose, a friendly tool is developed. First, the functionalities of the approved PEFs have been defined: processes of the chain, data inventory, functional unit, CFF and DQR. Second, all the European PEF compliant dataset have been reviewed to select and categorize those that are valuable for food sector. Third, the characteristics and interests of the distribution sector have been defined. Finally, the tool is developed divided into administrator desktop tool and web tool, which are developed using Visual Studio. NET, on Visual Studio 2017 and the database is centralized in a SQL Server 2017. Adobe Illustrator CC2018, Adobe Photoshop C2018 and Sketch 2019 have been used for designing.

Results

The tool calculates the environmental impact of food products following PEF methodology. Through the administrator tool, retailers define questionnaires per food product. Besides a flexible configuration of the questionnaires and calculation parameters, the tool allows retailers to know and compare the environmental impact of products from different suppliers and select those with a lower footprint.

Linked to the management tool, a user-friendly online platform has been developed, which allows the collection of the necessary data based on the questionnaires previously defined in the administrator tool. The aim is to facilitate the inventory phase to suppliers without environmental expertise, who can also request data to their supply chain through the web tool. Furthermore, suppliers could evaluate the environmental impact of their product and their relative contribution along the supply chain.

Discussion/Interpretation

The validation of the web-based tool is done with the beer product category as a proof of concept and the administrator tool is validated by one of the major retailers of Spain. In consequence, several challenges have been faced. Among others:

1- Confidentiality of the data. An agreement is compulsory between suppliers and retailer to have the latter access to the data in the desktop tool.

2- Complexity in inclusion of the category rules of PEF products. An expert knowledge is required to add the functionalities of the PEF methodology in the desktop tool.

3- Difficulty to collect data upstream. The methodology requires primary data collection in processes not run by the company. The tool allows to send and link questionnaires to upstream actors, but it is difficult to obtain the data from stakeholders which are far away of the final distribution step.

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Assessing the sustainability of high values crops in controlled environment production systems using life cycle analysis

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Abstract

. INTRODUCTION

Along with an increasing population, the world faces climate change, rising fossil fuel prices, ecosystem degradation, and water and land scarcity - all of which are making today's food production methods more challenging. The EU energy strategy (2030 Energy Strategy) calls for a 40% cut in greenhouse gas emissions compared to 1990 levels and at least a 27% share of renewable energy consumption whereas the EU directive for greenhouse gas emissions (GHG) forces for to at least 50 % reduction below 1990 levels by 2050. Limited water availability already poses a problem in many parts of Europe and the situation is likely to deteriorate further due to climate change, with Europe's high water stress areas expected to increase from 19% today to 35% by the 2070s. In Greece, but in general in the Mediterranean region, protected cultivation constitutes the most productive form of primary agricultural production. Although the climate conditions for greenhouse crop production are favourable, the Greek greenhouse industry, like many other parts of the agro-food chain, faces a major challenge: Meeting the increasing food needs whilst simultaneously reducing agriculture's environmental impact.

Thus, the assessment of the environmental impact of agricultural production has received increasing attention over the last years, because agriculture appears to have a major impact on the environment. Modern, intensive crop production is regarded as a source of solid, liquid and gaseous emissions, which can be both a nuisance and environmentally harmful. Plastic, waste water and greenhouse gases, coming from direct or indirect sources, are the most important effluents for polluting the air, the ground and surface water (nitrates and phosphate emissions), causing climate change, acidification, eutrophication and ecotoxicity (soil enrichment with heavy metals). Regarding protected cultivations, there are some environmental studies that are restricted to the use of national or EU level guiding policy

or in improving farm management by supplying information to the farmer or advisor. To reduce pollution sources from intensive agriculture production systems to the environment many technologies have been developed and applied, like closed hydroponic systems, closed greenhouse, degradable plastic covering materials etc. However, till today information and studies concerning a complete environmental assessment of greenhouse cropping system are limited. Therefore, there is an increasing interest in product-oriented and life cycle based environmental assessments (LCA), because there is a need to evaluate global emissions and impacts from the whole production chain in relation to types and amounts of products consumed. Life cycle assessment (LCA) is a generally accepted method to evaluate the environmental impact during the entire life cycle of a product. In the present paper, we built upon the results and data of previous EU and national projects related to a) rational irrigation strategies in greenhouses and b) energy saving measures in controlled environment crop production systems and using the LCA method through the SIMAPRO software we evaluated their environmental impact aiming to identify hot spot that affects the sustainability of the whole system.

Results show that the greenhouse crop production processes in total as well as the electricity production process were also proven to be important contributors to the total use of resources and emissions. Completion of LCA studies involving a number of different greenhouse producing systems (crops/structures/equipment), development of site and eventually country-specific emission factors for the processes at the greenhouse level and finally specifically designed LCA's for the greenhouse production processes, will be the main research interests in order to improve the quality of LCI results and therefore the estimation of the environmental performance of the greenhouse sector

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A life cycle approach to sustainable and healthy food service systems

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Abstract

Problem: As the trend of eating out increases, the food service sector has a great potential to lead the transition towards more sustainable and healthy food systems. However, research to date is still scarce on how this sector can manage resources efficiently and mitigate climate change while providing healthy meals. [1] Life cycle thinking plays a key role in identifying more sustainable solutions for the food service sector. Interventions promoting dietary change through menu planning prove to be especially effective in reducing environmental impacts.[2] The aim of this research is to assess the complete environmental life cycle impacts of different types of meals using LCA and identify environmental hotspots in meal planning. This research is part of an on-going project on developing a novel LCA methodology for incorporating comprehensive nutritional assessment so that the health impacts of meals can also be assessed along their environmental impacts.

Method: This research uses an institutional food service establishment in the UK as a case study. Meals analysed include chilli, lasagne, curry and teriyaki dishes. Four variations of each dish is analysed. Two variations use animal-based ingredients (e.g. beef lasagne and vegetarian lasagne), and the other two are plant-based versions of the same dish (i.e. vegan and whole food, plant-based (WFPB) lasagne). The functional unit is a single meal calculated from cradle to plate, and the phases included in the system boundary are food production, transportation, food storage and preparation. The environmental impact categories include global warming potential, water use, cumulative energy demand, acidification and eutrophication potential.

Results: Results show that the production phase has the largest contribution to the overall environmental impacts for all types of meals. Generally, WFPB meals have the lowest environmental impact as these meals are made with whole, minimally processed ingredients of plant origin, which require less resources to produce than meals made with animal products or processed plant-based

ingredients. Nevertheless, the magnitude of environmental impact is dependent on the food production method. Our results show that careful menu planning with considerations to procurement and ingredient choices can considerably reduce the overall environmental impact of meals.

Discussion: Replacing animal products with (whole) plant-based ingredients in meals is an effective way of reducing not only the environmental impact of meals but also the overall impact of catering operations, [2,3] and it also has positive health outcomes. It is widely known that healthy eating may be best achieved with a whole food plant-based diet,[4] therefore providing WFPB meals is a straightforward way of promoting both human and planetary health at institutional and other food service establishments. Nevertheless, meals centred around unprocessed, whole plant foods are often limited, if not completely missing from menus. Sharing evidence-based LCA results could therefore help the food service sector make more informed decisions about menu planning.

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Adjusting Food-Based Dietary Guidelines from a resource use perspective

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Abstract

Current food production causes adverse environmental impacts [1], while food consumption can be linked to several non-communicable diseases [2]. Food-based dietary guidelines (FBDG) serve as orientation for favourable food consumption from a human health perspective. With rising attention on environmental impacts, especially of animal-source foods (ASF), also FBDGs are increasingly in focus [3]. First attempts to include the environmental perspective into FBDGs have been made e.g. in Sweden. However, these adjustments do not necessarily include changes in production systems, which would be required to achieve consistent system transformations.

To this end, we developed a three-step procedure to adjust FBDGs towards including only amounts of ASF that can be sustained based on low-opportunity-cost feed (LCF), such as food processing by-products, food waste, and grass resources [4]. With this approach, principles of circular food systems are considered and competition for resources between food for humans and feed for animals is avoided. We apply this approach to the FBDGs of five European countries: the Netherlands, Sweden, Bulgaria, Malta, and Switzerland.

In step one, national FBDGs were quantified, and by applying food loss and processing coefficients [5], FBDG quantities were converted into production values. Then, food processing by-products and food waste at manufacturing stage resulting from the plant-source food production to supply the FBDG quantities were calculated. Further, grass resources were added to the LCF. In step two, the amount of ASF that can be sustained based on the available LCF was estimated based on the optimisation model developed in [6]. The objective function of the model is to maximise human-digestible protein output, with different animal production systems as options. If protein requirements of the original FBDG could not be met by the ASF produced with LCF, plant-based protein sources were added to close the gap. In step three, the original FBDGs and the circularity-adjusted FBDGs were compared with regard to their environmental and human health performance. Environmental performance was estimated by calculating the global warming potential, land occupation, and nitrogen surplus. Life cycle inventories were based on FAOSTAT and calculations with the biophysical mass flow model SOLm [7]. Diet quality was assessed by applying the Alternate Healthy Eating Index (AHEI) [8].

Initial results suggest that protein supply from ASF based on LCF can, to a large extent, meet the protein supply from ASF in the original FBDGs. However, for all case studies employed, the composition of ASF of the circularity-adjusted FBDGs differs from the original FBDGs. In particular, much less poultry meat would be available, because according to current knowledge, poultry are less well suited to feed on LCFs. Further, when FBDGs are fully implemented, trade-offs with regard to LCF availability occur; e.g. recommendations on whole grains would result in less food processing by-products. For cropland occupation, circularity-adjusted FBDGs perform better in all countries, while for GWP, signals differ between countries, depending on the available grass resources and the resulting amount of cattle. By combining circularity concepts with national FBDGs, we contribute to the discussion on how to integrate environmental considerations and human nutrition perspectives towards a more sustainable food system.

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Comparing different approaches to estimate nitrogen emissions from agriculture in LCA

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Abstract

Problem and Aim

Life Cycle Assessment (LCA) is a standardized method that calculates the environmental burdens of goods and services through quantification of emissions and resource consumptions. When LCA is conducted in agricultural systems, the best approach to estimate emissions from agricultural soils must be selected in order to achieve adequate results. Nitrogen emissions (N) – nitrate (NO_3), ammonia (NH_3) and nitrous oxide (N_2O) can be estimated using several methodologies with different levels of complexity. The aim of this research was to compare nitrogen emissions in agriculture provided by different approaches.

Methods

We selected four different models to estimate nitrogen emissions. In ascending order of complexity, PEF (EC-PEFCR 2017) advises calculating N emissions using a fixed fraction - emission factors (EF) - based on IPCC guidelines. SALCA (Gaillard & Nemecek, 2009) was created for LCA to estimate emissions using well-tested equations. Daisy (Hansen *et al.* 1991) and Animo (Groenendijk *et al.* 2005) are robust models which require several inputs being the most complex approaches used in this work.

Results

The models were applied in a case study for a maize crop in Spain (Table 1).

Table: NO^{-}_{3}, NH_3 and N_2O emissions

Emission (kg N/ha)	PEFCR	SALCA	DAISY	ANIMO
N_2O	2.94	1.70	2.09	-
NH_3	37.60	19.45	0.10	0.65
NO_3	63.22	19.70	45.89	31.72
Amount of organic and inorganic fertilizer applied in soil (kg N/ha) = 170.0 and 40.5				

Discussion/Interpretation

PEF overestimates all emissions due the model only uses the amount of fertilizer and DEFAULT emission factors (EF) for all emissions. The lowest variation (42%) between the estimations was in N_2O and the highest (99%) in NH_3. In SALCA, N_2O was estimated applying IPCC EFs. In Daisy, N_2O was estimated during nitrification. In Animo, N_2O is part of denitrification, but it is divided into N_2O and N_2. In SALCA, NH_3 volatilization is based on the amount of fertilizer used, emission factors and the organic matter in the fertilizer. In Animo and Daisy the user has to insert a fraction for volatilization. In SALCA, NO_3^- leaching is estimated as balance between inputs – fertilizer, irrigation and precipitation – and outputs – N emissions and plant uptake - throughout simplified equations. In Daisy and Animo, they consider the entire nitrogen cycle and differences in leaching are mainly related to intrinsic parameters at other N-cycle stages, such as mineralization and absorption of crops that interfere with leaching. In relation to the limitations: PEF does not consider climatic conditions or type of crop; SALCA considers climatic factors in a very simple way; in Daisy is not clear about N_2O in denitrification; in Animo, N_2O was not estimated.

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Opportunities for the Cantabrian agro-food system under a Food-Energy-Water nexus approach: the case study of organic tomatoes

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Abstract

Problem and aim

In a bio-circular economy, natural resources (soil, water and biodiversity, but also minerals) must be effectively used and managed. However, the current pattern of natural resources exploitation to meet humanity's demand for food threatens long-term food security. Food systems consume 30% of energy use and 70% of global freshwater withdrawals. In addition, they are responsible for around 30% of greenhouse gas (GHG) emissions [1]. On the other hand, since about one third of all food produced worldwide is lost or wasted throughout the supply chain, reducing food waste as well as the optimum use of residue streams is an important starting point to meet the increasing challenge of sustainable feeding of the world's population [2]. The goal of a bio-circular economy is high on national and international agendas. In fact, national and transnational programmes have been widely applied, but regional actions are crucial to foster interregional cooperation on circular economy activities. In this

sense, circular and bioeconomy policies [3, 4] and actions could present important opportunities for the agri-food sector of the Cantabrian Region, introducing tools to the local players to innovate in the bioeconomy both at the technological level and in the development of regional strategies. In this global framework, the Food-Energy-Water (FEW) Nexus approach applied to all stages of the entire agri-food sector, following a life cycle methodology, is the best methodological tool to assess food systems (including nutritional, economic and water and energy) in order to introduce strategies and actions for a bio- circular economy in the food sector. In particular, the FEW nexus approach is applied to the production of organic tomatoes in Cantabria with the aim of defining measurable environmental-nutritional-economic and energy efficiency targets to encourage the definition of strategies focused on those categories.

Methods

Life cycle assessment (LCA) is particularly important for understanding the interconnections in the nexus, as it enables the consideration of entire supply chains. The proposed method combines LCA and linear programming (LP) optimisation in order to obtain indicators linked to the WEF nexus and merge them at an aggregated index that facilitates the decision-making process.

Expected results

This study aims at addressing food waste prevention strategies linked to the entire organic tomato supply chain under a nexus approach, promoting continuous improvement measures by means the introduction of technical, environmental and nutritional criteria. As a result, it is expect to identify hotspots along the supply chain, to propose eco-innovation alternatives and to facilitate the decision-making process by means an aggregated nexus index in situations where it is not clear which is the best option from a point of view of resource consumption and environmental impacts.

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A comparison between Life Cycle Assessment and Multi-Regional Input-Output for the estimation of the carbon footprint of the Spanish food sector.

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Abstract

Decreasing green-house gas (GHG) emissions associated to agricultural production requires not only measures on the supply side (e.g. sustainable intensification), but also on the demand side (e.g. changes in diet). Thus, reliable and transparent indicators for monitoring environmental measures and policies targeting final demand and consumers behaviour are essential.

In this work, Life Cycle Assessment (LCA) and Multi-Regional Input-Output (MRIO) analysis, two of the main methods employed for estimating the carbon footprint (CF) of the food sector, were assessed, using Spain as case study. More specifically, three LCA studies from the literature were evaluated (Batle-Bayer et al., 2019; Muñoz et al., 2010; Sáez-Almendros et al., 2013) along with an LCA performed by the authors, in comparison to two MRIO databases, Exiobase (Stadler et al., 2018) and FABIO (Food and Agriculture Biomass IO) (Bruckner et al. 2019).

Our results showed that total CF of food consumption oscillates between 1.6 and 3.8 t/cap/yr, while with equivalent system boundaries between 1.6 and 3.0 t/cap/yr. Further, CF of meat products varies between 0.38 and 0.72 t/cap/yr, whereas for non-meat products the gap is wider using the MRIO models (1.23 t/cap/yr, whereas LCAs oscillate between 0.78-0.91 t/cap/yr). In general, the more

disaggregated the comparison, the higher the deviation. Regarding GHG emissions associated to global trade, it was observed that trade balance sign change depending on the method, that is, according to MRIO estimations, Spain would be a net importer of GHG emissions, while following LCA, the country would be neutral. This occurs due to variations in trade balances of meat, dairy, rice and 'other' products.

Differences between, but also within methods, explain the variations obtained for the CF of Spanish food consumption. LCA and MRIO have their benefits and disadvantages and there is not currently a superior method for making food carbon footprint estimations at the national level. MRIO has usually wider geographical coverage, but suffers on aggregation errors and poor product resolution. On the contrary, LCA has superior product classification allowing for finer assessments, but has the drawbacks of lack on country-specific data and truncation biases. Additionally, there are important differences within both methods. For example, all LCAs analysed had distinct system boundaries, e.g. regarding, post-consumption phases or land use change emissions, and used different data sources. Similarly, each MRIO model has its own particularities, for instance, Exiobase allocates emissions among industries and countries using monetary transactions (i.e. economic allocation), whereas FABIO uses kg of fresh matter (i.e. mass allocation). While a wide offer of modelling options is beneficial from an analytical point of view, this situation might as well compromise the effective monitoring of decarbonization measures targetting demand and thus, hinder international and national agreements and policies. Therefore, efforts for further understand and harmonize these indispensable methods to mitigate climate change are required.

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Health and climate impact of Swedish diets

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Abstract

Dietary change offers a great potential for improved environmental sustainability and public health. Food production is a main source of environmental pressure responsible for up to 30% of global greenhouse gas emissions (GHGE). Unhealthy diets are moreover ranked as one of the major risk factors contributing to non-communicable diseases, estimated to be responsible for more than half of the global burden of disease. Transition towards more sustainable diets is urgently needed and requires evidence-based recommendations considering diets combined environmental and health effects. In the present study the climate and health impacts of Swedish diets were assessed.

The aim was to identify dietary patterns with the lowest and highest climate impact and evaluate their impact on mortality. Dietary patterns and associated health impacts were based on data of 50 000 individuals within two population-based cohorts in Sweden (Swedish Mammography Cohort and the Cohort of Swedish Men), representative of the Swedish middle-aged and elderly population. Self-reported food consumption at baseline was assessed using a food frequency questionnaire. Information about deaths during follow-up was ascertained by linkage to the Cause of Death Register.

Greenhouse gas emissions were calculated based on life cycle assessment data from the literature, chosen to be representative for Swedish consumption and harmonized in terms of methodological choices in order to make the data comparable. Climate impact from the diet includes GHGE produced up

to moment when the food product reaches the plate of the consumer, including primary production, processing, packaging, international and national transportation, home transportation by the consumer, cooking and food losses and waste along the entire life cycle. Emissions were reported per edible weight, adjusted for non-edible parts and weight changes during cooking. The results provide new knowledge on existing dietary patterns that provide beneficial synergies, in terms of both low GHGE and health.

Dietary choices will be categorized as more or less sustainable based on their combined climate and health effects (Fig 1). Differences between dietary patterns characterized as less (A) or more (D)) sustainable will be mapped to give better insight into dietary changes required to enable a transition towards more sustainable diets that are realistic and acceptable in the Swedish population. The results will be useful as a concrete baseline for policy making e.g. in dietary advice to guide consumers and other stakeholders in the food chain towards food choices and diets that benefit both planetary and human health.

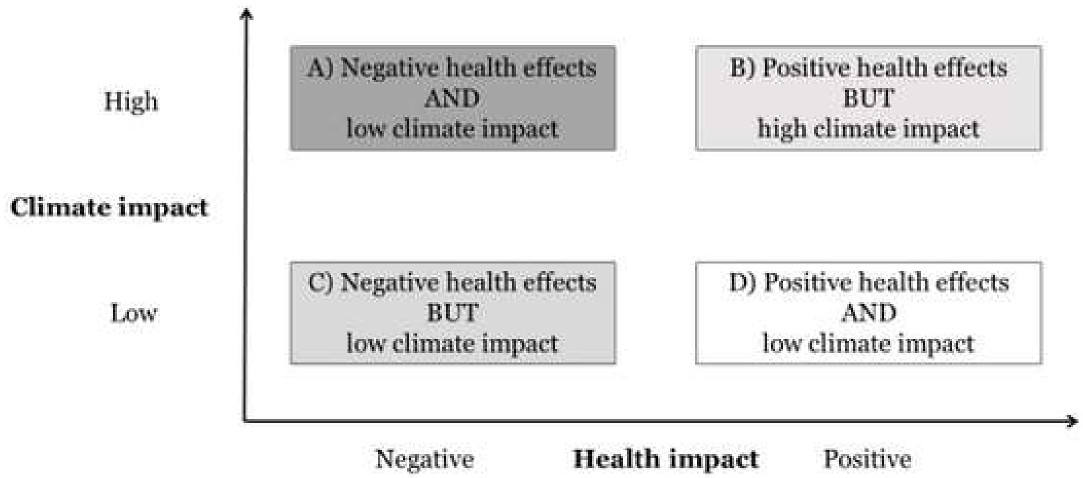

Fig.1 Conceptual figure of dietary patterns according to their combined climate and health effects.

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Assessing complex organic vegetable production systems using LCA

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Abstract

Problem and aim

In France, 11% of vegetable farms are organic (Dedieu et al., 2017). These farms are very diverse, both in terms of farm structure and farming practices, ranging from large farms growing few crops with a high level of external inputs –close to conventional agriculture – to biodiversity-based microfarms. Microfarms are characterized by a wide variety of vegetables produced - more than 30 - on small acreage - less than 1.5 ha per full-time equivalent (Morel and Leger, 2016). They also frequently combine vegetable production with other farming activities, resulting in a high degree of complexity. These systems are often conducted by farmers aiming to minimize environmental impacts, however, late adopters of organic farming have been shown to be less concerned about the environment than early adopters (Best, 2008). We aim to assess the environmental performance of these systems using life cycle assessment (LCA). LCA of agricultural systems still raises methodological challenges, especially when it comes to complex and diversified systems, which rely heavily on the services provided by biodiversity (Foresi et al., 2017). We have explored the potential of two contrasting data collection strategies to identify the best way to assess such complex systems using LCA.

Methods

First, the levels of complexity of organic vegetable production systems were defined and analysed thanks to a set of surveys and interviews. Second, we compared LCA results for vegetable systems based on two contrasted methods:

- A "black box" approach, considering total inputs and outputs of complex farms without taking into account internal processes;
- A detailed approach, based on a data collection tool that we developed to record farming practices with sufficient detail at the level of different relevant “management units”, without having to list all interventions for all crops. Furthermore, this approach maps out the physical and strategic interactions among farm components.

Results

The levels of complexity were:

- The mix of other farming activities (orchards, dairy farming, etc.) more or less interacting with the vegetables;
- The diversity of productive areas (open fields, greenhouses, vegetable gardens, etc.) and semi-natural areas;
- The existence of several "management units" (a plant cover managed in the same way) within the same productive area;
- The diversity of vegetables present on a management unit and its temporal dynamic;

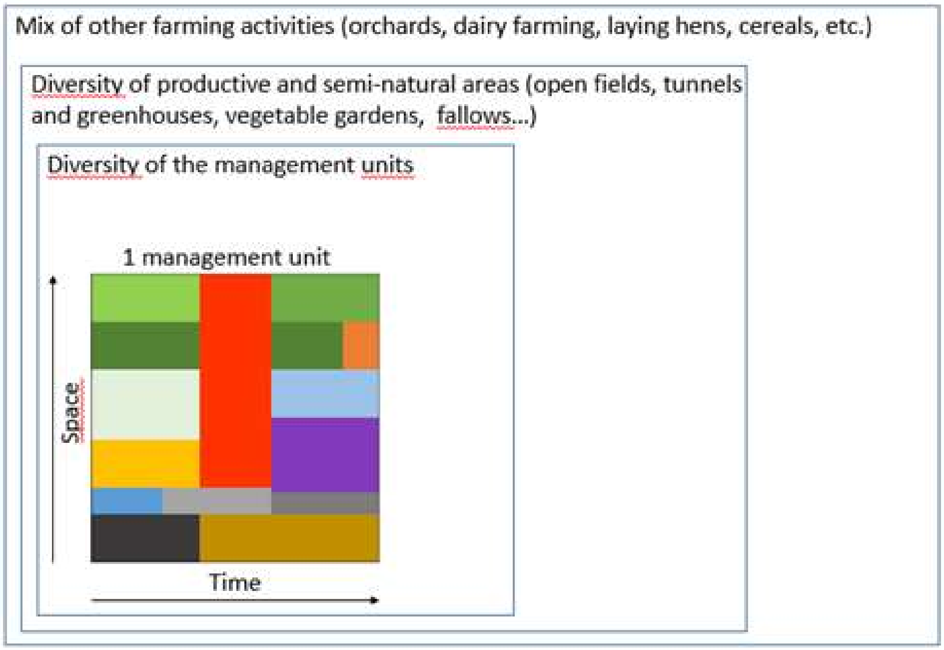

Fig. 1 – Different levels of complexity in organic vegetable farms, the colours represent different vegetables

The comparison of life cycle inventory and LCA data obtained using the detailed and the global black box approaches is ongoing and will be detailed in the presentation.

Discussion

Preliminary results indicate that the detailed approach is more time-consuming than the black box approach, but it allows an analysis of the contributions of the productive areas, management units, farming practices and different vegetables to the farm’s overall impacts. This information can be used to build scenarios for impact reduction. The main advantage of the "black-box" approach is the time saved in collecting data, which allows a rapid estimation of environmental hot spots, but does not allow a detailed contribution analysis.

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Is optimizing a sustainable diet a double duty action of nutritional quality and environmental footprint?

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Abstract

Problem and aim

The relation between diet and environment has been widely studied (1, 2). However, most of the studies only consider one or two environmental impact categories (e.g. climate change, land use). Food products are very diverse in terms of composition and production. Hence, they impact differently on the environment. Therefore, accounting for all the environmental impacts is highly relevant when evaluating diets. We aim to evaluate the correlation between nutritional quality and the European Food Environmental Footprint Single Index (EFSI) of modelled diets. The EFSI is a newly developed index including 16 environmental impacts.

Methods

We used the modelled diets described in the study of Springmann *et al*. (2018). The nutritional quality of the diet was evaluated with the FSAm-Nutrient Profile System, which is based in the proportion of

positive (fruits, vegetables, fiber and protein) and negative (energy, saturated fat, sugar and salt) food components (4). Food composition data was pulled from USDA Food Composition database. For the environmental impact of the diets, we calculate the environmental footprint (EF) based on the PEF method (3). Then, a normalization of the 16 environmental impacts based on the European food basket was applied (5). Finally, the EF of the diets (EFSI-DI) was calculated as the weighted (mass allocation) sum of the EFSI of all the food items in each diet.

Results

In total 13 modelled diets were evaluated. Overall correlation between quality (FSAm-NPS DI) and environmental footprint (EFSI-DI) for all model diets was high (r= 0.8554, p-value = 0.0002). The diet with the highest environmental impact score was BMK (Business as usual) and least nutritional quality was KCAL75 (75% improvement on energy imbalances). While the diet with the lowest environmental impact score was VEG (Vegetarian) and the best nutritional quality was VGN (Vegan).

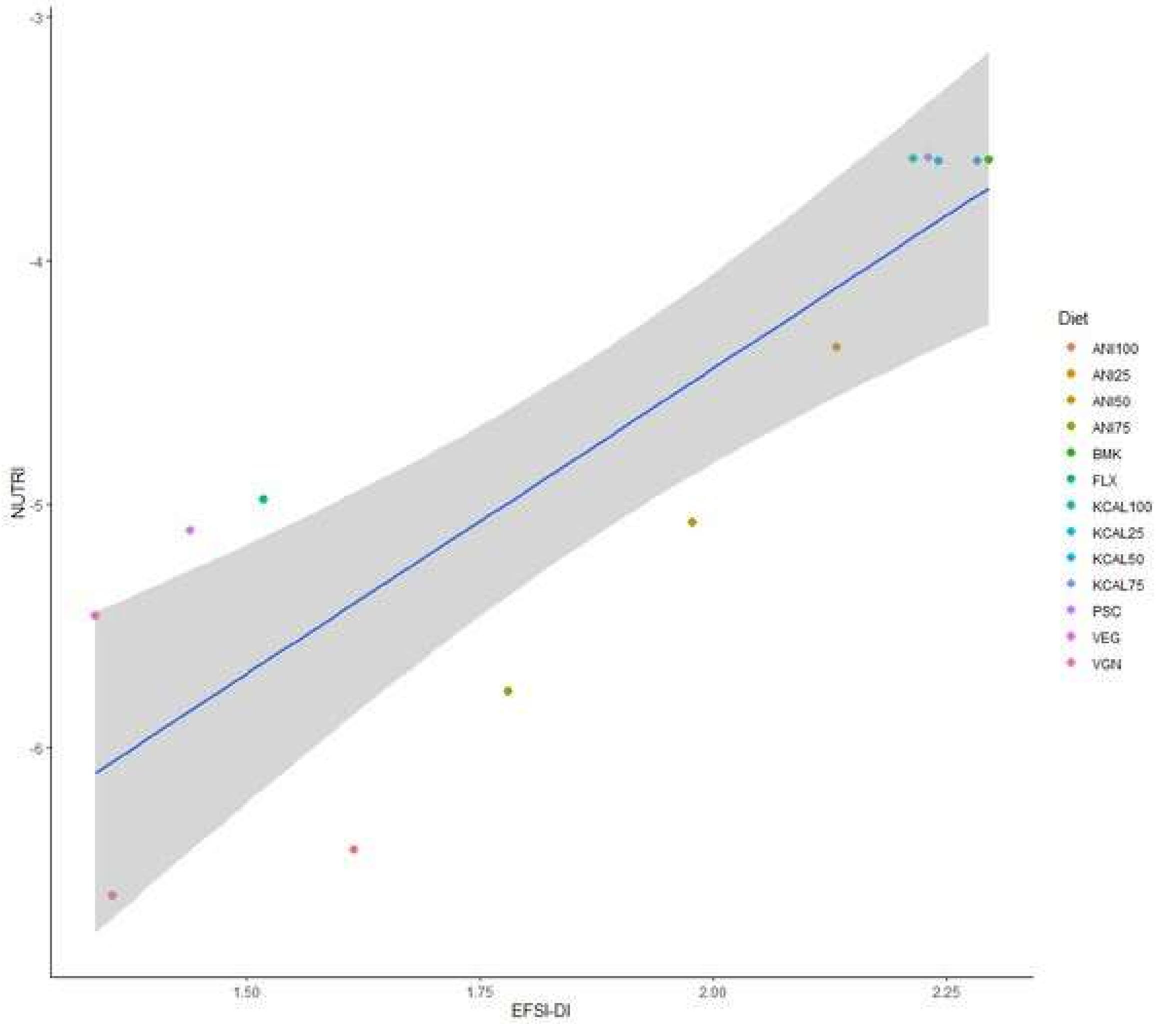

Figure 1: Correlation between the nutritional quality and environmental impact of the different diets

*ANI25-100 were a replacement of 25–100% of animal-source foods with plant-based. KCAL25-100 were an improvement of 25-100% in energy imbalance. FLX was flexitarian, PSC was pescatarian, VEG was vegetarian, VEG was vegan. BMK was business as usual.

Discussion/Interpretation

In conclusion, our findings are in line with previous findings, knowing that a more comprehensive method was used to calculate the environmental impact. However, modelled diets are not a trustworthy representation of real diets nor a representation of the variety of the current food environment. Hence, more data, both in term of variety of products and real (primary) data, are needed for an accurate calculation of the environmental impacts of real diets.

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Topic 9:
LCA Challenges in Americas

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REGIONALIZATION OF CHARACTERIZATION FACTORS FOR THE BRAZILIAN NORTHEAST REGION.

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Abstract

Problem and aim

The published and most used characterization models for assessing water scarcity have failed to demonstrate in their water scarcity factors (CF) the historically recognized semi-aridity at the Northeast region of Brazil. In order to give precision to these data, scarcity factors from the Water Scarcity Index (WSI), proposed by Pfister and Bayer (2014), and from the AWARE index, developed by Boulay et al. (2018), were regionalized for the Brazilian Northeast region.

Method

The regionalization process was performed using national hydrological data (demand, availability and the area) provided by the National Water Agency (ANA). Furthermore, the regional spatial division used by ANA, which accounts for State level Hydrological Units (SHU), were used. Rainfall data from 1961 to 2017 for the Northeast region were taken from Harris et al. (2013). Monthly and annual factors were calculated for 144 SHUs.

A descriptive analysis (DA) of both annual and monthly factors of all SHUs was carried out for the two methods, regionalized or not, to assess the behavior of the samples before and after regionalization. Also, the equation proposed by Boulay et al. (2017) to perform the comparison between methods was used. Such methodology uses the geometric standard deviation (GSD^2) to verify the proximity of the responses of different methods, therefore, the closer to 0 GSD^2 is, the closer the compared methods are.

Discussion

In the Pfister method, after the regionalization, there was an increase in the annual WSI of 116 SHUs, in which 54 passed from the "Low Water Stress" category to the "Very High Water Stress" category. However, there was a decrease in annual WSI in 28 SHUs. In the AWARE method, there was an increase in the value of the annual CF by 122 SHUs, and there was a a decrease in FC in 22 SHUs.

In the DA, the "Avarage" was higher in the both regionalized CFs, meaning that in the original CFs the scarcity was lower than in the regionalization. The "Mode" for the regionalized methods were 1 (maximum in WSI) and 100 (maximum in AWARE), showing the high presence of maximum CFs. According to the "standard deviation", the range in the CFs was higher in the regionalization than in original CFs, also justified by the "Maximum" and "Minimum" values. The mean value also increased considerably in both methods, showing that the sample now has higher values than before.

Descriptive analysis of the annual factors				
Method	Pfister e Bayer		Boulay	
Type	Original	Regionalized	Original	Regionalized
Average	0.135	0.628	4.777	61.458
Mode	0.020	1.000	3.100	100.000
Standard Deviation	0.257	0.434	4.097	38.738
Median	0.020	0.942	3.100	75.509
Maximum	0.989	1.000	32.900	100.000
Minimum	0.010	0.010	0.500	0.100

Subsequently, it was used the comparison strategy developed in Boulay et al. (2017) to verify the proximity of results after the regionalization. The GSD^2 (original x regionalized) for Pfister was 49.2 and for AWARE was 56.3, the GSD^2 for Pfister regionalized x AWARE regionalized was 56,029, that means the results after the regionalization are closer than comparing only inside the models after regionalization. This is due the same database and the watershed's shape used in the regionalization.

Conclusion

The regionalization of the CFs brought significant changes to assess water scarcity in Northeast Brazil, showing higher scarcity than in the original CFs. The application of these CFs generat results more consistent with the reality of the study area, due to the use of a national database for water availability and demand.

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Environmental efficiency in preparing meals outside the home

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Abstract

Times have changed and new lifestyles are gradually replacing the habits of people around the world today. Although eating at home still accounts for the largest share of food (68.9% of spending on food in 2008-2009), consumption of food outside the home has increased. This demand for ready-to-eat meals favored the increase in the number of establishments in the food sector outside the home and diversified its services, with emphasis on the growth in the number of restaurants, convenience stores, fast food chains, bakeries, among others. .

Research carried out in the country shows that the acquisition of food outside the home was reported by 41.2% of individuals, being higher among men than among women (44% versus 38.5%). The places with the highest frequency of consumption of food outside the home were a snack bar (16.9%) and a restaurant (16.4%). There is also a growing demand for healthier foods produced with less environmental impacts. In order to respond to this search for processes that cause less impact on the environment, this research aims to assess the environmental efficiency of the stages of preparing meals in industrial restaurants. In this article, in particular, some initial results obtained in the preparation of rice in these establishments are shown. Rice is an ingredient that form the basis of the Brazilian diet. Thus, the data presented here refer to three industrial restaurants located in the city of São Paulo, Brazil, which prepare between 10 and 150 daily meals. Data was collected through interviews, followed by measurement of the quantities of inputs used through balances and the times used for preparing cooked rice in industrial pots. Using principles of the Life Cycle Assessment tool, fossil energy consumption was calculated, specifically due to the cooking stage and Liquid Petroleum Gas consumption, ranging from 0.6 to 1.2 MJ / kg of processed raw rice, value well below the consumption used in the home, in the order of 6 MJ / kg of processed raw rice. The final work will include the stages of agricultural production of rice and the solid waste management from the system. The first results obtained seem to indicate that the meal outside the home can have a much smaller impact than the traditional meal made at home.

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Environmental performance and nutritional quality of milk obtained by family farms

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Abstract

The demand for food produced on a small scale, artisinal products or produced by family growers has grown significantly in recent years as they are understood by most consumers as processes that generate less impact on the environment, when compared to large scale processes. In addition to these reasons, particularly in Brazil, these establishments produce about 70% of the agricultural products consumed in the country, and their strengthening has been the goal of several government programs, since they guarantee employment and income for a significant portion of the population. The objective of this project was to measure the environmental performance of family production units for milk production associated with the nutritional quality of the products obtained, using the life cycle assessment tool. Data were obtained from 3 productive units (UP): UP2 and UP5 (intensive, family members), UP7 (intensive, non familiar). The stages of feed production, both internal and external to the farm, the growth and maintenance of cows, collection of their milk production were included. The milk collected on the farms had their physical and chemical properties measured in the laboratory. The emission of greenhouse gases was measured obtaining values between 4100 to 5200 $kgCO_{2eq}$ for 1000 liters of milk. However, this range has changed from 3300 to 6200 $kgCO_{2eq}$ to 1000 liters of FPCM - *Fat and Protein Corrected Milk*, with a significant change in profile between farms when nutritional quality is associated with the environmental indicator, highlighting the importance of associating the nutritional aspect to the food in environmental impact studies. In this study, it was observed that the biggest environmental impact stage was feed production, followed by animal growth and maintenance.

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Environmental and Economic Implications of a Small-Scale Canadian Aquaponics Facility: a Life Cycle Study

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Abstract

Problem and Aim

Current agricultural production places enormous burdens on the earth. Thus, food production systems will be challenged in the future to meet food security goals given growing populations and mounting pressure to limit resource use and environmental impact. In Canada especially, the short growing season and cold climate limit vegetable production and create reliance on indoor food production, which is energy-intensive, both in terms of cultivation and transport[1]. One proposed solution is to employ aquaponics, which simultaneously produces fish and vegetables, to diversify production and increase resilience in the food system; however, it is important to ensure this innovation does not cause further environmental harm. While aquaponics systems are generally accepted as a solution due to reduced waste and efficient nutrient cycling[2], there is a large amount of uncertainty surrounding sustainability, especially in cold regions.

The gap between theoretical knowledge and practical application of aquaponics systems exacerbates the uncertainty surrounding their sustainability assessment and ideal operating conditions. Even more challenging is assessing emerging technologies with no clear definitions of structure and practice. Thus, this project aims to identify environmental and economic implications of a small-scale commercial aquaponics facility in Canada using a life cycle approach.

Methods

A life cycle assessment (LCA) and life cycle costing (LCC) model will be developed and tested with data collected from a small-scale facility in Nova Scotia, Canada. This system, located in a refurbished warehouse, produced trout and lettuce throughout the period of 1 year. Inputs, including feed, water, and energy, and outputs, including plants and fish, were boundaries for this cradle-to-gate study. As well, wastes produced on-site up to harvest, i.e. unusable fish and plant parts, are considered. Functional unit selection reflects mass allocation done in similar studies, where 1 kg of combined product consists of 90% plant and 10% fish. Then, life cycle inventory data is a culmination of published and operational data from literature and the facility. Based on this scope, impact assessment includes the categories of: ozone depletion, global warming potential, and eutrophication. Improvement scenarios are explored.

Results and Discussion

Preliminary findings from this study indicate that regardless of system type, large energy requirements in cold regions contribute to reduced profitability and increased environment degradation due to Nova Scotia's reliance on fossil-based energy. It is expected that other system inputs, including fish feed and water, will also impact environmental and economic sustainability. This is comparable to other studies that found that lighting and heating requirements were large and unsustainably costly in cold regions[3]. Overall, it is apparent that optimization of inputs and operational parameters, especially fish feed, lighting and heating, requires additional research, especially in cold regions. Results from this study will provide much needed clarity on the sustainability of aquaponics applications in Canada and in cold climates in general. In optimizing aquaponics, potential for responsibly increasing fish and vegetable production can be developed in the future.

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Carbon footprint of Brazilian ethanol from corn and sugarcane using RenovaCalc

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Abstract

Brazil is a country recognized internationally due to its energetic matrix based on renewable sources. According to EPE report (2019), in 2018 45% of the energy generated in Brazil was based on renewable sources; in the vehicular matrix, 23% of the total fuel used is a renewable-based fuel. Diesel is the most used with 43.6% of the market, followed by gasoline with 25.8% and ethanol with 18.8%. The Brazilian National Supply Company (CONAB, 2019) forecast for the season 2019/2020 a production of 30.3 billion liters of ethanol from sugarcane and 1.4 billion liters of ethanol from corn. The participation of corn as a feedstock for ethanol production has been growing in Brazil, and for the season 2019/2020 it is expected that the production of corn ethanol is going to be 70% higher than season 2018/2019. Brazil has various public policies to promote biofuels, like The Brazilian National Biofuels Policy (RenovaBio) established in 2017 with the aims to reduce the carbon footprint of the national fuel mix as well as ensuring a long-term demand for low carbon fuels in the country. In order to calculate the carbon footprint of the biofuels, a calculation tool named RenovaCalc was developed. The main goal of this study was to compare three different ethanol production scenarios in Brazil based on their carbon intensity calculated using RenovaCalc. The study focused on three scenarios, representative of the actual situation of the production of ethanol in Brazil: sugarcane ethanol (SE), corn ethanol (CE), and sugarcane and corn ethanol (SCE). In order to calculate the carbon intensity of biofuels, RenovaCalc demands agricultural and industrial data. In this study, the life cycle inventories (LCI) related to sugarcane and corn growth, like fertilizers, fuel and seeds amounts were completed using data from the RANP 758 (ANP, 2018). The industrial yields and energy consumption were obtained from literature and from specialists. After entering the data in the calculator, RenovaCalc calculates the carbon intensity for each phase of the life cycle of ethanol: agricultural, industrial, distribution and use. Next, RenovaCalc compares the carbon intensity of the biofuel with its equivalent fossil fuel (for ethanol, the equivalent is gasoline), generating the Energetic-Environmental Efficiency Score (NEEA). The NEEA associated with the volume of biofuel will allow the emission of Descarbonization Credits (CBios), which will be traded in

the financial market. NEEA and CBios were calculated for each scenario, assuming that all the scenarios yielded the same volume of ethanol. Even though the study was not prepared with real data from ethanol producing plants, the results achieved with this study are important for the sugar-energy sector, as it allows the mills to evaluate, under RenovaBio, how the origin of the raw material may influence the intensity of carbon. Calculating the amount of CBIOs emitted by the fuel is also an important factor for mills, as their commercialization will generate revenue for biofuel producers.

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Topic 10:
New Models
and Databases

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Methodological challenges for nutrition quality and health impact assessment of innovative food products within the FOX project

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Abstract

Problem and aim

Consumers demand for healthier as well as local and traditional food requires innovations in food production, processing and distribution chains. In 2019 the European Commission approved the Food processing in a box (FOX) research project as part of the Horizon 2020 Research and Innovation programme (1). FOX is dealing with mildly processed fruits and vegetables through innovative, small-scale technologies in flexible and mobile processing units to be used in regional food systems. This innovative approach will simultaneously meet consumers' expectations for a wider range of food offer, both healthily and sustainably produced within the region. One of the project's objectives is to develop

efficient tools for evaluation of in FOX produced foods in the scope of balanced nutrition considering the limits of environmental carrying capacity.

Methods

In the study the options for deepening and broadening the methodologies for evaluation of sustainability of food products with the emphasis on nutritional quality and health impact are researched. A methodology for the evaluation of food products is being developed by consolidation of scientific knowledge from the fields of nutrition and LCA.

Findings

A point-of-departure for nutritional quality and health impact evaluation could be Nutriscore (Julia et al., 2017) nutrient profile model. The model will be upgraded with additional parameters to provide sufficient sensitivity for the content of micronutrients and will allow to evaluate the nutritional quality of studied units in comparison with reference units (conventional). Health impacts will be derived by assessing the impacts of changes in dietary intakes. For the latter, we rely on a consumer survey to define consumption scenarios in which FOX products, i.e. healthy adulteration, substitute less healthy foods (e.g. potato chips vs. apple chips).

Interpretation

Our goal is to develop a methodological approach for dietary sustainability assessment of the food products, together with scenarios of dietary intakes, nutritional epidemiology-based information captured by the Global Burdne of Disease analyses (Afshin et al., 2019), enabling the assessment of the health impact for innovative fruit and vegetable products.

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HESTIA: Using LCA to structure, store, and deliver the world's agri-environmental data

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Abstract

Problem: Vast amounts of useful data on the environmental impacts and productivity of different food products and production practices exist. However these data are either: 1) hard to access, often sitting in printed journal articles or stored in disparate databases; 2) are methodologically incomparable, which in turn makes the data hard to re-use and act upon, particularly for non-specialists; or are 3) domain specific, for example, ecologists collect data in a certain way and rarely exchange them with agronomists, despite the potential benefits of greater knowledge exchange.

Aim: HESTIA – Harmonized Environmental Storage and Tracking of the Impacts of Agriculture – aims to become a widely used open-access data repository for research on food productivity and sustainability. It allows researchers to upload the primary data behind their field trials and surveys, or upload the foreground LCA data related their agri-food studies. By building HESTIA collaboratively with the productivity and sustainability research community, we hope to deliver a step-change in data availability

and data sharing in this field – like PubChem did for chemistry or GenBank did for genetics – while also supporting increased harmonization of environmental impact methodology.

Methods: HESTIA defines a near complete system boundary and a mid-point indicator set for the food system, and then works back to define the activity data and other foreground inventory flows that describe the system. Each inventory flow has a standard name and definition. For example, the inventory flow 'urea, as N, applied to field' means kilograms of nitrogen applied per hectare and is either a single value or an array of values with associated dates of application.

The LCA framework then allows data from disparate sources to be structured – from agronomic field trials, to biodiversity assessments, to full supply-chain LCAs. For example, a nitrate leaching field trial can be represented with just a few fields (columns) out of all the possible fields available: meta-data on soil type; and inventory flows on fertilizer use, crop yield, and nitrate emissions to groundwater. An on-farm biodiversity assessment can be represented with: meta-data on study location, crop type, and production practices; and an inventory flow on species richness. This approach can also take advantage of noSQL databases which are optimised for storing sparse and heterogeneous data and are scalable to millions of records.

Researchers can upload their data, linking their data items to the field names. They then receive a permanent digital object identifier (doi) for the submission. By uploading researchers can make their data available and promote new scientific discovery; share their findings globally with producers and policymakers; unlock new collaborations; integrate with other databases; and meet funder or journal requirements for open-access data sharing. The HESTIA team is also uploading data through meta-analysis. In the future, we may allow direct upload by producers.

Expected Results: Mid-point assessments are calculated from the inventory using standardised methods and existing background datasets. With machine learning, different environmental impact indicators are estimated from the sample of underlying data for different geographies, products, and production practices. HESTIA provides freely available periodic averages, benchmark impacts, and mitigation options, in a format that is actionable for producers, consumers, and policymakers. It also provides original and harmonized data, free and openly accessible, to researchers.

Discussion: There is a significant opportunity to unlock the insights from research on productivity and sustainability in food, but this data must be harmonized. LCA offers a framework to do this and HESTIA could help open up vast amounts of information to the world.

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LCA tools: appraising their background to evaluate alternatives to contentious inputs in organic farming

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Abstract

Problem and aim: Agriculture is a large contributor to global emissions of greenhouse gases, nitrates and pesticides, as well as a large contributing factor in soil and biodiversity loss. Currently, organic farming (OF) is gaining popularity due to its view as a more sustainable method of farming. This principle is now shared by the EU Bio-economy agenda and is also applicable to non-OF systems seeking to adopt more agroecological solutions. However, there is still some controversy surrounding potential contentious inputs in OF such as copper fungicides, antibiotics, peat, etc, which would need to be minimized or phased out. An H2020 project, ORGANIC +, aims to provide alternatives to these contentious inputs, showing not only their feasibility but also sustainability. In order to judge the environmental impacts of these improvements, we plan to use Life Cycle Assessment (LCA) tools. However, the current state of this methodology could not accurately reflect the effects of certain OF practices (Meier et al., 2015).

Therefore, there were two main aims of this research: 1) assess the environmental impact of alternatives to contentious inputs in OF and in turn, 2) appraise LCA tools in application to OF.

Methods: In order to achieve the first aim, OF reference scenarios were prepared for tomato, eggplant and citrus crops, as well as sheep, pig and chicken meat production. Then, a comprehensive list of

contentious inputs in OF and their potential alternatives was compiled in order to collect information regarding the nature of the substance, legislative status and effectiveness of the substance, among other characteristics. Subsequently, the environmental impact of the feasible alternative scenarios will be assessed using LCA.

Whilst creating the reference scenarios as well as reviewing secondary OF datasets from "recommended" LCA databases, a review of the methodological gaps in the life cycle inventory (LCI) and characterization models was performed. Then, to account for the multifunctionality of OF, different allocation methods and functional unit options were explored, as well as normalization by an environment's carrying capacity.

Results: We found that background processes such as plant protection products (PPPs) and organic fertilizers datasets were not representative of organic farms. Some common types of PPPs and fertilizers used in OF were not available in selected databases. Thus, many PPPs and fertilizers listed in organic LCI's used an average pesticide or fertilizer proxy, indirectly including prohibited OF substances. In a foreground analysis, PPP and fertilizer emissions were also unrepresentative, often using conventional emission fraction proxies. There was also a lack of secondary datasets mainly for "natural" products such as essential oils, natural anthelmintic, bioplastics, etc, and corresponding emissions and characterization factors.

Land use, toxicity, eutrophication and acidification were found to be the main impact categories that can be heavily affected by farming practices. Land use is the only impact category that analyses the benefits of OF, such as biodiversity and soil quality, thus some models can be favoured over others due to their comprehensiveness.

Discussion/Interpretation: Much work is still needed in the field of OF and LCA, but we provide some recommendations for improving organic LCIs, emissions modelling and characterization models in order to distinguish different agricultural practices. To gather the data needed to advance organic farming LCA, we would suggest the creation of a task force composed of frontrunners in the fields of OF and agricultural LCA and/or an easily accessible database/library that can be shared internationally.

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Data quality and acquisition in PEF studies – cases in LCA studies of Finnish potato, pork and milk

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Abstract

Rationale The PEF guidance has been developed for the harmonization of environmental footprint assessments of products in the EU, as a response to concerns regarding the use of unverified methods in the rising number of green claims for products. PEF guidance is divided to common methods to measure and communicate the life cycle environmental performance of products and organisations, and guide for development of PEFCRs and guides (PCRs) which have been developed in the piloting phase. These guidelines give specific restrictions e.g. for calculation methods, primary data requirements and data quality. Here, our focus is on primary data requirements and data quality in PEF studies of potato, pork and raw milk. The aim is to estimate data acquisition protocol for these products in Finland and assess the applicability of PEF guidance, with focus on primary data requirements concerning agricultural production in different food supply chains.

Methods PEF guidance was reviewed and evaluated with companies and available statistical data for each case separately and combined with Nordic guidelines for interpreting data acquisition (Hermansen

et al. 2017). For potato, study was performed as a case study of a company producing raw, peeled and/or cooked potato products. Here, due to the lack of PCRs for vegetable products, assessment was conducted following the general PEF guidance. The total volume of the sample was app. 28000 tons corresponding to 62% of the supply. For dairy, the study was similarly a case study for a company and one product. PEF guidance for dairy products was followed in the sampling. For pork production, assessment was conducted following the draft version of the red meat PEF guidance together with general PEF guidance to support the sampling procedure. Unlike in the other cases, pork production was estimated as national average production in collaboration with two pork producers with share of app. 75% of the total pork produced in Finland and with on average 750 farms as suppliers. According to guidance, sampling can be based on production volume or farm quantity (Hermansen et al. 2017). The sample should cover the supply corresponding to 50% of the production volume of the product or if sampling is based on farm quantity, stratified method is followed to divide production in groups for sampling with square root of each subpopulation size. Here, the stratification was conducted as technological differences could be defined in multiple feeding and production strategies on pork farms.

Results and discussion In the potato case, field parcel data provided by farms was analysed. The total data covered three years of production and over 50% of the total annual (2018) potato supply, corresponding to PEF requirements. In the assessment of pork, it was found that while stratification based on feeding strategy is justifiable, the grouping itself was problematic. In order to determine the range of feeding strategies, a survey to farms was needed as the data was not readily available. Pork farms were categorized also based on management strategies. We found that in conducting PEF studies, the sampling methods can be very variable and definitions are unclear. PEF guidance seems to lack definite protocol for forming strata when agricultural products are considered. Hermansen et al. (2017) provide a list of characteristics which can be utilized for cattle production. Feed composition and management strategies that significantly influence the environmental impacts are well justified in forming subcategories. Yet, in pork production feeding strategies vary and stratification can end up biased. For harmonization of the environmental sustainability, more focus should be given also to harmonization of sampling.

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An approach for territory scale LCA of vineyard management for informing practice change

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Abstract

Problem and aim

Eco-design in Agriculture is recent and was mainly conducted on crop management at field scale. A methodological framework for scaling up LCA of agricultural management to farm scale in the purpose of informing practice change was recently proposed by Czyrnek-Delêtre al. (2018). However, practice change is also a question raised at territorial scale; that is particularly the case in Protected Denomination of Origin (PDO) in viticulture. Some practices are imposed by an official set of rules specific to each PDO and the French government has recently encouraged the PDOs to include environmental-friendly practices in their set of rules. Thus, there is an actual need to define a specific approach for LCA at territorial scale concerning the eco-design of farm practices to accompany the PDO groups in their choices. The poster presents the development of a method to meet this demand.

Methods

The study was conducted in a small wine PDO located in the Loire Valley in France. The aim was to assess vineyard soil management practices impacts to inform the collective choices of their evolution. A survey was realised at the field scale. Its purpose was to collect all the information about their Pathway of Technical Operations (PTO) for soil management in 2019 and their relative locations. The PDO being small, an exhaustive inventory of practices was planned, so a life cycle inventory of main types of soil management was conducted in 29 out of 35 winegrowers of the PDO. The geographic information permitted to collect more data about the biophysical context representing important parameters for direct emission calculation. Then, a database was created comprising all collected information which was used for clustering through statistical analysis using R. In parallel, exhaustive maps of practices related to biophysical context were drawn using QGIS software.

To design the specific approach for LCA at territorial scale, a Principal Component Analysis (PCA) and a Multiple Component Analysis (MCA) have been executed upstream to conduct a Hierarchical Clustering on Principal Components (HCPC), and thus create two typologies. One is a clustering of PTOs and the other is a grouping of biophysical context, both at field scale. Thereafter, the two typologies were combined to form a new clustering "PTO-field structure". The LCAs are being done, with Vit'LCA software (doing LCI and LCA for viticulture), on the most relevant individuals for each cluster from the "PTO-field structure" clustering. So, one assessment per cluster is being realised. Then, the LCA results will be extrapolated by using the surface area of each cluster to upscale the LCA from the field to the PDO.

To check the accuracy of this method, a detailed LCA approach is being done, consisting in conducting LCAs for each field with its PTO and biophysical context. Then, the LCA results of this approach will be extrapolated by using the surface area of each field. Finally, the LCA results at PDO scale from the two approaches will be compared.

To animate the participative workshops with the stakeholders, the use of LCA results will be used as a support to design a realistic environmentally friendly pathway of technical operations for soil management with different stakeholders of wine production.

Expected results and discussion

The establishment of a new method to use LCA at a territory scale for vineyard practices could be one of the outcomes of this project, depending on the comparison of two different approaches. The LCA impacts of soil management practices and the influence of the natural environment will be displayed to the scientific and technical community. The aggregated impacts coming from the LCA results of the clustering approach will then be represented on maps and used in participative workshops to trigger a collective thinking about the PTO evolution in the PDO. Finally, this project could contribute to a decrease of environmental impacts in PTO of soil management.

The method used for this small PDO cannot be directly transferred to bigger territories where all the farmers cannot be interviewed. A declination will be designed for these situations, based on the present experience.

Acknowledgements

The Authors thank Aurélie Perrin, Sidy Fall, and the winegrowers for their contribution

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French tool for the environmental assessment of vegetable oil products

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Abstract

Problem and aim

The reduction of environmental footprint is now a strategic challenge to help keep businesses in business and improve competitiveness of food industries. Conscious of this key issue, the French vegetable oil sector wanted to provide to producers and users of vegetable oils a tool for evaluating the environmental impacts of food products formulated from vegetable oils: the AcéVOIL tool.

Methods

ITERG, the French research institute of oils and fats, developed this tool. The scope and functionalities of the tool have been determined in consultation with French interprofessional organization, federation and producers of vegetable oils. This tool has been designed from previous ITERG's works: (i) establishment of methodological guidelines of environmental assessment in the vegetable oil sector, (ii) development of an internal environmental database for vegetable oils and some derivatives. It is available to French oil producers and regularly updated. A group of external and independent experts had reviewed this tool and related documents, following the ISO 14040 standard.

Results

This tool and related documents are available for free on the ITERG website, in French language. The aim of this tool is to give a better understanding of the environmental impacts of products and processes used in the sector and to identify the room for environmental improvement. It can be used to validate the environmental value benefits of ecodesign initiatives as-deployed or as-designed.

ACéVOIL is dedicated to users and producers of vegetable oils. This tool can be used for (i) vegetable oils coming from oleaginous seeds, (ii) processes of transformation of seeds into vegetable oils and (iii) food-products produced from vegetable oils (margarine, mayonnaise, etc.). The environmental assessment can be completed from the agricultural step (production of seed) to the transport of the final product to

warehouse (including production and end-of-life of the packaging). The users can implement the tool with their own activity data (eg energy consumption, water, etc.) or pick available default values, coming from literature or ITERG's framework. The environmental impacts are calculated through four indicators: the emissions of greenhouse gases, the net water consumption, marine eutrophication and aquatic ecotoxicity.

The ACéVOIL tool has been downloaded more than 270 times, mainly by food companies. It is also used for training session at Universities as example of LCA application in food industries.

Discussion/Interpretation

The tool also outputs results that can be readily communicated out to clients and/or consumers as part of a product information backbone to differentiate from competitor products and up-value the ecodesign initiatives implemented. However, communicating LCA results out to the public can prove tricky business, so the exercise needs to be managed with care and forethought.

At this time, this tool suits the French production context. Several upgrades are envisioned to extend the scope of ACéVOIL out to other European countries.

Acknowledgments

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A new pesticide emission model for life cycle inventories of paddy rice

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Abstract

Problem and Aim

There is an urgent need to develop proper science based models for estimating pesticide emissions in relation to agricultural, food and nutritional LCAs. Previous practices were often based on the very general assumptions that all applied pesticides are discharged into the soil and/or water in constant ratios independent of the chemical properties of the pesticide being applied. The PestLCI model[1], which contains three primary modules (loss by wind drift, deposition on leaves, and deposition on soil), has been developed for estimation of emissions in LCA studies by allowing for estimation of the amounts of pesticides released to the surrounding environment taking into account agricultural practicises, pesticide properties, soil properties and meteorological conditions. The PestLCI model, however, focuses only on arable land, and does not cover fate processes after deposition on paddy water. In this study, we present a new version of the PestLCI model for estimating pesticide emissions from paddy cultivations in Japan for the use in LCA involving rice production.

Methods

To develop the new PestLCI model version for paddy fields, the whole framework of PestLCI was adopted, except for the module of deposition on soil, which was replaced with a new module representing pesticide deposition in the paddy water. The modeling approach of the relevant fate processes in the new module were based on the pesticide paddy field model called PADDY[2]. Figure 1 gives an overview of all the fate processes considered in our novel model which like the original version of PestLCI can estimate the emission fractions to air (f_{air}), surface water (f_{sw}), and vertical leaching (f_{vl}) of pesticides applied in paddy field.

Results

By applying the presented novel model version, the emission fractions of 37 pesticides commonly used in Japan were estimated. A sensitivity analysis was conducted by varying selected parameters applied in the model to reveal their influence on the emission fractions. For f_{air}, parameters affecting the results greatly includes the formulation applied. For f_{sw}, the water-holding period and waterproofing of the levee were found to be important regardless of the formulation adopted, which suggests that local management could effectively reduce emissions to surface water. f_{vl} is greatly affected by the organic carbon content in the soil, suggesting a large regional dependency of the emission factor.

Discussion/Interpretation

The developed model is expected to greatly improve the realism of inventory and hence impact assessment of pesticides in LCAs of paddy rice cultivation. The reason is that the presented model enables life cycle assessors to bridge the gap in fate modeling for estimating pesticide emissions to air, surface water, and soil in the current practice of LCA of paddy rice.

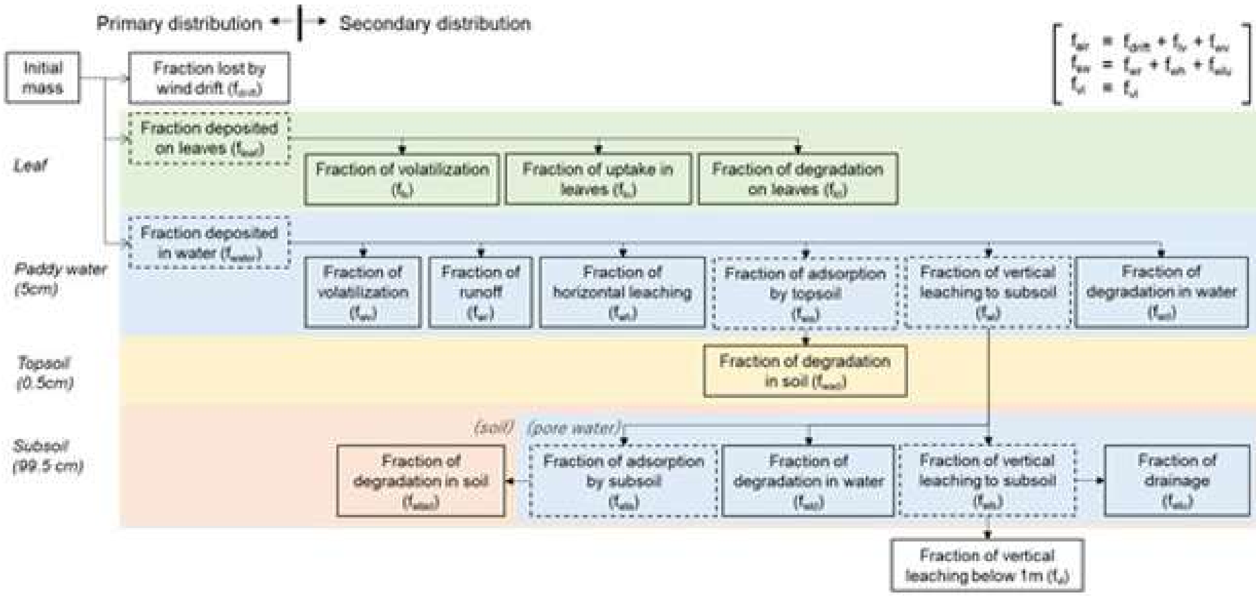

Fig. 1 Overall model structure and mass flows accounted for. Dotted line indicates fate processes that moves pesticide mass to different model layers.

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BaGaTel: an ontology driven database to ecodesign food products taking into account their nutritional and sensory qualities

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Abstract

Problem & Aim

Multicriteria assessment of agrifood systems is essential in ecodesign approaches aiming to improve sustainability of food value chains. Environment, nutrition, and sensory acceptance by consumers are key criteria. With this purpose, collection and management of data on agrifood system activities are of primary importance. There is a real need of tools to structure, store and share data related to the transformation of agricultural products into food, domain currently poorly documented.

Methods

A process and observation ontology in food science, PO² ontology [1], has been built to structure a relational database, BaGaTel, in order to integrate data in the field of dairy products taking into account their environmental impact computed by LCA as well as their nutritional and sensory properties, using a consensual model and a shared structured vocabulary. Data from a total of 40 different projects (collaborative national/European, publications, PhD theses, reports) have been integrated with their

associated metadata (project information, linked publications, nature of the data, incertitude, process steps, materials, methods…). The metadata associated to each project, the list of the terms used in BaGaTel and a video tutorial, which presents the data entry interface and the visualization of data, are available on the NutriSensAl portal [2].

Results & Discussion

BaGaTel database was shown to be very useful to support Life Cycle Inventories (LCI) in the case of Comté cheese assessment [3]. A detailed process chart could be built, and guidance to data collection could be provided by querying the different projects in the database on available collected data for LCA (electricity consumption, liquid wastes…). LCA practitioner then has to consider if these data are relevant for the studied system, and if other similar data have to be included. BaGaTel database was also successfully used to estimate quantified data on electrical consumptions, by querying the data available for the materials (power of equipment) and methods (duration of process stages) used.

When LCA has been computed: inventory data and results can be stored in the BaGaTel database, together with all the corresponding metadata (e.g. system boundaries, functional unit, impact assessment method) necessary to eventually re-use them. Thanks to the fact that data on cheese quality, process and ecodesign are in the same database, and that many projects and data are available, it is possible to estimate missing data on the environmental impact of projects only focused on food quality. Such an approach is very useful for knowledge and data capitalization, as well as to produce new knowledge and data by combining and integrating existing resources. Multicriteria assessment is obviously facilitated by such a database.

Our objective is now to combine the database with adequate tools to deliver open access data in accordance with FAIR principles (Findable, Accessible, Interoperable, Reusable). We are also working on the interoperability between BaGaTel and MEANS platform [4], which provides tools and database for LCA practitioners. MEANS-InOut software currently allows the description of farming practices for crop and livestock productions, inclusion of food processing will provide a major step towards sustainability assessment of agrifood systems.

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Development of an animal welfare LCIA method for laying hens, with application to the Canadian egg industry

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Abstract

Problem and aim: It is widely accepted that sustainability is a multi-faceted concept incorporating environmental, social, and economic aspects, and that each situation presents a unique combination of these (Brundtland 1987; Miemczyk and Luzzini 2019). The adoption of the LCA framework for assessment of the collective resource demands, environmental burdens, and socioeconomic costs and benefits associated with the food production sector is a valuable way to take into account numerous aspects of sustainability, thereby accurately reflecting the potential impacts associated with food production systems (Zamagni 2012; Pelletier 2015). To this end, significant progress has been made in development of environmental LCA, social LCA, and life cycle costing methodologies, and application to food systems. However, in application to animal production systems, integration of animal welfare assessment into the LCA framework has significantly lagged behind, representing a major shortcoming. In order to ensure net positive outcomes, resource/environmental indicators need necessarily be considered alongside animal welfare indicators on a methodologically consistent basis. As such, this study aimed to develop methods for assessment of welfare in laying hen systems, with differentiation by housing type (ie. conventional and enriched cage, free run/range, and organic), and in accordance with accepted principles of animal welfare science, for integration into the LCA framework.

Methods: Using the definition of animal welfare proposed by Fraser et al. (1997), in which welfare is composed of the domains of biological function, affective state, and the ability to perform natural

behaviours, a critical review of the animal welfare literature was performed. This review identified appropriate impact categories and category indicators, as well as the bases for classification and characterization of pieces of welfare data to different impact categories during assessment of laying hen systems. This method was then applied to a case study of the Canadian egg industry.

Results and discussion: Development of this impact assessment methodology allows for integrated assessment of welfare in laying hen systems within the LCA framework. Application of this method using data collected from farms across Canada elucidates trade-offs across welfare domains that are characteristic of different housing systems. Identification of these trade-offs will provide valuable support to the Canadian egg industry as they move to transition away from conventional cage-based housing systems in favour of alternatives. At a global scale, this work contributes to on-going efforts to integrate animal welfare assessment into the LCA framework.

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Can a customised agricultural LCA tool respond to the needs of different user types? The case of MEANS-InOut

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Abstract

Problem and aim

Customised agricultural LCA tools provide a user-friendly interface for collecting data and focus on the most significant life cycle phases for assessment of agricultural systems. They are increasingly popular, because they simplify LCA studies of agricultural production systems. These tools provide a framework, thus help the user not to forget any flow and reduce the risk of errors. However, compared to more generalist LCA tools, customised LCA tools are less flexible, and it is harder to tackle questions that were not anticipated during the design of the tool. This often leads to a multiplication of tools, each dedicated

to a single type of system. Developing many specialised tools is costly in terms of resources, that can be considered wasted if the tools are not much used [1]. The adaptation of existing tools to a diversity of uses may be a better way forward, essential to their sustainability.

This study shows how the MEANS-InOut software answers to different types of users and how it can be adapted.

Methods

The MEANS-InOut application is a customised LCA tool that generates LCIs of agricultural production systems [2]. MEANS-InOut provides forms to guide data collection, mathematic models to calculate direct pollutant emissions, and an export module that generates LCI files compatible with LCA software. MEANS-InOut was designed for users with limited LCA knowledge. It allows to describe finely the system management, but not to configure the characteristics of inputs.

MEANS-InOut was chosen as the tool to produce LCI data in a project dedicated to the LCA of products of French organic agriculture. Twelve project partners used MEANS-InOut to described organic production systems and generate 105 LCIs data. All of them were agronomists or animal scientists, with different levels of experience in LCA.

This study was the first using MEANS-InOut to generate LCIs for a diversity of production systems by this number of users. A survey was carried out to assess how MEANS-InOut responded to their needs.

Results

Table 1: Level of satisfaction of MEANS-InOut users depending on their objective

		Satisfaction				
Objective	Importance of objective	Very satisfied	Fairly satisfied	Not very satisfied	Not satisfied at all	Total
Evaluation of agricultural system	Highest	1	4	0	0	5
	High	0	6	2	0	8
	Medium	0	1	0	0	1
	Low	0	0	0	0	0
	Total	1	11	2	0	14
Creation of new agricultural LCI	Highest	4	1	1	0	6
	High	2	1	0	0	3
	Medium	0	1	0	0	1
	Low	0	0	0	0	0
	Total	6	3	1	0	10
System eco-design	Highest	0	0	0	2	2
	High	0	3	2	0	5
	Medium	0	1	0	0	1
	Low	0	0	0	0	0
	Total	0	4	2	2	8

The most satisfying functionality of MEANS-InOut was the creation of agricultural LCI. The evaluation of systems appeared satisfying, while eco-design was not satisfying. Advanced LCA practitioners were satisfied by the use of MEANS-InOut and suggested some improvements. LCA specialists were fairly satisfied by MEANS-InOut but frustrated by some limitations of the tool. LCA beginners were less satisfied, they considered that system modelling was too complicated.

Discussion/Interpretation

MEANS-InOut achieves its objectives for advanced LCA users: to facilitate LCA studies by generating agricultural LCIs. They consider the tool to be user friendly and efficient. However, LCA beginners consider the tool to be fairly inefficient. This can be explained by their lack of experience of the inherent complexity of LCA, so they cannot see the tool's advantages. Their demand for more detailed instructions and a simpler modelling should be taken into account to provide a real user friendly tool.

A key functionality missing for eco-design is the possibility to parametrize relevant levers for the studied system. After this survey new functionalities are under development to match the needs of users. A special attention is paid on these features because demand for more precise functionalities is often in contradiction with the request for a simpler software.

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Decisional units instead of functional units to allow life cycle-based decision making for consumer choices

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Abstract

1.1 Problem and aim

The ISO 14040/44 standard was originally developed for the comparison of products or services from an environmental point of view. A critical issue in this framework is the "functional unit" which is defined in the ISO standard as the "quantified performance of a product system for use as a reference unit". Furthermore, ISO says "Comparisons between systems shall be made based on the same function(s), quantified by the same functional unit(s) in the form of their "reference flows.

Today life cycle thinking is often applied in broader sense than foreseen by the ISO 14044 standard. Especially in the field of beverages, food, and pet animals several questions arise from a consumers' point of view, for which choices go beyond the limitations of the ISO standard. Such questions are e.g.

- What do you like to drink today (asked by a waiter in the restaurant)?
- What do we eat for lunch or dinner?
- Which pet animal should we keep in our family?
- Which topping should I chose for my sandwich?

We made the experience that this leads to rejections if e.g. studies dealing with such questions are submitted for scientific publications.

These questions are relevant from an environmental point of view and from the single persons point of view even options with quite distinct functions might be taken as comparable in a specific situation.

1.2 Results

The issue is further elaborated e.g. for pets. Strictly speaking, different pets are hardly comparable in the sense of the ISO standard. Too different are the needs that different animals can meet and too individual are the reasons to buy a pet. Some functions of keeping a pet are for example:

- Leisure activities and hobbies (breeding, competitions)
- Sports (walking with dogs, horse riding)
- Education (responsibility of children for a pet, appreciation of living beings)
- Social contacts (pet as a life companion, contact with other pet owners)
- Health (positive influence e.g. on depression or other mental illnesses)

If, for example, the purchase of a domestic animal is considered in principle, then various aspects are discussed in a family before a decision is made for a certain pet. Environmental aspects may be one of the criteria to make such a decision.

In this sense, we think LCA should also be used to guide such decisions. Several examples have been elaborated in the past on the questions shown above. In all these studies there is no strict comparability as in product LCA, but they can certainly help to compare personal lifestyle decisions and present them from the perspective of the entire life cycle. These studies thus contribute to making personal lifestyles more environmentally friendly and to supporting decisions in this regard.

1.3 Discussion/Interpretation

Such an expanded use of the instrument and the idea of life cycle assessment is also reflected in the developments for the life cycle assessment of entire companies. Here, too, comparability is generally not possible. Therefore, the calculations are carried out for a reporting unit instead of a functional unit. The method of life cycle assessment nevertheless provides important inputs for improvement from the perspective of the entire life cycle of such a unit.

To make the difference to a comparative product life cycle assessment clear, we propose to speak about a "calculation unit" instead of a functional unit. In addition, we propose talking about a juxtaposition of different consumer choices and instead of a comparison. We think it is important to further develop relevant standards in this sense and want to contribute to this discussion with the proposed presentation.

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Methodological pitfalls of aggregating life cycle assessment data in global food system sustainability models and scenario analyses

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Abstract

Problem and Aim: To understand the environmental impacts of regional and global food consumption patterns, and to model future food system scenarios, a growing number of researchers are aggregating and synthesizing published food life cycle assessment (LCA) data. The processes of identifying, winnowing, and combining extant LCA data for individual food items to model complex food systems involve several important methodological decisions. Because methodological choices made by practitioners can so heavily influence both the results of the synthesis studies and how those results are interpreted, and because many of these studies have garnering much attention through mainstream news media, these methodological choices may very well have significant policy implications. This paper analyzes a subset of recent studies that combined results from food LCAs, identifies common methodological pitfalls in relation to stated objectives, and suggests improvements for future syntheses of published food LCA research.

Methods: Following a large-scale review of food LCA synthesis research (i.e. studies which synthesize food product LCAs to model regional or global food consumption, to compare different diets, or to explore future food consumption scenarios), we chose a subset of papers for deeper analysis. The selected papers met these criteria: 1) they were published within the past five years (2015-present); 2) the papers had significant impact (cited in other research and policy documents, news media attention, etc); and 3) the research was ambitious in scope, requiring the synthesis of a large amount of published data.

Using guidelines and standards for systematic reviews and meta-syntheses generally, as well as guidelines and standards aimed at synthesizing environmental data and LCA data, key methodological decisions were identified. The approaches taken in the selected studies were then evaluated with respect to their adherence to published meta-synthesis guidelines, as well as their appropriateness in addressing the authors' stated objectives. The potential impact of these methodological approaches on the studies' results and interpretation were also identified.

Results & Discussion: Our analysis suggests that the published food LCA synthesis research is lacking in methodological transparency and does not demonstrate widespread application of data synthesis best practices. In particular, the following methodological decisions were identified as critical for effective food LCA data synthesis: the selection of studies for inclusion in the synthesis; treatment of data uncertainty and variability; treatment of methodological variability within the group of studies to be synthesized; the application of methods to ensure data representativeness (e.g. weighting); how food products are grouped into categories; and data aggregation methods. The papers analysed vary widely in their treatment of the methodological issues raised in this critique, with many of these issues seemingly not addressed at all. Similarly, there is often little discussion of the impact that meta-synthesis methodology has on results and on the reader's ability to reliably interpret and apply this research. We present suggestions for improving the quality of food LCA syntheses, drawing from standards for data synthesis coming out of health and environmental sciences, knowledge synthesis and translation literature, as well as LCA methodological and LCA meta-synthesis literature.

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Environmental footprint data of food products: quo vadis?

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Abstract

These days, thousands of data are available listing carbon footprints (CO_2 footprints, greenhouse gas footprints) of hundreds of food items and/or meals. They include online data bases, tools or applications (such as WFLD 2015, IFEU 2016, and KEEKS 2019) as well as hundreds of literature publications covering more or less individual food products or a whole set of food items.

The same situation, though to a less extent, applies also for other environmental footprints, especially water footprint and land use footprint, which are extremely important if environmental implications of food is considered. And of course for many other environmental impacts, which are usually assessed in ISO 1040/44 conform life cycle assessments (LCA) such as acidification, eutrophication, ozone depletion, photo smog, human toxicity etc.

If results of those environmental footprints for food items from different literature sources are compared, very often big differences are observed – in some cases they sum up to up to 10 times higher or lower. The reasons for this are fairly obvious for LCA experts, though sometimes difficult to trace down because of lacking documentation. But this situation is not satisfactory at all, especially if the data mentioned are addressed to advice decision makers including consumers as they usually don't have the knowledge to understand the differences. In the long run, those decision makers will loose more and more trust into the strengths of LCA results, if the situation doesn't change.

At the upcoming LCA Food 2020 we want to raise awareness about this situation and suggest options how to proceed to gain more trust into LCA results of food products in the future. The presentation will cover:

- An overview about the differences of the environmental footprint data for food products
- Identification of the reasons covering all relevant aspects such as methodology, system boundaries, primary data, geographical issues etc
- Options how to proceed to build up a solid, confidential trust on LCA of food findings in the long term.
- Conclusions and recommendations

The conclusive discussion and presentation of the scientific findings regarding these topics are rounded off by recommendations for science, policy, society and industry.

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Topic 11: Regionalization and Urbanization

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Socio-economic and environmental performance of small-scale and mild fruit and vegetable processing technologies

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Abstract

Socio-economic and environmental performance of small-scale and mild fruit and vegetable processing technologies

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Problem and aim

Food represents one of the most important commodities for human beings, but its production and processing can put pressure on the environment. The technical and technological development has made possible to bring hundreds of millions of people out of hunger (although the problem of hunger in the world is still currently one of the main of challenges in the achievement of the Sustainable Development Goals SDGs for 2030) but the larger availability of food as a merely result of an economy-of-scale production and distribution raised several issues on its social and environmental sustainability. In the framework of Horizon 2020, the FOX[1] (Food processing in a Box) project will design, model and assess four innovative and flexible small-scaled food processing technologies in six European transnational regions.

Methods
The new technologies are expected to permit the production of high quality and mildly processed

food products with better nutritional characteristics in a more sustainable way. A social and environmental impact assessment of these new technologies will be done.

The potential economic benefits will be assessed through the integration of economic data and business models in a so-called LCC (Life Cycle Costing) analysis. The analysis will include data regarding the commercialization in local markets of the products processed with the four new innovative and flexible technologies, data about investments and costs (direct, indirect, fixed, variable, opportunity, etc.) and data about potential business opportunities. For the social benefits, potential job creation in the local areas will be assessed.

In order to consider all the possible environmental aspects, impacts and issues; and in compliance to both the ISO 14040 and ISO 14044 directives, an LCA (Life Cycle Analysis) will be carried out for all the four innovative technologies presented in FOX. The impact of the final products developed with the FOX processing technologies will be compared with the impact of a reference product. Each product's impact will be expressed relative to the impact of the European Food Basket. Data on consumer preferences and consumers' consumption intention will be used to model the overall impact of a shift away of the reference product towards the products developed with the FOX technologies.

Results & Discussion

The final outcome is a socio-economic and environmental impact assessment of the four innovative small-scaled food processing technologies. Since LCA and LCC are expected to inform the development of the technologies, data collection for small scale processing technologies should occur during the development phase. This will be challenging.

Literature

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Enhancing sustainable strategies in local food varieties: Pomodoro Siccagno

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Abstract

With the increased health consciousness of consumers, a huge number of traditional and almost abandoned varieties of food are being re-visited. This is the case of the cultivation of *Pomodoro Siccagno,* a type of tomato produced in South Italy. Its nutritional and health related benefits include the presence of carotene and also a high concentration of sugar and mineral salts. It is grown using a traditional dry-farming method which has been developed and used in the internal part of Sicily (Italy). It is particularly suitable for water scarcity regions such as South Italy, because it drastically reduces water consumption and also the use of anti-parasites compared to widespread irrigated tomato. Despite these positive attributes, the cultivation of *Pomodoro Siccagno* has been declining over the years and currently represents only 20 % of total tomato cultivation land in the region (Venezia et al., 2010). This is partly due to the low yields as a result of the little or no water use and the low availability of planting seeds. However, this trend is being reversed nowadays as more and more consumers demand for products with high nutritional and health benefits as well as those products which aim at fulfilling requirements of organic farming.

While it is important to promote the valorisation and consumption of indigenous products of recognized nutritional and health related attributes, such as *Pomodoro Siccagno*, it is equally important to establish their environmental performance. A large number of studies have identified high contributions to environmental impacts coming from the cultivation and packaging life cycle stages of tomato products (LIFE PREFER, 2016). Results show huge impacts on land use and water consumption related to cultivation as well as significant energy requirements for agricultural

machineries (Ingrao et al., 2019). The objective of this paper is to compare the environmental impacts of *Pomodoro Siccagno* vis-a-vis irrigated tomato.

A comparative Life Cycle Assessment methodology according to ISO 14040/44 (ISO, 2006a) (ISO, 2006b) is applied to *Pomodoro Siccagno* and irrigated tomato cultivated in the Italian Region of Sicily. The LCA study will be based on primary data related to the actual cultivation process of the different types of tomato. This is part of an ongoing research project of the University of Palermo to investigate the genetic and nutritional properties of *Pomodoro Siccagno* and optimize cultivation methods.

The LCA methodology will provide robust and representative results essential for decision making and as such will inform policies or strategies aimed at promoting sustainable production and consumption. Hence, this will contribute to advancements towards the United Nations Sustainable Development Goals at local contexts which are usually characterized by typical production and consumption patterns. Complete findings will be available at the conclusion of the project in summer 2020. These will be presented and discussed, identifying further research gaps and implementation strategies.

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An LCA approach to determine the self-sufficiency potential of the Hamburg region according to required resources and diet scenarios

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Abstract

Problem and Aim

The industrialized food system – widely practiced today on a global scale – is imbalanced and unsustainable. Fruits, vegetables, grains, fish, and meat circulate around the globe in complex networks, characterized by a lack of transparency and traceability in the food supply chain, posing environmental, health and social equity challenges. Shifting towards a more transparent and localized food system, in which production is aligned to the natural resources available and does not require high inputs of artificial chemicals and fertilizers, has the potential to provide a positive shift towards more sustainable production and consumption.

In this project we use a Life Cycle Assessment (LCA) approach to analyze the potential for regional self-sufficiency for the city-state of Hamburg and the surrounding region (100 km radius). Our contribution lies in both the context and method. To the best of our knowledge no other study has interlocked multiple regional resources with diet scenarios. Additionally, we use LCA to quantify the production requirements of complete diets, and the effects of substituting for less resource intensive alternatives – a new method contribution.

Methods

The main method used in this project is LCA. This method is used to quantify the environmental requirements and impacts associated with producing a specific product. Resources include land, water and energy.

Step one: Identify diet scenarios and required resources for production

We identify the impacts of switching from a “status quo” German diet to one that can be produced solely regionally, backed up by the data from statistical databases and expert interviews. The main required resources per kilogram of product are then quantified. Data is collected from the literature, statistical databases and the EcoInvent database.

Step two: Identify resource availability in the region and visualize in ArcGIS

Using the national, regional and open-source databases, we identify the available resources for production within the Hamburg region. We then create (in the case there is not a layer available) or load the data into ArcGIS as individual layers. We then use the Spatial Analyst tool to quantify the layers of the map (e.g. available water), which can be exported as tables to Excel.

Step three: Run LCA analysis to assess regional self-sufficiency potential

In the last step, we take an LCA approach to determine how many people can be fed (calculated as complete diets that can be produced with the resources available). This is first based on average consumption quantities of different food groups. Additionally, we plan to identify product consumption that must be reduced and/or substituted (e.g. legumes for meat) to use resources more efficiently. The goal is to calculate the results using MatLab, so that we can generate multiple scenarios to determine the optimal diet to feed the most amount of people in the case of a complete break in the supply chain.

Results

This is a working paper, results have not yet been produced.

Discussion/Interpretation

This is a working paper, no discussion and/or interpretation available as of yet.

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Home cooking in the UK: what is the most sustainable method, and does it depend on gender?

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Abstract

Problem and aim

Food is a core component for development and has been clearly captured in the UN-Sustainable Development Goals being a contributor of up to 30% of global greenhouse gas emissions (GHGe)[1]. Although great efforts have been made towards understanding the impacts of food production and consumption, little is known about the contribution from cooking methods, and how they might impact society. This is particularly important as more sustainable and healthy diets are advocating plant-based food[2]. Studies[3,4] estimated that in the UK the contribution to climate change of cooking

stage to total impacts vary from up to 20% for meat products to up to 40% for vegetables. For ready meals, cooking could contribute between 18%[5] and 35%[6]. Additionally, considering the health-related issues of processed and ultra-processed food, studies are also promoting cooking from scratch[7].

With home cooking being the responsibility of mainly women[8], gender inequality is an issue in sustainable diets.

This project aims to compare the environmental impacts of different cooking methods identifying its contribution to the total impact of food consumption in the UK and drawing recommendation for best practices. A further goal is to identify potential patterns between gender aspects and cooking methods.

Methods

This study assesses the contribution of cooking methods to the overall impacts of climate change of 30 food items commonly consumed in the UK.

The analysis draws on data that was collected from a UK wide representative sample survey of cooking habits (n=524). After data cleaning (n=397), GHGe were calculated for each food item based on the respective cooking methods. A UK cooking appliance database was built containing the energy demand of the different appliances.

GHGe of cooking were calculated using the carbon emissions factor for the UK electricity mix and natural gas for the year 2019[9]. The impacts of the pre-consumption were taken from literature[1] to then estimate the contribution of cooking to the overall environmental impacts of food.

The survey also captured demographics, to assess potential trends between gender aspects and cooking habits in the UK.

Results

Preliminary results show that cooking contributes significantly to the overall climate change impact ranging between 8%-84%. For vegetables, cooking plays an important part to GHGe accounting for 33%-84%. For starchy products, meat and fish, home preparation contributes between 20%-60% to the overall impact.

Gender issues connected with cooking methods in the UK are still under studied.

Interpretation

The impact of the cooking phase depends on the chosen cooking method and time. For instance, long roasting or baking in the oven causes the highest GHGe, while preparing in the microwave shows much lower emissions. GHGe can be reduced between 40% and more than three-fold by avoiding cooking in the oven and choosing preparation methods that require less cooking time.

The study makes several recommendations for households and related stakeholders to reduce climate change while promoting more sustainable cooking practices and equal responsibilities in society.

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Food origin matters: The role of regionalized inventory and impact assessment for the environmental impacts of the Swiss food sector

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Abstract

Food systems in many countries rely on imports. At the same time, reducing the intensity of domestic production is seen as a way to reduce the environmental impact of the local food sector. This leads to the question of the impact of imported products. In Switzerland, current political discussions aim at reducing pesticide use and livestock numbers in domestic agriculture so as to reduce pesticide and nutrient emissions. The food sector already depends heavily on imports; lower crop and animal yields will increase them even more. In this paper, we discuss the importance of imports and their origin for the environmental impact of the Swiss food sector in the current situation and in several low-input, low-livestock scenarios.

Schmidt et al. (2019) examined the impact of pesticide-free production with lower crop yields and lower livestock numbers on agricultural productivity in Switzerland and concluded that calorie production would decrease by 12-21%. Based on their data, we analyzed the overall environmental impact of the Swiss food system in various scenarios, considering both domestic production and imports. We estimated the development of crop- and animal-based food imports from the base year 2016 to the target year 2025 using an econometric forecasting method. The environmental impacts were calculated by building a "basket of products" for each scenario, which consists of about 400 datasets representing the production of all necessary products and origins. The datasets came from Agroscope's SALCA database, ecoinvent v3.5, and AGRIBALYSE v1.2. The impacts of these "baskets of products" were calculated using a set of midpoint LCIA methods. We investigated impacts on biodiversity, acidification, terrestrial eutrophication and water scarcity using methods with regionalized characterization factors that take into account the susceptibility to damage caused by a specific land use or emission in different countries. In addition, we calculated global warming potential, aquatic eutrophication, use of non-renewable energy and abiotic resources, land use, deforestation and freshwater ecotoxicity.

In most scenarios, crop product imports increased by up to 200%, and animal product imports by up to 700%. In most environmental impacts, imported animal products were crucial for the rating order

of the scenarios, while imported plant products were only decisive for ecotoxicity and water scarcity. The countries of origin were relevant at several levels. At the life cycle inventory level, production intensity was important, which often differed significantly between world regions. For example, input-intensive European meat and milk production was decisive for resource use and global warming potential, while meat from South America dominated land use, deforestation and aquatic eutrophication due to extensive production systems with low animal growth rates. At the impact assessment level, regionalized methods caused a systematic difference between domestic and imported production and between different countries of origin. With regard to biodiversity, acidification and water scarcity, production in Switzerland had an advantage over production abroad due to the local ecosystems' lower susceptibility to damage. Conversely, production in Switzerland had a much greater impact on terrestrial eutrophication than imports because the burden is already high and additional emissions are rated more harmful than in other countries.

The study leads to the conclusion that food origin plays a role at different points during LCA of food systems. If local agriculture becomes more extensive, the consequences abroad must be considered in detail with regionalized inventory and impact assessment to ensure that the whole food system does not increase its overall impact.

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Evaluating the environmental sustainability of legume-modified rotations: exploring the potential of human nutrition

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Abstract

Agricultural practices must evolve to deliver food security whilst reducing environmental impact and adapting to climate change. On one hand, modern technologies have been adopted to more precisely apply inputs including fertilisers and water, producing crops more efficiently and reducing waste within “conventional” systems. On the other hand, there are efforts to break the current state of technological lock-in of intensive mono cropping by promoting more complex cropping systems that may include more biological nitrogen fixation by legumes, extended rotations and intercropping. Such “agroecological” intensification could mitigate some of the environmental impacts linked to agriculture, including high dependence on finite resources such as phosphorus fertilizers and fossil energy, greenhouse gas (GHG) emission, loss of reactive nitrogen and soil degradation.

Incorporating legumes into cereal rotations is a promising form of ecological intensification for Europe. Legumes are an important source of plant protein and have the ability to fix nitrogen from the atmosphere biologically. Legumes provide a significant quantity of nitrogen to following crops, reducing mineral fertilizer requirements and consequently decreasing GHG emissions (Watson, et al 2017) across entire rotations. Currently, only 1.5% of European arable land is planted with legumes, compared to 14.5% worldwide. Meanwhile, a deficit of protein-rich plant products in Europe is compensated by importing soybean from other countries where its production may drive deforestation (Watson, et al 2017).

Previous legume studies have often focussed only on GHG emissions and nitrogen leaching, with a few exceptions looking at a wider suite of pertinent impact categories (Nemecek et al., 2008). There is an urgent need for more holistic LCA to evaluate the environmental sustainability of legume interventions in Europe, using complex functional units such as nutritional density (van Dooren 2016) or population needs (Costa et al 2018) across entire rotations, or more sophisticated biophysical allocation across crop products (Brankatschk and Finkbeiner,2014), or a consequential approach.

Following a review of previous legume LCA studies, we apply different approaches to explore the environmental efficiency of legume-modified and cereal-cereal or cereal-oilseed rotations across three arable cropping regions in Europe (Scotland, Romania and Italy). More specifically, we apply attributional LCA with simple functional units such as gross energy and crude protein output, and with more complex functional units such as the cereal unit (Brankatschk and Finkbeiner, 2014) and a unit of potential human nutrition. The latter approach involves novel application of the Nutrient Density Unit (van Dooren 2016) to integrate the main commodity outputs from entire rotation sequences.

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Urban symbiosis for more sustainable vertical hydroponic farming

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Abstract

Vertical farming has emerged in urban areas as an approach to provide more resilient food production. However, a substantial share of the material requirements come from outside their urban environments. With urban environments producing a large share of residual and waste streams, extensive potential exists to employ these material and energy streams as inputs in urban farming systems to promote more circular economy approaches.

The aim is to assess the environmental performance of employing residual material flows for vertical hydroponic farming in urban environments in order to support more circular, resilient, and sustainable urban food supply. As such, vertical farming systems can make use of their urban environments by coupling to existing infrastructure, space, and co-locate to improve their flexibility and material and energy requirements.

Life cycle assessment (LCA) is used to assess replacing conventional growing media and fertilizers with urban residual streams employing OpenLCA. Paper, compost, and brewers' spent grains were assessed for replacements to conventional gardening soil employed in the studied system. Biogas digestate was also assessed as a replacement for conventional fertilizers used in the recirculating water bath.

The results suggest that large environmental performance benefits are illustrated when conventional growing media is replaced. Although not as significant, employing fertilizers from residual urban streams also leads to large potential benefits, suggesting the two residual streams have the potential for more circular hydroponic systems. Furthermore, as similar to previous studies, the results also address a number of processes to improve the sustainability of these systems and many further synergies (with e.g. brewing industry and water systems) to improve the performance of vertical hydroponic farming through urban symbiosis.

The results can provide the vertical hydroponic farming community with support on important impacts, and measures to improve and innovate their systems. Furthermore, it addresses and provides information on the benefits and potential for cooperation with municipal and other stakeholders in urban environments; providing information that may be crucial for further support to the novel industry in European cities.

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Life Cycle Analysis of a demonstrative Solar-Urban Agriculture Pilot for lettuce production in a mid-income area of Central Chile.

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Abstract

Problem and aim: Chile is one of the countries with the highest impact of current climate conditions and over-exploitation of land, for which an agricultural emergency has been declared: Central Chile is suffering an uninterrupted period of dry years since 2010. The agricultural footprint is one of the main concerns regarding the human impact on the environment since it implies the loss of biodiversity and the increase of greenhouse gas (GHG) emissions. Urban agriculture (UA) seems to be one of the best ways to increase the food supply with a lower environmental impact [1]. Traditional greenhouses are characterized by high electrical consumption supplied by fossil fuels. The aim of this work was to combine UA and NCRE to evaluate the performance of a demonstration pilot, through Life Cycle Analysis (LCA) methodology, to supply food locally in Santiago, Chile.

Methods: Urban Farm-PhotoVoltaic (UFPV) pilot was designed to support lettuce growth as a model food by using a popular and versatile hydroponic system called Nutrient Film Technique. This system uses a pump to deliver nutrients that plant requires and a drain pipe with a continuous recirculation of the solution. Moreover, this system provides a controlled environment with temperature, relative humidity, and air quality. Briefly, UFPV pilot design comprised a metallic container with PV panels placed in wood support. Each pilot contained a set of 4 levels to grow the plants accounting for an available area of 10 m^2. PAR@LED Bars® were used for lightning. On-line measurement system was based on machine learning for energy efficiency. Environmental performance was assessed by using a “cradle-to-gate” LCA (mid-point) approach using the UMBERTO LCA+ software and the ecoInvent Database v2.2.

Results: The first stage of the project is currently ending. UFPV Pilot was constructed and placed in a mid-income area in Santiago. Analysis of the local conditions derived in a photovoltaic plant with a on-grid system design for having a maximum potency of 4.08 kWp with north orientation and 15% inclination. It is expected a daily demand of 30 - 45 kWh/day, with a consume rate of 43 – 65%. The excedent of electrical energy can be injected into the grid under the net billing in Chile. In the second part of the project, plants will be grown under specific and controlled conditions. Currently, economic and LCA evaluation is been carried on for the ERNC-UA Pilot and for the traditional open field lettuce production. Once the first batch of lettuces in the pilot is produced and evaluated, the comparison between both technologies will be performed.

Figure 1: UFPV-UA demonstration pilot for local lettuce production.

Discussion/Interpretation: Construction and placing feasibility of the ERNC-UA Pilot was assessed by several months of design and negotiation with the local administration, in order to provide the best configuration for the local residents to adopt this new local production model. Some constraints on the ERNC approach and the functioning of the pilot through the year also raised. Up to this point, preliminary results on yields and performance can only be assumed. It is well known that plant yields (including lettuce) are higher in controlled conditions, such as greenhouses, vertical farms, etc. [1]. Moreover, materials (water, fertilizers, etc.) Usage will be lower, and the independence of fossil fuels for energy in the pilot compared to the fossil fuel consumption for tillage [2] in the open field should be the main breakpoint to achieve a high sustainability index for this type of UA.

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A method to better qualify the sustainability of the French meat within the Organizational Social Responsibility approach of the sector

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Abstract

Within the framework of its joint initiative of social responsibility (SR) entitled in French "Pacte pour un Engagement Sociétal", Interbev, the French livestock and meat association, requires to be equipped with a set of indicators corresponding to the main stakes of the sector regarding sustainability. The aim is, on the one hand, to establish a current situation, and on the other hand, to identify collective axes of progress and to follow the adoption of good practices.

The method established to select this set of indicators passed successively by an identification of the priorities, the definition of objectives, their declensions in criteria, then in indicators. It relies on the ISO 26000 standard on Social Responsibility (ISO, 2001) and the SDGs. It includes the stakeholders' expectations, a regulatory and scientific monitoring, and a benchmark on other initiatives of other sectors and abroad (Canada, USA, New-Zealand, Brazil, Ireland, Netherlands, Global Roundtable for Sustainable Beef, European Roundtable for Beef Sustainability).

Among the main environmental stakes of the materiality matrix drawn, two appear as top topics of concern: Mitigation of climate change and Whole value of grass. The Table 1 presents the 7 stakes retained and a selection of indicators.

Stake	Indicators
Climate	Carbon footprint of meat Carbon sequestration/ ha
Air	Ammonia emissions of the sector
	Trend of refrigerants use
Ressources	Quantity of waste
	Direct and indirect consumption of energy
	km travelled by feed
	Water footprint of meat
	Practices in plants
Animal feeding	% of coproducts in feed
	% of grass in feed
Link to the soil	% N organic / N mineral on areas
	% of local protein, soybean alternatives or sustainable soybean
	% of the area with legumes
	% of the soil covered all year
Biodiversity	Areas of ecological interest in cattle farms
Toxicity	% of area without any treatment

Table 1. Environmental stakes selected for the SR of the French beef sector and examples of indicators

Regarding Animal Welfare, Interbev has set up evaluation tools at each stage: farm, transport and slaughterhouse based upon the European recognized method "Welfare Quality" and Good Practices Guides. Interbev will gather from these diagnosis a bench of indicators.

This first set of indicators will be mobilized in the upcoming SR report of Interbev (to be published at the beginning of 2020). Concerning environment, it has now to be completed by other LCA indicators regarding soil quality, biodiversity and use of plant-health products. To ensure this, an ongoing study, coupling skills from Quantis and Idele, aims at developing or applying existing methods (Bos et al., 2016, Knudsen et al., 2017, OLCA-PEST, C-Sequ) to French livestock farming data.

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Topic 12: Special Products and Supply Chains

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Attitudes towards PEF and environmental labelling in the Nordic agri-food sector-case studies

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Abstract

Problem and aim

The PEF guide was developed to establish a common methodological approach to enable EU member states to assess, display and benchmark the environmental performance of products, services and organisations. Included in the implementation of PEF is the communication of PEF results to consumer (B2C) and business to business (B2B) communication. A labelling scheme has been presented as one potential way of communicating PEF to consumers.

The aim of this study was to examine 1) the attitudes of Nordic agri-food stakeholders to PEF as a concept and as a label, 2) how an effective label should be designed (emphasizing on message rather than visual design) and 3) possible barriers to the implementation of PEF.

Methods

Stakeholders in the Nordic Agri-food chains representing different types of food chains were contacted to be interviewed, based on share of the national markets and their influence in the agri-food chain. Seventeen representatives from the food industry, retail and business associations representing primary producers participated.

The method consisted of approx. 1,5 hour interview on Skype with sustainability and communication personnel. The interviews were held in a free form and a list of questions was used to form a basis, but additional questions were also asked depending on the replies from the respondent.

Results

The knowledge of PEF varies greatly between the different organizations. A barrier that was identified is who will go first implementing PEF and if others will follow. Also the cost was feared to be too high for sustainable products/ products reporting their environmental performance.

As for labelling, respondents were positive but emphasized that it needs to be simple yet accurately reflecting the environmental impact, which is the main challenge for the PEF label. We found that for B2C communication more work is needed to find the most suitable label as no consensus on how the label should look like and contain was found among the respondents. For B2B communication there was consensus that a fact sheet is a suitable communication vehicle.

Retailers were identified as gatekeepers for introducing PEF since they are the most powerful chain actor. Their responsibility is high regarding using PEF for driving towards a more sustainable consumption.

Respondents raised concerns on how results will be displayed on a label; if results are compared to the company's own baseline or to an average benchmark. Most of the respondents also found that the comparisons between product categories that can be made, is a problem. For example, a consumer would perhaps compare between a cucumber and tomato even if the intention is to only compare within a product group. Before launching, the PEF label and the information it is delivering, needs to be made well known for acceptance.

Discussion

It is important that information on PEF is communicated more strongly for the concept to be accepted and tried. Action from the EU commission to communicate what PEF is of importance and vital if PEF shall be accepted and used widely soon. More organizations need to be convinced to participate actively, rather than standing aside and see what comes out of it. There are several new initiatives on communicating environmental information to consumers, and there are risks with these initiatives that consumers stop using environmental information in their decisions, however the benefits of not waiting on PEF have been assessed to overweigh the risks. Thus, there is a strong need for PEF and hence a need for PEF to be well known.

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Environmental impacts of replacing dairy production with cellular agriculture

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Abstract

Problem and Aim

One of the main arguments for reasoning the importance of ruminants as a part of the sustainable food systems is the fact that ruminants can utilise feed that would not otherwise be possible to use for food production. Sheep and beef cattle can graze grasslands that are not suitable for arable crop production. Grass leys are also important in crop rotations as they improve soil quality and grass-clover leys fix nitrogen from the atmosphere reducing the need for synthetic fertilisers. Grass-leys also maintain higher soil carbon stocks, which helps with climate change mitigation. Furthermore, grass-leys survive in wider range of environments and climatic conditions than grain crops.

The concept of cellular agriculture involves technologies that use cell-cultures for producing food in bioreactors, such as by cultivating livestock muscle cells for meat, or by using microbes to synthesise milk proteins or egg albumin[1]. Some microbes can obtain carbon directly from carbon dioxide or methane, and therefore, do not require production of any other organism as a feedstock[2]. Previous life cycle assessment (LCA) studies have shown that cellular agriculture has a relatively high industrial energy use compared to conventionally produced meat[2,3,4,5]. Therefore, low-emission source of energy is crucial for ensuring the sustainability of cell-culturing technologies. The aim of this paper is to estimate the environmental impacts of incorporating cellular agriculture in sustainable farming systems including grass-leys and bioenergy production. Various scenarios of

utilising microbes and other cellular agricultural technologies for producing food are compared to the impacts of a dairy farm.

Methods

LCA is used for estimating the environmental impacts of various farming system scenarios. A baseline scenario is a 100 ha dairy farm that produces all the feed for the dairy herd. The alternative scenarios use the same area of land and produces the same output of protein, fat and carbohydrates than the dairy farm. The land area that is not needed for food production is assumed to be used for production of grass-silage that is used for biogas production. The alternative production scenarios include the following: i) a system that produces the same amount of milk, meat and co-products than the dairy system by using cell-culturing technologies to replace livestock; ii) a system that produces hydrogen-oxidizing bacteria, and iii) a system that uses methane from biogas production as a carbon source for microbes (Figure 1). The data were based on literature and own data from ongoing projects that estimate the environmental impacts of various products from cellular agriculture. The inventory data for cellular agriculture processes were obtained from companies and research institutes developing the technologies.

Results

The preliminary results show that the conversion of the dairy system to cellular agriculture and biogas production reduced the environmental impacts substantially. The systems utilising cellular agriculture required under 20% of the field area for producing the same amount of protein, fat and carbohydrates than the dairy farm leaving most of the land area available for production of grass-silage for biogas.

Discussion/Interpretation

The study shows that cellular agriculture can have major environmental benefits compared to dairy farming when the production is integrated in sustainable farming systems. As the micronutrient content of products from cellular agriculture differ from milk and meat, further research is needed for diet level assessment.

Literature

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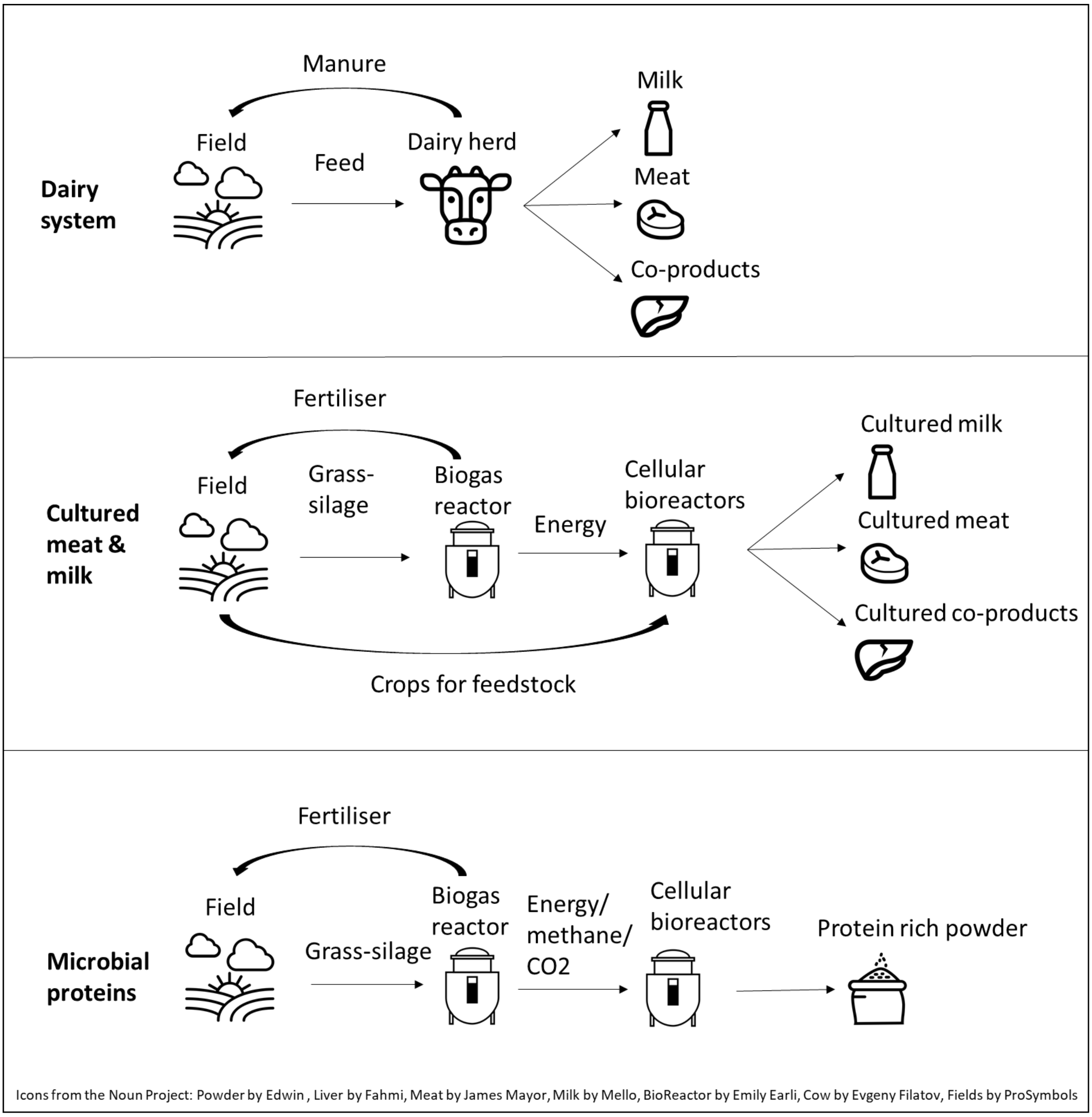
Figure 1. System diagram illustrating the alternative production scenarios



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Life cycle assessment of Christmas trees

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Abstract

1.1 Problem and aim

In the period before Christmas, the question often arises, "Which Christmas tree is the most environmentally friendly option?". The aim of this study was therefore to find the best option and to identify the factors, which have the highest influence on the environmental impacts during the lifetime of a Christmas tree.

For the comparison of the trees, different alternatives were considered:

- Cut Christmas trees from the forest (neither pesticides nor fertilizer)
- Trees from intensive and extensive cultivation
- Rented Christmas trees
- Two types of plastic Christmas trees.

1.2 Methods

To compare the different Christmas tree alternatives and to find out the impacts of the separate phases of a fir or a plastic tree a cradle to grave life cycle assessment (LCA) was performed. The production (including fertiliser and pesticides), the transportation, the manufacturing, the distribution, and the disposal are considered.

The data for the cut and the plastic trees are from different LCA studies and internet sources. For the rented Christmas tree different suppliers were questioned. The tree is delivered and picked up by the company and grows in a pot. For the cultivation the same data was taken as for the cut Christmas tree with extensive cultivation.

For the life cycle impact assessment (LCIA) the Swiss Ecological Scarcity Method 2013 (UBP) and the Global Warming Potential (GWP) 2013 are evaluated.

Furthermore, an Excel key parameter calculation tool was developed. For the different tree variations, the transport distance and medium, the Christmas tree height and origin and for the rented and plastic tree also the useful live can be entered. Based on these entries the environmental impact is calculated.

1.3 Results

The results for the different Christmas trees and the two LCIA methods are presented in the following figures. The calculation is based on the following scenario:

· Height: 2m (rented tree starts with 1.2m)

· Transport: 10km, car; forest tree

10km delivery van; rented tree

5km, car; all others

· Useful live: 5a, rented and plastic tree

1a, cut trees

· Origin: Directly on site; forest tree, rented tree

China: both plastic trees

Switzerland: cut tree, extensive

Denmark: cut tree, intensive

1.4 Discussion/Interpretation

A general statement as to which variant is always the best isn't possible. Different influencing factors (type of tree, transport, usage time, etc.) are important for comparison as well as the considered evaluation method.

In general fir trees from forestry without fertilizers and pesticides perform better than trees from plantations in terms of overall environmental impact. Pesticides, fertilisers, land use, heavy metals from the fertiliser, etc. are evaluated negatively by the Swiss Ecological Scarcity Method.

Considering the GWP the use and disposal of the plastic tree and the private transport get a higher relevance in the juxtaposition. At just a few kilometres of private transportation, the related emissions exceed the ones of all other factors combined.

In the case of the rented fir, the storing of the trees in a hall in winter is the most relevant factor.

The service life, the materials used (PVC, PE, Steel) and the total weight is relevant for artificial firs. However, they often perform better than firs from the plantation after just a few years, especially when considering the Swiss Ecological Scarcity Method.

Finally, and most important: In contrast to the huge discussion about the most environmentally friendly tree, most often other factors such as gifts, meals or traveling for Christmas eve have a much higher impact on the environment than the tree itself. For comparison: The average consumption per person in Switzerland causes emissions of 38kg CO_2-eq per day.

1.5 Literature

Key parameter calculation tool for Christmas trees http://esu-services.ch/de/software/weihnachtsbaum/

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Fractionation of structured crops into functional ingredients

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Abstract

Plant protein-and starch-isolates are applied as ingredients in food products. Fractionation methods for the production of these highly purified ingredients require large amounts of energy and water, and result in low quality side streams and material losses. However, a complete fractionation might not be necessary, since the pure ingredients are re-mixed for the application in foods. In addition, in most food products only the interaction of different ingredients leads to functionality (Van Der Goot et al., 2016). By producing enriched fractions instead of pure fractions, while reducing the number of processing steps and omitting the use of chemicals, the energy input, water footprint and material losses can be decreased (Berghout, Boom, & Van Der Goot, 2014). Mild wet fractionation, as introduced by Geerts, Mienis, Nikiforidis, van der Padt, & van der Goot, (2017), see Figure 1, results in three fractions, enriched in starch, soluble protein and non-soluble protein. These fractions are multi-component systems in which the ratio of each component influences the functional properties of the fraction, which results in the necessity to assess the functional properties of each fraction and the influence of the single components on it. This presentation evaluates the functional properties in model systems, where the applicability of the fractions can be compared to conventional ingredients and existing products, by using rheological and chemical analysis. Different applications are considered based on the results and finally the processing route is optimized by linking functionality and sustainability to the process.

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Topic 13:
Sustainability, Eco-Efficiency, Ecodesign and Circularity

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Assessing Environmental Sustainability of Integrated Biorefinery Process for the Conversion of Dairy Side Streams to Value Added Biochemicals

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Abstract

Problem and aim: Currently, the dairy processing industries face a significant issue related to the disposal of waste. Whey permeate (WP) and delactose whey permeate (DLP) represent a key challenge for dairy processors in view of its high organic load and lack of reliable current disposal routes (Prazeres et al., 2012). So, AgriChemWhey seeks to build a world's first integrated biorefinery to transform these residues to establish sustainable bio-based products such as biochemicals and biopolymers. The technology development stage majorly focusses on achieving technically viable solutions, while environmental burdens are evaluated after the stage of process design. Integrating Life cycle assessment (LCA) in the early stages of the technology development process is expected to enhance the understanding of the consequences of design choices on the environmental performance of biorefinery technology (Piccinno et al., 2016). Therefore, the overall objective of the current work is to develop an integrated LCA model to address the environmental performance of the existing and future biorefinery process, at an early design stage along with its possible consequences in the future due to change-oriented decisions.

Methodology: The main goal of the study is to develop an LCA model to evaluate the environmental performance of the early stage integrated biorefinery process for the production of polylactic acid (PLA) and other by-products from the dairy side-streams and its consequences towards the scaling up of the pilot process to industrial scale. Functional unit is considered as 1 ton of LA produced from dairy side streams (WP and DLP). The system boundary was considered as "gate to gate".

Information regarding mass, energy flows, and environmental losses were collected from the pilot-scale biorefinery plant and translated into life cycle inventory (LCI). The biorefinery model was scaled up using chemical engineering concepts, physical laws, and equations and simulated in SuperPro (Zhou et al., 2017). Additional data that are not available or difficult to determine at this stage are adopted from the Ecoinvent database.

The LCI data based on pilot scale data was linked with LCA analysis (OpenLCA software) to evaluate the environmental burdens. The environmental impact categories considered in the current study are Global warming potential (GWP), Eutrophication potential (EP), Acidification potential (AP) and Marine aquatic ecotoxicity potential (MAETP)

Results & Discussion: The fermentaion process was found to be the major hot spot in the LA production process and can be attributed to its higher consumption of chemicals (majorly $Ca\ (OH)_2$) and energy (thermal). Replacing $Ca\ (OH)_2$ with KOH or $MgSO_4$ hasn't demonstrated any significant reduction of GWP and EP, whereas reduction of usage H_2SO_4 in the process represented a strong impact on energy demand and MAETP. It was achieved by shifting the LA production system to gypsum free process, where it utilizes acid-resistant bacteria to avoid acidification step cutting down the GWP and MAETP to almost 50%. System expansion of the process by including the avoided burden of the dairy-based gypsum can replace the mined or quarried gypsum, thus significantly benefit the end-users (used in the agricultural sector as biofertilizer and mushroom production) both in an economic and environmental perspective.

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Acybulle Project - Using LCA as a decision-support tool in the Champagne industry at different scales: process ecodesign, vineyard and winery management, collective regional strategy

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Abstract

Problem and aim:

Comité Champagne has been monitoring the environmental impact of viticulture and winemaking processes for the last 20 years: qualitative assessment of 450 processes from vineyard plantation to bottles shipment (2000-2001), carbon footprint of the Champagne industry (every 5 years since 2003), following of 300 environmental indicators regarding water, soil, air, waste, energy and biodiversity (since 2005), and lastly lifecycle assessment studies to support ecodesign and R&D projects (since 2008).

The diversity of impacts and questions across Champagne lifecycle stressed the need for harmonization of those successive layers of assessments methods, that where maintained in parallel, towards a single, LCA-based, state-of-the-art methodology. This is the aim of the Acybulle project (2017-2020), here described.

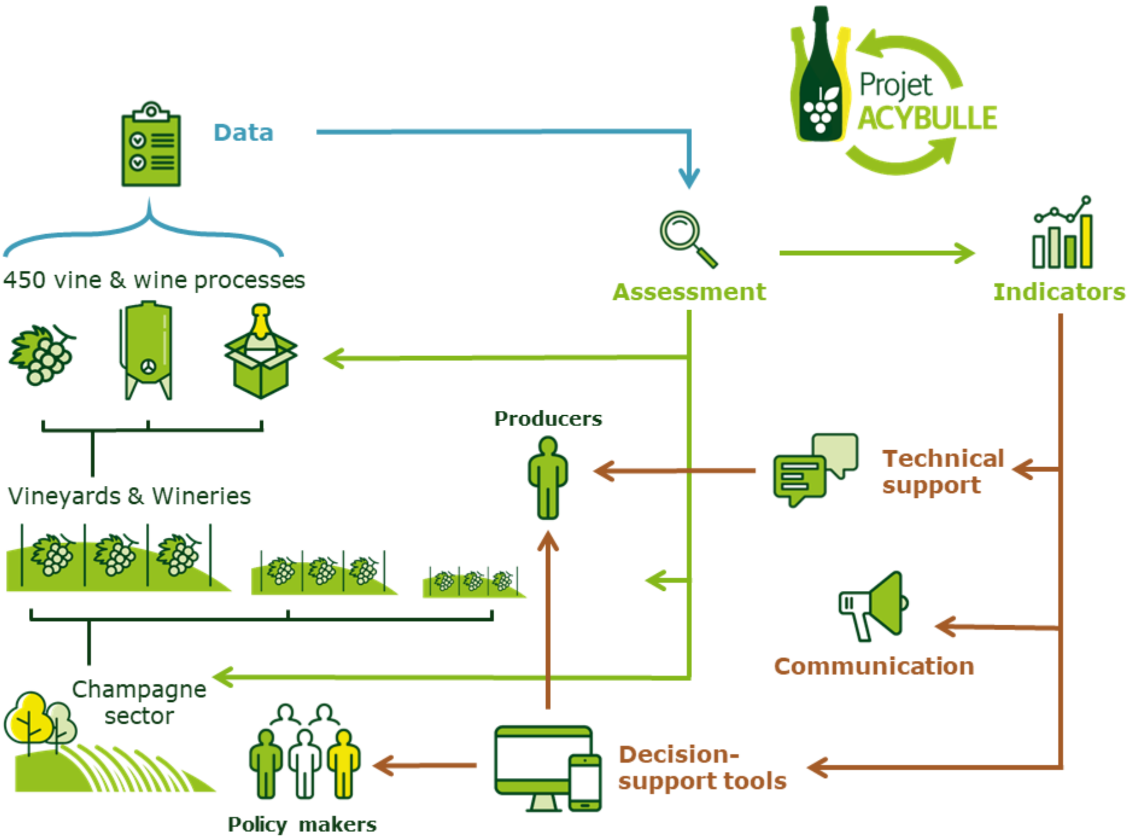
Method. The main tasks of the Acybulle Project are:

1) To identify, gather and analyse all the data already available regarding viticulture, winemaking and suppliers, in order to build a global LCI database for the Champagne industry. When necessary, an additional data collection was performed to fill gaps in the inventory (for instance plants nursery). A specific focus was put on data quality assessment.

2) To select the state-of-the art methods regarding field emissions and impact assessment (mainly based on Agribalyse and ILCD guidelines, plus the outcomes of the OLCA-Pest), in order to define a common framework for LCAs to be performed.

3) To undertake lifecycle assessments at several scales; at a specific process/input scale in order to support ecodesign, hand-in-hand with suppliers (for instance wood vs. steel stakes, anti-frost systems, etc.); at vineyard or winery scale to allow winegrowers to assess their own situation, identify their hotspots and adjust their strategy (for instance “Organic viticulture” vs. “Sustainable viticulture” vs. average practices) ; And at a regional scale to allow policy-makers to build the Champagne area collective strategy (for instance distillation vs. methanisation vs. composting vs. land spreading for pomace recycling).

4) To communicate LCA results for maximum usefulness: personal ecocalculator for winegrowers on the Comité Champagne extranet, trainings and conferences, articles on viticulture technical reviews, environmental score to be added on each page of the reference technical guide, etc. Also useful for facts-based mainstream communication (for instance, positive consumers reaction on the fact that the carbon footprint of a Champagne bottle had been reduced by 20% between 2003 and 2018).



Outcomes and discussion:

Many LCAs where performed thanks to this framework ; some results will be shown as an illustration of the variety of cases studied and the outcoming decisions they allowed.

Acybulle project is an important milestone of Champagne environmental strategy, renewing the way environmental factors support decision making. Taking the time to build a comprehensive LCI database instead of ad hoc data collection for a specific LCA study was a significant initial investment, but is paying off on the long-term: whenever a new question emerges, it can quickly be answered by only focusing on the new parameters, relying on the existing backbone for the rest. The variety of scales at which studies can be done allows for dialogue with different stakeholders

(suppliers, vinegrowers, winemakers, merchants, cooperatives, distributors, consultants, policy-makers, media)

The main challenges are building a simple way of communicating LCA results without losing relevant information, and developing the online ecocalculator to allow professional to assess themselves in autonomy.

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How to deal with biobased packaging in environmental sustainability assessments?

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Abstract

Problem and aim

Food packaging helps to preserve food during storage, to ensure consumer safety and to reduce food losses by protecting the food product. In the transition to a circular economy, research to biobased, innovative packaging is increasing, aiming for a reduction of the environmental impact of both food packaging and food waste. To compare the environmental sustainability of fossil- and biobased packaging, life cycle (impact) assessment (LC(I)A) can be used. However, not all the drivers for innovative packaging might be encompassed in a traditional LCA.[1]

This study is part of the Horizon 2020 GLOPACK (Granting society with LOw environmental impact innovative PACKaging) project (2018-2021). Focusing on accelerating the transition to a circular economy, the project aims to support users and consumers' access to innovative packaging solutions.

Therefore, next to a wide-ranging and thorough evaluation of the environmental sustainability of food packaging, a comprehensible and transparent communication of the results is required. In this study, a framework implying several indicators is introduced in order to meet these objectives.

Challenges in LCA

By introducing innovative biobased packaging, the project wants to contribute to a reduced need for chemical preservatives and to a lower environmental footprint of food packaging. Therefore, the framework should be able to quantify the following factors: the impact of reduced waste in food (e.g. through extended shelf-life) and packaging materials, the impacts on the environment in terms of resource use, pollution and greenhouse gas emissions and to support the transition from a linear to a circular economy.

The traditional LCA methodology faces still some challenges. First, not all of these factors are captured in the current LCA methods. For instance, to asses specifically the impact of food waste, agreed modelling guidelines are still missing.[1] Next, also more research is needed to model the full cause-effect chain of plastic marine litter.[2] Finally, a comprehensive assessment should integrate the impact of both resource consumption and emissions.

Results

In order to meet the discussed aspects, a framework is presented, consisting of three parts (Fig. 1).

The first category focuses on those impacts where all cause-and-effect chains are not well understood. Therefore, we propose to communicate the change in chemical preservatives, plastic in environment and food losses at the inventory level. The second category implies indicators at the LCIA level to quantify pollution and global warming. Next, this category also deals with the evaluation in terms of resources, including the quantification of resource consumption and resource efficiency by e.g. the cumulative degree of perfection. Finally, the contribution of biobased packaging material to the circular economy can be expressed as the credits as a result of end-of-life recovery. Indeed, as virgin inputs can be avoided, this will contribute to a reduction of pollution, global warming and resource footprint.

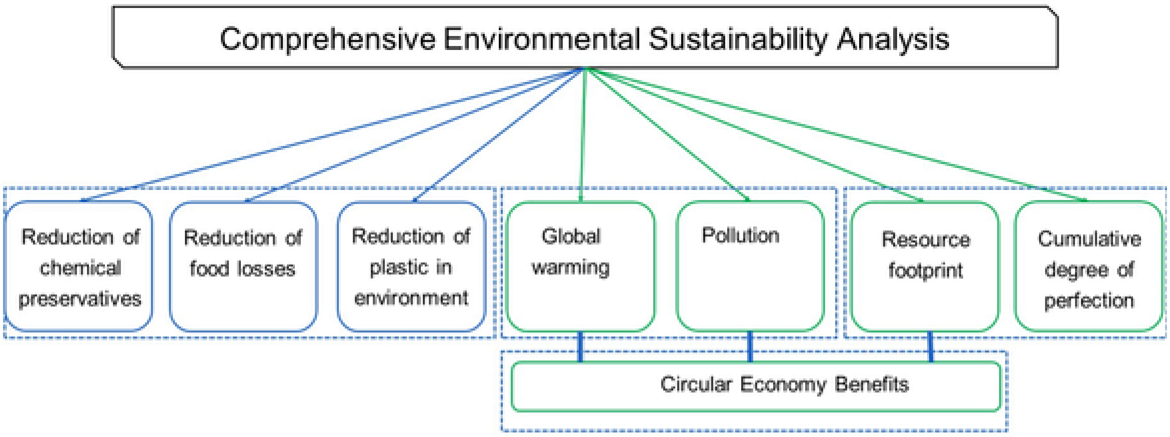

Figure 1: Proposed framework to evaluate the environmental sustainability of biobased packaging

Discussion

The proposed framework complements the classical life cycle impact assessment to achieve a comprehensive environmental sustainability analysis. In this way, a comparison of the environmental impact of biobased and fossil-based packaging can be performed in a more balanced way. On top, it ensures an improved communicability, which is important to affect consumers behaviour to achieve food loss reduction.

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Environmental footprint of high-pressure pasteurization of Ready to Eat products

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Abstract

Problem and aim

Ready-to-eat foods are a growing segment within the food industry. Proper disinfestation without negatively affect the taste and quality of each food product and the whole meal in its self. Improving food shelf-life and food security have been on the food industry's agenda for over a century as can be seen from Hite's research on high pressure pasteurization (HPP) in 1899 [1]. Growing concerns over environmental impacts caused by the food industry have intensified the focus towards increased shelf-life and food waste reduction. However, it influences sales negatively using shelf-life prolonging additives. Nowadays, HPP technology is widely applied in the food industry and has been broadened to other food products such as raw and cooked meats, fish and shellfish, fruit and vegetable products, cheeses, salads, dips, grains and grain products, and liquids including juices, sauces, and soups [2].

The key advantages of this technology can be summarized as follows [3]:

1. it enables food processing at ambient temperature or even lower temperatures;

2. it enables instant transmittance of pressure throughout the system, irrespective of size and geometry, thereby making size reduction optional, which can be a great advantage;

3. it causes microbial death whilst virtually eliminating heat damage and the use of chemical preservatives/additives, thereby leading to improvements in the overall quality of foods; and

4. it can be used to create ingredients with novel functional properties.

There are few LCA studies that include food processing as part of the life cycle inventory and fewer still that assess shelf-life and quality effects on food waste. Through the iNOBox project (Grant nr: 281106) this study aims at closing this data gap and to contextualise the environmental performance of HPP on Ready to Eat (RTE) meals and other food products in a Norwegian context. Datasets were collected form Hiperbaric S.A. based on guaranteed processing rates. Preliminary results are presented for Global Warming Potential (GWP) but the full study will include eutrophication, land use and water consumption.

Methods

The LCA is performed based on ISO14044:2006 investigating environmental footprint of infrastructure, energy consumption and productivity. The system boundary is for the preliminary assessment only at processing level but will be contextualised within the full life cycle for RTE foods. The functional unit is 1 kg food processed by HPP.

Results

Preliminary results show some variability of impact between types of food being processed. For RTE foods the results indicate that the greater machines which is more effective also contribute to lower global warming impacts.

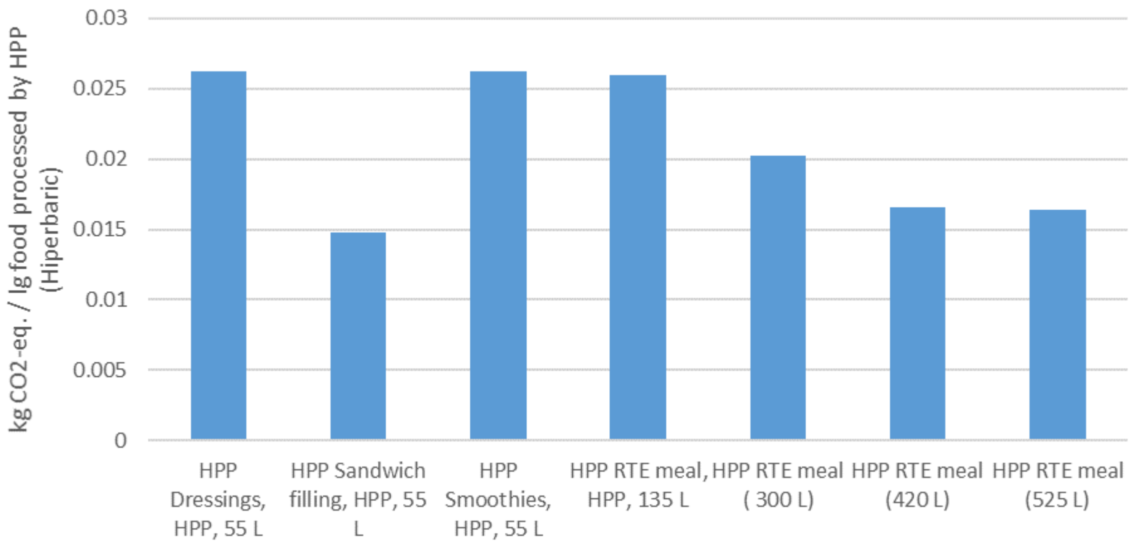

Figure 1: Preliminary global warming potential per kg food processed

Discussions and interpretation

The results show large scale benefits and that the treated product have significant contribution to the environmental profile of HPP. Further investigations onto the relative contribution of HPP for a RTE meal remains to be assessed. The results itself should be possible to add into any RTE context.

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Comparative LCA on conventional and active packaging systems for pastrycream

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Abstract

Problem and Aim

Halving the rate of food loss and waste is an strategy that would contribute to achieve the UN Sustainable Development Goals, meeting the goals of the Paris Agreement on climate change, and sustainably feeding the planet. It is well known that shelf life extension plays a key role for reducing food waste. Along these lines, the development of active packaging (AP), which inhibites the microorganisms that cause food spoilage, araises as an interesting way to extend the product´s shelf life. Thus, the aim of this study is to compare the environmental impacts of conventional packaging (CP) and AP for fresh buttercream, also considering the reduction in the product´s waste.

Methods

The AP has a coating which contains fitic acid and lactic acid bacteria (*Lactococcus lactis subsp. lactis*), which is incorporated onto polyethylene film. The use of AP allows the fresh buttercream´s shelf life to be extended from 3 to 13 days, with the consequent reduction in food waste and waste treatment. The functional unit was 200 mL of packaged buttercream considering the whole life cycle

of the milk-package system, from the production of raw materials (eggs, maize flour, milk and sugar) to potential pastrycream waste and the packaging's life cycle. Pastrycream reference flows for CP and AP were calculated by using the percentages of losses and waste provided by FAO (2011) for dairy products, except household waste which was calculated as a function of products' shelf life following the model developed by WRAP (2013) for fresh milk. Experimental data related to buttercream processing, AP production, and shelf life were provided by Institute of Agrochemistry and Food Technology (Valencia, Spain). Data on the producción of lactic acid bacteria were obtained from Pénicaud et al. (2018), whereas other inventory data were obtained from Ecoinvent 3.5. ReCiPe 2016 (Huijbregts et al., 2016) was used to assess the impacts.

Results and Discussion

The environmental impacts caused by the AP system were lower than those of CP system, with reductions from 38 to 45% depending on the impact category. Buttercream production is the main contributor to the impacts (around 95% of total impact for all the impact categories when using AP, and between 75-99% with CP). The results show how the reduction in buttercream waste at household level obtained with AP compensates for the impacts caused by the coating's life cycle due to product saving. In addition, this study highlights the importance of including food waste in LCA studies of packaging systems. Future research is needed to improve the models to estimate the relation between shel life and food waste.

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A Framework for Sustainable Feed Formulation for Laying Hens Based on Integration of Goal Programming and Life Cycle Assessment

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Abstract

Problem and aim:

Livestock production plays an essential role in satisfying human demand for animal protein (Vergé *et al.*, 2009). Feed production is a large contributor to the environmental footprint of livestock products (Oladokun and Johnson, 2012). Feed formulation may, therefore, provide important opportunities to reduce impacts in livestock production. Nutritionists employs multiple techniques for feed formulation, including goal programming (Dogan, Dogan and Akcan, 2000), linear and non linear programming (Oladokun and Johnson, 2012), the Pearson square method (Hardy, 1980; Liam *et al.*, 2014), genetic algorithm (Sahman *et al.*, 2009), and multi-criteria modeling (Castrodeza, Lara and Peña, 2005). Goal programming, an extension of linear programming, is currently the leading multi-criteria decision analysis tool used in feed formulation, taking into account cost and nutritional considerations. Environmental goals are not typically included.

Methods:

Published literature addressing three sub-topics were reviewed: LCA, goal programming, and feed formulation. On this basis, we identify the necessary elements of a framework for the integration of life cycle impact assessment (LCIA) results for laying hen feed input supply chains into goal programming-based feed formulation.

Results and Discussion:

In order to integrate sustainability considerations into feed formulation, four essential aspects must be taken into account: the amount of individual feed ingredients (as decision variables), the nutritional requirements of laying hens (as nutrient constraints), the price of ingredients (objective functions), and their associated life cycle-based environmental impacts (as objective functions).

Keywords:

eggs, feed formulation, LCIA, MCDA

Literature:

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Carbon Footprint of the Raw Sheep & Goat Milk Production in Greece

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Abstract

Problem and Aim: The aim of this work was to apply an LCA method in order to assess the carbon footprint (CF) of selected sheep and goat systems in Greece which supplied with raw milk the same dairy industry whose major production line was Feta cheese PDO.

Methods: Data was collected from four dairy sheep and goat farms for the year 2016. Two of them reared sheep (DSF1; DSF2), one goats (DGF) and the last one both sheep and goats (DMF). The functional unit (FU) for LCA was 1 kg of FPCM with a 'cradle to farm gate' system boundary. Emissions of CH_4 from enteric fermentation and from manure, as well as direct and indirect N_2O emissions from manure were estimated with the respective IPCC Tier 2 methodologies (IPCC, 2006a, 2006b). Direct and indirect N_2O emissions were also estimated for the case of N fertilizer application to the land for feed crop cultivation as well as for the feed crop residues on an annual basis (Tier 1 methods, IPCC (2006b)). Official data from FAOSTAT for Greece was employed to define the country's market mixes. Ecoinvent v.3.4, Agri-footprint v.4.0 and Agribalyse v. 1.3. datasets as available in the SimaPro v. 8.5.2 PhD software (Pré, 2017) were used as a basis for modeling. A biophysical approach (dietary energy requirements' model for sheep and goats - IPCC (2006a)) was used for allocating the environmental burden to the various co-products of the dairy farms (i.e. raw milk, animal live-weight and raw fiber). The IPCC 2013 method was utilized for the estimation of the CF and it was separately presented for Direct Land Use Change (dLUC).

Results. The range of the results for the systems studied was 2.68-4.02 and 0.09-0.50 kg CO_2-eq/kg FPCM for the GWP_{100} and $GWP_{100,\ dLUC}$, respectively. DLUC was found to contribute less to the total

Climate Change (CC) potential of the system (max. 11.9% in DSF2), in all cases. From the sheep producing farming systems, DSF2 was connected with the highest GWP estimates while small differences were found for the total CC potential between DSF1 and DMF_sheep. On the other hand, the GWP estimates of the DGF were the highest from the goat producing systems investigated.

Discussion/Interpretation. The results suggested that the milk delivered by the most intensive sheep farm (i.e. DSF2) was associated with the highest CF indicators' estimates from the sheep rearing systems while DGF with the highest from the goat rearing systems. Direct land use change (dLUC) was found to contribute less to the total CC potential in all the supply chains and its contribution was mainly dependent on the existence of soybean meal in the sheep and goats' diets. In all the studied systems, the ruminants' enteric fermentation process was the most important contributor to the total GWP_{100}. Emissions of CH_4 from the on-farm manure management and sheep enteric fermentation were the major factors for the differentiation between the total GWP_{100} estimates of the ewe milk supply chains. The supply of agrochemicals (for the on-fam feed crop cultivation processes) in the DGF system was the main responsible factor for the respective differentiation between the doe milk supply chains as well as between the supply chains with the highest CC potential (i.e. DGF, DSF2).

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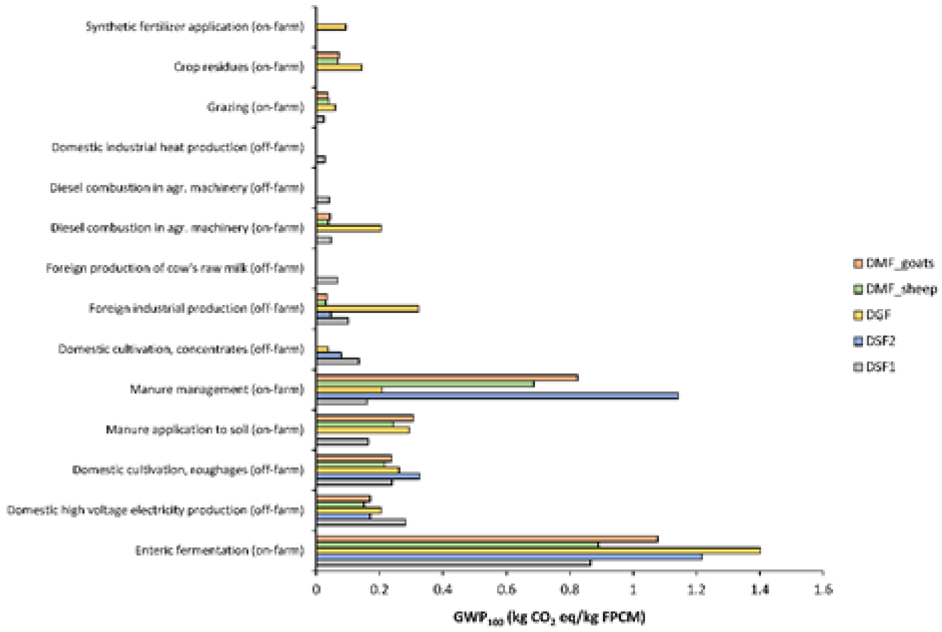

Figure 1. The GWP_{100} hot spots and their estimates.

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ENVIRONMENTAL IMPACTS AND STRATEGIES MITIGATIONS FOR STRAWBERRY PRODUCTION

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Abstract

Strawberry is cultivated worldwide in different production systems. The Life cycle assessment methodology has been applied to evaluate the carbon footprint, freshwater eutrophication and freshwater ecotoxicity of different strawberry production systems in Spain, considering from the raw material extraction of inputs to the farm gate, including transport to the waste treatment plant. Data for the three main systems representing the actual situation of strawberry production in Spain were gathered: two soil systems (conventional and organic) and one soilless system (conventional) in macrotunnels. The crop practices were grouped in different stages: structure, auxiliary equipment, fertilizers, pesticides and crop management. Fertilizers was the stage that acquired the most importance in most of the environmental categories, specifically the carbon footprint in all the systems evaluated. Therefore, the reduction and optimization of fertilization is the first priority to improve the process environmentally. The organic system showed low environmental impacts in all categories, but their productivity was the lowest compared to the rest. The most innovative system (macrotunnel soilless) offered the best environmental results for all categories from an overall environmental and productive point of view.

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Marine litter contribution of plastic packaging in Germany, a case study and awareness tool for consumers using life cycle thinking

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Abstract

Problem&aim
Plastics and marine litter have become a global concern as the accumulation in the world's oceans is evident (Jambeck, 2015). Due to their long-lasting lifetime, plastics are ubiquitous and have been associated with many environmental impacts (Bergmann, 2015). In the EU, most plastic is consumed for packaging production, with Germany having the highest plastic demand (PlasticsEurope, 2019). Often designed for single-use, packaging rapidly transforms into waste. A missing design for circularity leads to incineration, landfiling or literring. This study targets the estimation of littering to quantify the share of plastic packaging entering the aquatic environments. The overall goal is to understand how to reduce the impact of products that are currently packed in plastic without causing a shift in burden (e.g. food waste). Furthermore, it will enable the identification of trade-offs associated with the use of plastics and other materials in a product and service system like packaging. The results of this thesis could be used to include littering as end-of-life scenario, 'plastic leakage' as a midpoint indicator and 'plastic footprint' as an area of concern into Life Cycle Assessment (LCA).

Methods
The study is conducted through an extensive approach in the fields of packaging, waste management and LCA. It provides an overview of the waste management system in Germany with a focus on post-consumer plastic packaging waste. The estimation of marine litter contribution is presented through a case study of tomatoes sold in German supermarkets. The functional unit of the study is set to be 'the one-time purchase of 1 kg tomatoes'. Additionally, the inclusion of marine litter as an evaluation criterion into a packaging sustainability assessment is presented as a tool for consumers' awareness. With these efforts, a baseline for an indicator expressing the likelihood of a packaging item to enter the environment as littered waste and an overall environmental impact using life cycle thinking is calculated.

Results
The marine litter contribution is presented as a percentage, indicating the likelihood of a packaging item to enter the aquatic system as littered waste.

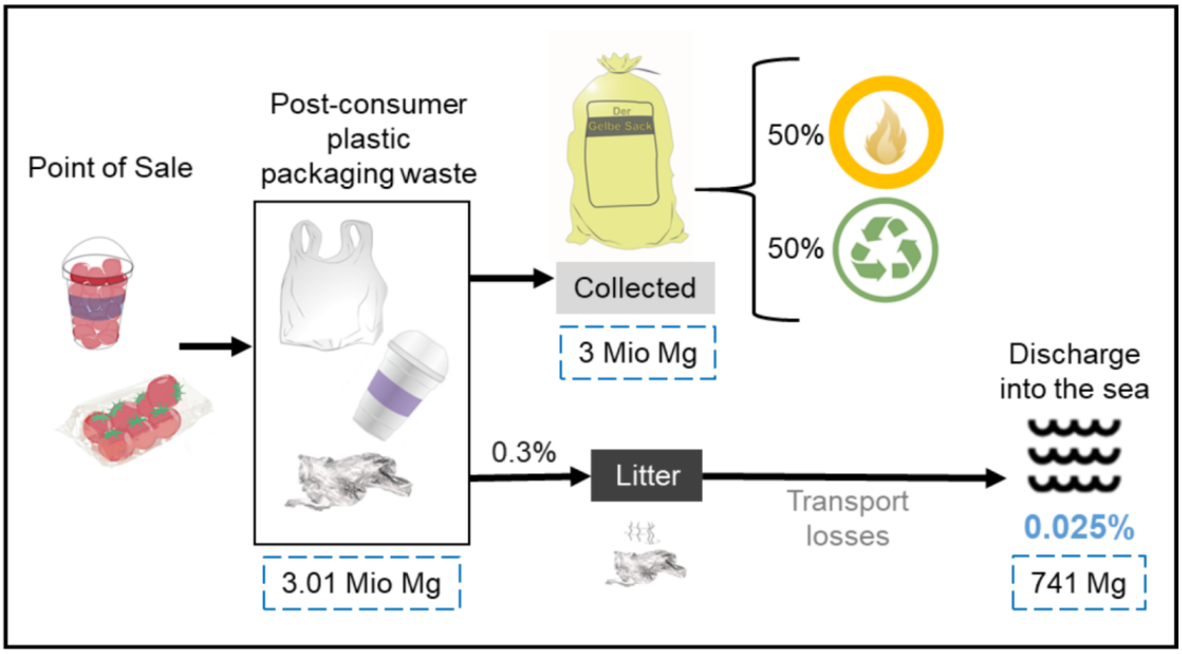

Figure 1: Estimation of marine litter contribution of plastic packaging waste in Germany

Through the present case study, the products that did not have any plastic as packaging material had the lowest marine litter contribution, whereas the packaging identified as a food product consumed on-the-go (e.g. PET container) had the highest marine litter contribution.

The inclusion of marine litter into a comparative assessment of packaging types enables the consumer to evaluate different environmental contributors and provides a broader picture of the impact, not only dependent on the selected material. This is crucial to avoid shifts in burden and counterproductive behavior. The goal of the study is to develop a baseline for an inventory-level indicator expressing the likelihood of an item to enter the environment as littered waste.

Interpretation
Despite remaining challenges in studying environmental impacts of marine litter, the increasing evidence of plastic pollution, the rapid growth in plastics consumption, and the impacts on marine biodiversity support the immediate implementation of source-reducing measures. Subsequently, consumers' awareness and behavior change are key aspects to reduce littering and the potential impacts of plastic leakage. Informing of the importance of best practices and explaining the possible alternatives without leading to counterproductive behavior is of great responsibility. The information must reach a communicative clarity that could influence citizens, interest the media and persuade politicians and legislation into action. For this purpose, a user-friendly indicator informing the impacts of a product and its packaging could be a supportive tool to achieve this communication.

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Sustainability analysis of different apple cultivation systems with AgBalance®

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Abstract

Problem and aim: Sustainability is an integral feature of modern farming. Based on the principles of Life Cycle Assessment (LCA), BASF has developed AgBalance® to allow farmers reviewing and improving the sustainability of their farming practices.
In this context, BASF SE works together with KOB Bavendorf, in order to analyze the sustainability of 1kg of apples grown in four different cultivation systems. Each system is distinguished by an individual combination of fruit protection system, crop protection program, and fertilizer scheme.

Methods: In AgBalance®, the most important inputs (e.g. fertilizers, crop protection agents, irrigation, land use, etc.), outputs (e.g. agricultural products, waste, emissions to soil, air and water) and the applied farming practices are considered and analysed in a comprehensive way. This way, the analysis in AgBalance® enables the comparison of the sustainability performance of different farming practices. In this study concerning the cultivation of apples, the generated results quantify

the environmental impact and economic performance of the analyzed agricultural product for each alternative. A social analysis was not conducted in this study, as no significant differences between the four cultivation systems are expected.
In the study conducted together with KOB Bavendorf, four different fields with the same variety of apples, but different cultivation systems are compared (see figure 1). In Field 1, the apples are protected from hail with the usual net cover and with a standardized crop protection protocol, whereas in Field 2 the crop protection is reduced. Foil covers in Field 3 and 4 are supposed to bring additional protection and therefore the application of plant protection products is further reduced. In Field 4, nets at the sides are installed to protect the apples in addition to the foil cover.

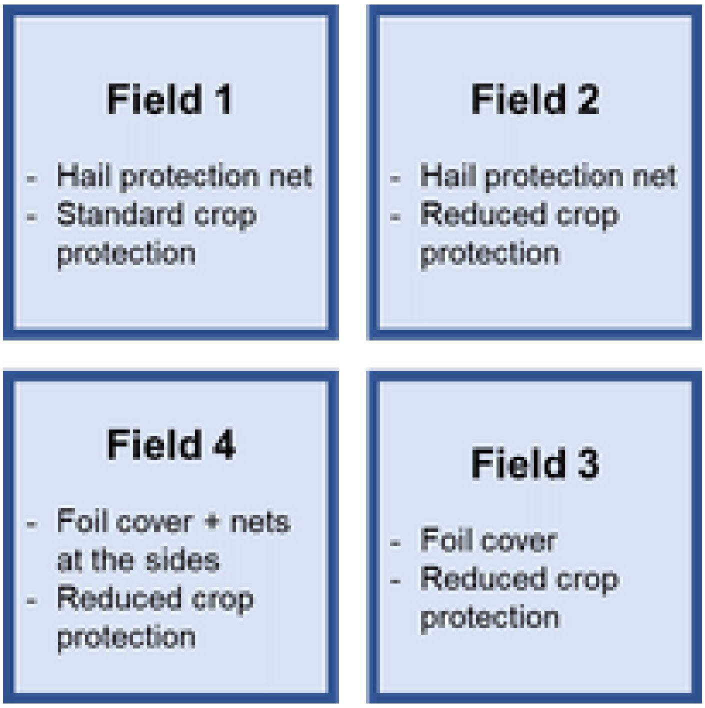

Figure 1: Experimental set-up at KOB Bavendorf

Results, Discussion: Results comparing the first harvest of 2018 with the harvest of 2019 are expected in summer 2020. With AgBalance®, the sustainability of the different cultivation systems will be assessed and demonstrated.

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Environmental impact assessment of organic egg production

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Abstract

Italy in 2018 hosted a population of about 39 million laying hens and the national egg production reached about 12.6 billion eggs, which made the country almost self-sufficient (about 94%) for eggs production. According to the adopted rearing system, livestock facilities support various stocking densities and respond to different norms of welfare. However, laying hens are reared commonly in huge numbers in conventional intensive systems, where their welfare is often put under pressure; hence, organic systems are wide-spreading: according with national statistics, 9% of the Italian egg production is organic (ISMEA, 2019).

In this study, the aim is to quantify the potential environmental impact of eggs production on an organic farm rearing laying hens. This is done by means of the Life Cycle Assessment approach, thus considering all inputs and outputs related to the system under study.

The analyzed farm is located in northeast Italy and was visited to complete a survey for the inventory data collection. The adopted Functional Unit was the production of 1 kg of eggs in a cradle-to-farm gate perspective. For each production cycle, 3000 pullets at 16 weeks of age are bought from another farm and managed by the farmer only during their egg-laying cycle, which lasts 1.5 year. At the end, spent hens are sent to slaughterhouse. Laying hens are reared inside a barn and have daily access to a free range cultivated with alfalfa, sown every 3 years.

Average daily egg production is 2700 eggs. Data about drinking water and commercial feed are obtained from the farmer. No feed self-production is present, as the farm has no land except for the one dedicated to pasturing. The litter is composed by sand locally purchased, and 40 t of dry hens' manure are collected yearly and sold to a close farm for field distribution. Emissions to field for manure spreading were not included, as the distribution occurs out of the system boundary. Electricity is consumed in the amount of 0.127 kWh/kg egg for lighting, automatic feeding system and automatic eggs collection. Emissions were evaluated adopting the IPPC method Tier 1 and Tier 2, quantifying emissions from manure management (CH_4 and N_2O) and emissions to air, soil and water for N_2O, NH_3 and NO_3^-. The ILCD characterization method was used for the impact assessment.

Regarding Climate Change, the observed result (1.56 kg CO_2 eq/kg egg) is positioned in the lower part of the range of values available in the literature, showing the production of organic eggs in the analyzed farm to have a good environmental performance. This result was achieved thanks both to the good productivity of the farm and to the avoidance of using soybean-based feed imported from South America, which were replaced with Italian produced ones, thus not involving carbon dioxide emissions related to Land Use Change.

The consumption of purchased feed was still the main driver of the impact over all the evaluated categories due to emissions linked to their field production and processing. NH_3 emissions from manure were also an environmental hotspot, by influencing significantly (35 to 39%) Particulate Matter formation, Acidification Potential and Terrestrial Eutrophication. Therefore, efficiency improvements in feeding and manure management would be the best strategies to adopt in order to mitigate the environmental impact. Furthermore, even the energetic valorization of manure would be a viable option for this purpose.

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The Coffee Blockchain: Strengthening transparency and trust in agro-food business with distributed ledger technology

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Abstract

Problem and Aim

Global food value chains, such as coffee, are complex systems, which pose major challenges in terms of product transparency. Consumers receive hardly any trustworthy information about the origin and sustainability of products. In addition, coffee farmers suffer from intransparent supply chains causing their earnings to heavily depend on the coffee price on the world market. New approaches are needed to give farmers as well as consumers more transparency and co-determination. The blockchain technology offers many opportunities to address these challenges. The aim of the coffee blockchain is to show the possibilities, opportunities and limits of the distributed ledger technology in the agro-food business for automated Life Cycle Inventory modelling as well as explore new approaches for co-determination within the coffee value chain.

Methods

The blockchain technology stores cryptographically secured chains of non-changeable data blocks on a distributed network of computers (Tripoli & Schmidhuber, 2018). This decentralized network ensures validity and distributes the transaction history as well as information among the nodes allowing any change to be tracked. These features complicate the manipulation of data and ensure transparency and trust.

A blockchain for the coffee value chain will be designed, implemented and tested in cooperation with the coffee processor Delica and the coffee trader Volcafe. Additionally, we make use of an

already digitised data collection system developed by Volcafe using an agronomic coaching programme to collect information on agricultural practices of individual coffee farmers. The blockchain technology will enable simplified data management, partial automation of data collection and individualised Life Cycle Inventory modelling for actors within the supply chain.

<u>Results</u>

The first major innovation aspect of the coffee blockchain is an improved digitisation process of relevant information on the quality and sustainability of coffee. The information on the cultivation provided by Volcafe is complemented with data on processing as well as logistics and recorded in the coffee blockchain. This data then can be used to create partly automated up-to-date Life Cycle Inventory models of individual coffee farms.

The second major innovation aspect is the possibility for consumers and retailers to obtain transparent sustainability information on their coffee using QR codes. Besides the exchange of information, the coffee blockchain brings the consumer and the producer closer together. With the coffee blockchain, the consumers will have the possibility to support the farmers directly or specific community driven projects within the coffee value chain. These transactions will be verified using the blockchain. In this way, the coffee blockchain will help to increase the earnings of the farmers and incentivize a more equal distribution of the added value within the value chain.

Figure 1: Schematic illustration of the co-determination within the coffee value chain using the coffee blockchain

Discussion

Blockchain poses a number of challenges to benefit from the technology. In order to achieve high data quality, errors in data entry must be avoided with the combined use of automated quality checks and smart digitized data collection systems . Another challenge is to balance the confidentiality of the data with the accessibility of the blockchain technology. Furthermore, it is necessary to keep improving digital infrastructure, particularly in developing countries and in rural areas (Tripoli & Schmidhuber, 2018). If this is taken into account, the agro-food business can be made more transparent and sustainable.

Literature

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Life cycle assessment of greenhouse tomatoes for the Swedish market

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Abstract

The agricultural sector is responsible for a large share of the total anthropogenic greenhouse gas emissions, and it is therefore important to increase the efficiency of the food production chain. One important aspect of the climate impact of food is the location of production, as factors such as local climate, light conditions and availability of necessary resources will have a direct or indirect impact on the associated emissions. This study aims to analyze how factors such as the amount of energy required, and the choices of heat source, lighting technology and transport mode affects the global warming potential of greenhouse tomatoes intended for Swedish consumption. Both Swedish and Dutch production scenarios are included in the study, as Sweden currently imports a large share of the total tomatoes consumed from the Netherlands.

The analysis is made in a series of steps, using the same theoretical greenhouse model for both locations. Because of this, the amounts of energy required for heating and lighting will be different depending on local conditions. First, this is accounted for by using a greenhouse simulation tool for acquiring data on the energy use. Second, for the heat source, an examination of existing literature is made to determine the possible alternatives for both locations. Third, several different lighting technologies are applied in the greenhouse to analyze how this impacts the energy balance and the environmental impact. Fourth, for the scenario where the tomatoes are produced in the Netherlands there is a need to include the emissions from transports to Sweden. Several alternative ways of transporting the tomatoes are included in the study, such as road transport using either fossil fuel or biofuel, as well as sea transport.

The results indicate which combinations of heat sources, lighting technologies and ways of transportation that are the most sustainable in terms of climate impact of Swedish tomato consumption. This can be used as a part of a decision making process when deciding on regional/national food policy including sustainability concerns and food security.

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Carbon footprints of processed potato and tomato products-use of LCA method to identify the mitigation opportunities

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Abstract

Problem and aim: The aim of this study is to identify the environmental hotspots of potato products (chips, frozen fries and dehydrated), and tomato-pasta sauce, in a “cradle-to-grave” perspective.

Methods: The study evaluates the carbon footprint (CF) of the selected product, using a life cycle assessment (LCA) method. The functional unit (FU) was 1 kg of product(s), eaten by consumer. The crop reporting districts (CRDs) of the United States, where the selected crops are primarily produced are selected for the evaluation. Data sources for on-farm activities were partly based on the Crop Modeling Protocol (Zhao, C. et al., 2019), and further enhanced by regional crop budget reports and national statistics. Detailed materials and methods for both on-farm and post-harvest stages are governed by LCA Protocol (Parajuli R. et al., 2020). Handling of biowaste/losses followed (i) basic scenario- composting (consumer waste) and as animal feed (waste from other stages), (ii) in alternative scenario- anaerobic conversion and combustion in a cogeneration plant. For potato products, coproduct handling included the recovery of starch from processor.

Results and Discussions: The carbon footprint (kg CO2 eq/FU) for potato products: chips, fries, and dehydrated was 0.69, 1.57 and 0.58. For tomato sauce the CF was 1.31. Contribution due to farming system was 32% for tomato sauce, whilst it was 48%, 22% and 40% respectively for potato-chips, fries and dehydrated product. The on-farm impact was mostly influenced by agro-chemical used and energy consumed for farm operations and pumping irrigation water. Processing of chips contributed 48% of the total CF, whereas it was 22% for fries, 40% (dehydrated) and 38% (tomato sauce). A higher consumer contribution was obtained for fries (52%), mainly due to vegetable oil used for deep frying. Contribution due to use and disposal of packaging material was 12%, 3% and 16% respectively for chips, fries and dehydrated; and 4% for tomato sauce. Transportation, included within the supply results, had 22%, 13%, 27% and 34% of the impact respectively for chips, fries, dehydrated-potatoes and tomato sauce. Environmental credits due to biowaste management was 1-

4% and 5% of the total CF obtained for potato products and tomato sauce respectively. Alternatively, conversion of biowaste to energy had potential to mitigate 7-15% of the total GHG emissions for the potato products, and 10% for tomato-sauce. The study also revealed that if the use of secondary and tertiary packaging materials is excluded, the above impact can be significantly reduced, e.g. by 13% in the case of chips and tomato-sauce. Transporting the raw and processed products in a train instead of lorry can mitigate the GHG emissions by 7-10%. Other identified mitigation opportunities from the current study were in the form of: using drip irrigation technologies (e.g. in potato), and reduction of biowaste and the food miles. The recommended future research directions are: inclusion of wider environmental impact categories and consideration of induced GHG emissions due to indirect land use change effects, potentially occurring at the cost of occupying arable land, as used for producing the selected crops.

Conclusions: The CF and the relative contributions were largely dependent on the supply chain efficiency, e.g. processing efficiency, use of raw materials during processing and food preparation, and waste generated.

Acknowledgement: The research project was funded by the USDA- NIFA Award #: 2017-68002-26789. Special thanks to the Crop Modeling team of the project and other project members for the direct/indirect assistance.

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The Packaging Index (PIX) as user friendly sustainability assessment – A method development

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Abstract

Problem&Aim

Packaging is considered as a necessity to communicate the values of the product to the consumer. One of these values is environmental sustainability which responds to the increasing concern and interest among the involved stakeholders in this matter [1]. The environmental impact of different packaging depends on several factors such as material type, amount and design. To understand which packaging is more sustainable and environmentally friendly is challenging.

To provide an "easy to use" assessment of the environmental impacts of different packagings without a full Life Cycle Assessment (LCA) the Packaging Index (PIX) is developed as an indicator to compare the packaging in various industry sectors. The PIX enables a product-specific quantification of packaging along the supply chain of a product. The goal of the PIX is to identify and avoid unnecessary use of packaging, and provide an environmental evaluation based on the factors "Amount", "Recyclability" and "Environmental impact" of the packaging. A qualitative warning system following a traffic light system is intended to compare different packaging in an easy understandable and visible way to the user.

Method

The PIX consists of four criteria. The first criterion (F1) analyses the total quantity of the product with the total quantity of the packaging over the life cycle of the product. This provides a first opportunity to look at the mass ratio. The second criterion (F2) represents the recyclability of the packaging and

is calculated according to the evaluation procedure from the 'Institute for Recyclability and Product Responsibility' Cyclos-HTP [2]. These evaluations rate the Recyclability of a packaging according to various industry criteria. The third criterion (F3) represents the environmental impact of the packaging in the production phase expressed in LCA data such as global warming potential and fossil primary energy demand from GaBi ts data base. The End-of-life (EoL) depends strongly on the stakeholders involved and is thus not included in the standard assessment. For higher detail different EoL scenarios are included and can be used for varying aims such as awareness creation. The fourth criterion (F4) is to classify the quality of the existing data. Depending on whether the data is primary or secondary a safety margin can be added.

F1 to F4 can be calculated and measured. The result is then used to compare one packaging with other applications fulfilling the same purpose of packaging.

Therefore the calculated value for F1 to F4 is transferred to a rating value between 0 and 100, with 100 being the best score possible. The average value produces the overall PIX score which can be used for direct comparison. The best practice in a field of appliance serves as most sustainable packaging reference.

Besides the assessment of a single packaging, a supply chain assessment is possible and allows to assess the entire packaging occurrence in the life cycle. The results can be displayed as single point as well as divided in the life cycle stages.

Results

In a case study, the developed methodology is presented and proven. Tomatoes in several packaging types serve as example for the PIX analysis including different generic supply chains present on the German market.

The assessment includes common packaging options as well as new developments such as multi use bag from different materials.

Discussion

The purpose of the PIX as a user-friendly indicator is to present the environmental impacts of the packaging in comparison to the best practice available. The method sets a base line for a sustainability assessment of packaging aiming on several stakeholders in the supply chain.

In a further refinement, factors like food loss and littering should be included in the packaging analysis.

Literature

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Blockchain-based technologies in the food supply chain – a comparative assessment

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Abstract

This study presents ongoing work and preliminary results of the Sustainable Blockchain Technologies project. Blockchain-based technologies (BBT) are expected to become an innovative and disruptive force in the future, and some claim these technologies have a great potential to foster sustainable development. BBT are appealing because they should allow for secure, robust, and trustworthy solutions, and bring improvements compared to current technologies or management systems in terms of traceability and transparency. However, the blockchain backbone is essentially that of a "redundant" system, where multiple parties need to be committed and involved simultaneously and inefficiently. The study proposes a selection of case studies where BBT are used to innovate the food supply chain, and their comparative analysis. Four hypotheses are tested: 1) there is no one way of implementing blockchain technology in the food supply chain; 2) BBT are systems of technologies where blockchain is only one of several elements needed for their functioning; 3) the main role of the blockchain element in the food supply chain is to increase trust; 4) implementing BBT brings positive social or environmental impacts in the food supply chain. The goal of the study is to provide a deeper understanding on the state-of-the-art role of BBT in food supply chains as well as critical reflections on their potential to innovate this domain and to bring social and environmental improvements.

Six case studies were chosen for the analysis: Provenance (tuna)[2], WWF (tuna)[1], IBM (all foodstuffs)[3], FairChain (coffee)[4], and TE-FOOD (meat and eggs)[5]. They reflect a range of different implementations of blockchain in food supply chains. Main reasons for choosing these cases were a traceability focus, availability of information, and the maturity of the implementation. The technology assessment was carried out using a simple prospective framework, each BBT was described in its four components: technique, knowledge, organization, and product[6]. Technique comprises all physical implements including factors such as software. The knowledge component refers to acquired skills, tacit knowledge and intuition. Organization is structured according to the internal division of labor and pattern of specialization. Product is regarded to be the immediate result of the combination of technique, knowledge and organization[6].

The four components are examined separately for the six cases. Finally, the trade-offs between drawbacks and advantages of implementing BBT in each case are made explicit. The study shows that BBT are expected to bring a variety of benefits. However, only some (trust, traceability, transparency, authenticity) are directly attributable to the use of blockchain. Other benefits such as improved data management are a side-effect of digitizing non-digital processes. Still other benefits, such as increased sustainability, are expected to be indirectly induced by the use of blockchain, but only time will show if this expectation can be fulfilled. This assessment was used to test four hypotheses and provide a deeper understanding of the state-of-the-art role of BBT in food supply chains in order to further the discussion of social and environmental implications of blockchain in the supply chain traceability.

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KNOWLEDGE INTEGRATION FOR EFFICIENT DECISION-MAKING: A CASE STUDY FROM FISH CANNING WASTEWATER VALORISATION

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Abstract

Problem and aim: The recovery of resources from food industries wastewater and further transformation into high performance biodegradable plastics is an ambitious objective which fulfils the objectives of circular economy and SDGs 6&14: i) a potentially harmful water pollutant if discharged is converted instead into an added-value product; ii) ensuring biodegradability in marine conditions, the plastic pollution is greatly minimised. In the framework of H2020 project USABLE-PACKAGING (www.usable-packaging.eu), we are carrying out a comprehensive analysis of a selection of representative value chains, from the industrial effluent to the final bioplastic product and potential by-products to ensure its economic and environmental sustainability. In particular, we are integrating knowledge from different sources, namely from deliberately designed experiments, mathematical models and literature reviews, for the holistic assessment of the environmental performance of several scenarios, with different wastewater characteristics (i.e. substrate) and a diverse range of bioplastic applications (i.e. final product).

Methods: The challenges inherent to the production of bioplastic from a residual source are multiple. The development of a new value-chain unavoidably faces the coexistence of technologies with different levels of maturity, as some conventional technologies are being complemented by lab- and pilot-scale developments or adapted to the new process. Likewise, the sources of knowledge available to design or optimise a whole novel process are scattered and have different levels of detail, validity, robustness, etc.[1]. In this work we are developing a knowledge integration framework (Kalakul et al. 2014) composed by: i) Experimental data from novel bacterial cultures with a potentially higher productivity into PHA and lower production cost; ii) Literature meta analysis of PHA extraction and purification methods, including solvent selection and yield, mechanical

treatments, enzymatic digestion, etc.; iii) Mathematical models describing PHA production bottlenecks: the production of VFA and the posterior accumulation of PHA, and iv) LCA of the whole value chain fed, leading to a preliminary evaluation of the process sustainability that provides the tools, in an early-stage of development, for selecting the right technology when different options are available.

Results: The project is still on its early stage and therefore only preliminary results will be presented at the conference, although the structure itself and the integration building process is considered already a result of the activities done.

Discussion: Focusing on the LCA role within USABLE, we have followed the guidelines of the ambitious Plastic Strategy [3]. This Strategy involves the development of different measures to decrease the impact of plastic on the environment, being one of them the search for alternative feedstocks for plastic production if they result in genuine environmental benefits compared to the non-renewable alternatives under a life cycle perspective. So, the LCA methodology has already been used to assess the environmental performance of PHA production against competing materials [4], raising the fact that different methodological choices, such as the selection of the impact categories considered or the definition of the system boundaries, have to be done and there is still room for improvement and consensus.

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Topic 14:
LCA of Products
from Around the World

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Opportunities for olive oil value chain enhancement through the by-products valorisation. A Life Cycle Assessment in the Andalusian region (Spain)

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Abstract

Problem and aim

The olive oil industry generates a variety of by-products, particularly during the agricultural and production phase, which currently are neglected and managed as a waste. This increases the costs for waste treatment of each olive mill, resulting in a higher economic and environmental burden across the value chain. The Project OLIVEN [1] defines successful technologies for olive industry wastes valorisation focusing on the value chain enhancement for Spain, Tunisia and Turkey. Thus, the main goal of this first study will be to obtain quality reference values of the environmental impacts in different categories of the farming and extraction phase of the virgin olive oil in the most representative Spanish region (Andalusia).

Methods

In order to design a more efficient and environmentally friendly olive oil value chain, Life Cycle Assessment (*LCA*) is an important methodology to identify processes or phases, representing the highest influence in the environmental profile. The methodology applied in this paper follows the international standards of series ISO 14040 and 14044 [2]. Along with these international standards, the LCA followed the rules described in “Product Environmental Footprint Category Rules for olive oil – 3rd draft” (PEFCR) [3].

In this study, the first step has been to collect datasets from the different productive phases of the olive oil (farming and industrial) to know the particularities of them in Andalusia. The questionnaires

were built, demanding information about fuel, electricity, irrigation, products, by-products, residues, emissions, incorporating other information relevant for the process. The data needed was quantitative and qualitative, so that several face-to-face interviews were developed, visit to their tree crops and facilities. In order to evaluate the environmental profile, the selected functional unit has been 1kg of virgin olive oil.

Results

Over the development of the study the collection of around 1500 ha of olive crop and more than 100 mills were carried out following the requirements of the PEFCR. The mean of the inputs and outputs collected was evaluated, and several sensitive scenarios have been analysed in order to understand possible differences of the environmental profile of olive oil. Once defined the base case scenario, the environmental impact of the agricultural and production phase were estimated, using midpoint indicators of the ILCD Method. As a common trend among all the indicators, in the case of agricultural phase, fertilizers, pesticides and fuels have been identified as hot-spots to be improved. The energy employed for the production process has been identified as a high influence in the environmental study.

As an output, the identification and quantification of the sub-products of olive oil value chain have been determined in order to recover the material and energy, and finally improve the environmental profile of the agricultural phases.

Discussion

In this study, three main stages (olive production, olive oil extraction and olive by products) have been analysed, the identification of the hot-spot of the agricultural and productive phase have been quantified, not only in terms of mean of production, but also standard deviation of alternative producers. In addition, the main aspects involved in the valorisation of the sub-products have been defined and several possible scenarios proposed, in order to find the most environmentally friendly option for the following stage of the project.

Literature

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Lamb Meat Production Systems in Turkey and the EU – An Analysis from a Life Cycle Perspective covering LCA, LCC and Land use

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Abstract

The EraNet SUSAN project EcoLamb assessed the sustainability of various European sheep production systems focusing on the ecological footprint, animal welfare aspects and nutrition value of lamb meat. The project engaged a trans-national research of academic and industry based stakeholders from 6 countries made up of Germany, Italy, Portugal, Slovenia, Spain and Turkey. Main goal of the project was the analysis of resource-efficient, competitive and low-carbon lamb production models on case studies in every stakeholder country. The participating farmers were located in the Rhön Mountains and the Swabian Alb in Southern Germany, in the South Slowenian Alps, in Piedmont in Northern in Italy, in Galicia and Castile and León in Northern Spain, in Braganza in Northern Portugal and at the Aegean coast and in central Anatolia in Western and Central Turkey. Besides the LCA, LCC and land use (LANCA®) analysis, biodiversity impact, animal welfare, meat quality and sheep performance was examined. The multidisciplinary approach and the multi-actor involvement of the EU sheep sector gave a unique overview and insight on the different aspects and impacts of lamb meat production. The results shall not only be used for the sake of scientific progress, but shall also give farm consultants, farmer groups and policy officers recommendations to re-design consulting approaches and plan new initiatives to make all aspects of the European sheep industry more sustainable.

The LCA was conducted according to ISO 14040/14044 using the GaBi software and databases. The assessment focusses on the impact categories global warming potential, acidification potential and eutrophication potential. The inventory data cover primary data from the management practices of investigated case studies and were completed by LCA dataset and literature data for modelling the background system. Since the yield of meat per kg liveweight strongly varies depending on management form and sheep breed, the functional unit was set to 1 kg of lamb meat to provide the comparability among the different case studies. Given that the non-meat parts of the lambs are not used in all case studies equally they were not counted as allocated secondary products but the gain in electric and thermal energy by incineration was credited to the overall result. First results show a higher emissions of extensive production systems due to the higher effectivity and the larger gain of meat of intensive farms. However, land use impacts indicated more positive effects of extensive sheep flocks on the surrounding flora and fauna. To put the suitability of global warming potential as an indicator of sustainable food production respectively animal farming up for discussion should therefore be another outcome of this study.

The established models can now be applied on any sheep farm in the respective countries.

The presentation respectively the poster will give an overview on the methodological approach of the study and will discuss the main results, findings and lessons learned from the assessment.

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Comparing apples and oranges in diet LCA: A functional unit by any other name…

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Abstract

Problem & Aim: The selection of functional unit is a critical decision in life cycle assessments (LCAs) of food products. Generally, a functional unit representing mass of a product at farm-gate is selected. However, when considering dietary LCA, mass-based functional units fail to account for the primary function of diets, which is typically to provide nutrition (i.e. protein, caloric energy, and/or provision of other nutrients). More recently, there is a focus on functional units that reflect nutrition and health aspects of food products in a diet; however, there are a range of perspectives on how these functional units capture the function, ranging from the use of macronutrients to dietary quality scores. As a result, different functional units can lead to different results for the same product systems. The purpose of this study is to use the ISO 14040/14044 LCA requirements to evaluate how the function, functional unit, and reference flows are expressed in dietary LCAs, and to show how different researchers (e.g. nutritionists, LCA practitioners) use and interpret these concepts. The aim is to provide some recommendations regarding clarifying these concepts for more rigorous diet LCA.

Methods: We used the following keywords in Scopus "LCA", "life AND cycle AND assessment OR analysis" and "carbon footprint" and "diet*" and "nutri*" and limited the dates to 2017 to the present. This time period was chosen to reflect LCAs done after key review papers on LCA that have flagged the functional unit issue in dietary LCAs. This yielded more than 30 LCA studies. We reviewed the documents using the ISO 14040/14044 guidelines for goal definition, and for function, functional unit, and the reference flow, and the guidance by Reap et al. (2008)[1] on the errors that occur in this step of LCA. The results were tabulated based on the presence of these concepts.

Results & Discussion: The studies were found in nutritional and environmental journals, and were conducted by health researchers, LCA researchers, or both. Most studies did not clearly describe the function of the diets, nor did they explicitly specify the units when defining functional units (e.g. mass of foods). Furthermore, the reference flow (what is needed to fulfill the function) is rarely mentioned, or it is confused with the functional unit. We also found that the goal of each study

affects the functional units chosen, and some studies used carbon footprinting, which does not require the use of a functional unit but can be done based on consumption. Finally, these studies did not conduct a sensitivity analysis to determine how different functional units may affect the interpretation of results. The findings of this study suggest that more rigour is needed in expressing function, functional unit, and reference flows in dietary LCAs, otherwise it is challenging to compare these studies. Given that both health and LCA practitioners are involved in doing these studies and that diets have health and environmental implications, this research community needs to develop a more standardized approach for expressing these concepts.

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Life Cycle Assessment of industrial scale rearing and processing of *Hermetia illucens*

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Abstract

Problem and aim

In facing the global issues defined by the United Nations Sustainable Development Goals, new solutions are needed to replace fossil resources and find new ways and sources of food production [1,2]. Insects are a promising alternative in various regards. On the one hand, insect meal is a protein-rich alternative to meat with the potential to contribute to global food security and reduce the risk of hunger [3]. Furthermore, a reduction in meat demand contributes to tackling climate change and other related issues [4,5]. On the other hand, insect oil can be used for technical non-food applications as well, such as for fuel production [6] or biotechnological applications, unlocking further potentials in these areas. The sustainability benefits of insect products are being researched and discussed in literature [7-11], such as benefits through reduced greenhouse gas emissions, reduction potentials regarding water consumption, land use and biodiversity loss compared to agricultural crops. The aim of this study is to assess the environmental impacts of a planned industrial scale production of *Hermetia illucens* (black soldier fly) using Life Cycle Assessment (LCA).

Methods

LCA is implemented for industrial scale rearing and processing of *Hermetia illucens*. Primary data was provided by the company Hermetia Baruth GmbH and implemented using GaBi ts software and databases. The system boundary (cradle-to-gate) includes substrate production, substrate

preparation and mixing, egg and larvae production, larvae killing, drying and processing as well as auxiliary processes [12]. The CML 2001 (Jan. 2016) method is chosen for impact assessment. The focus is put on the Global Warming Potential (GWP 100 years, excluding biogenic carbon) and the primary energy demand from non-renewable resources. Other relevant impact indicators are also discussed.

Results

The baseline scenario analyzes the insect rearing and processing practice for four different substrates (commercial pig feed, distiller's grains with solubles mixture (DGS) from bioethanol production, food household waste, and sugar beet pulp mixture), using the German electricity grid for electricity supply and natural gas for heat generation. The results show the high influence of both the chosen substrate and energy sources. A sensitivity analysis is performed regarding the chosen energy and heat sources. The results show that the use of side-stream or waste products as substrate and the use of renewable energy or waste heat are favorable regarding the environmental impacts of insect rearing and processing.

Discussion/Interpretation

The obtained results are comparable to those of other similar studies [7-11]. The in detail analysis of the results reveals the most relevant levers to improve production conditions in a way that the environmental impacts are minimized. At the same time, from an LCA perspective, the discussion of synergies and cascade use are of relevance in this context. The chosen approach (giving credits or cutting off) for including by-products or waste from other systems has a high influence on the results. For example, the use of substrate leftover as fertilizer shows environmental benefits compared to industrial nitrogen fertilizer and depending on the chosen approach can heavily influence the overall result. This should be taken into account when giving recommendations for policy and decision makers.

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Life Cycle Assessment of sardine products in Portugal

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Abstract

Problem and aim:

Sardine (*Sardina Pilchardus*) is one of the most captured species by purse seiners in the Portuguese coastal waters, detaining a significative relevance in the Portuguese fishery context and also in the Portuguese diet. This species is normally consumed fresh, frozen and canned. Fresh consumption normally takes place during the summer. The surplus sardine that is neither consumed fresh nor processed by the canning industry is frozen to be consumed along the year. Given the relevance of these products in Portugal, it is important to quantify their environmental impacts from a life cycle perspective using Life Cycle Assessment (LCA), aiming to provide supporting information for defining strategies for improving the environmental performance along the value chain, for supporting the establishment of benchmarks for Portuguese sardine products aligned with Product Environmental Footprint (PEF) guidance (EC, 2018) and the comparison with the performance in other countries and other fishery products. Therefore, the goal of this study is to apply LCA to assess the environmental impacts associated with sardine products: fresh sardine, frozen sardine and canned sardine (with olive oil and sunflower oil).

Methods:

The study is based on a "cradle-to-gate" approach, comprising the fishing and landing stage for the fresh sardines and, additionally, the processing stage for the canned sardine, and the freezing and storage stage for frozen sardine. The functional unit is 1 kg of edible product of sardine for all products. The inventory data are mainly of primary origin. For the sardine fishery, data were retrieved from the most important cluster of purse seining vessels in northern Portugal, which represents approximately 35% of Portuguese landings. For the production of frozen and canned sardine, data were obtained in Portugal from a cold storage plant and a canning factory, respectively. The characterisation factors adopted for the environmental impact quantification are those recommended in PEF guidance (EC, 2018).

Results:

The results show that canned sardine has higher environmental impacts than the other products at the processing gate (2 to 12 times greater than fresh sardine, depending on the category) and most of the impacts are related with the processing stage. In this stage, the majority of the impacts derive from the use of aluminium cans and olive oil or sunflower oil. The hotspot in the case of frozen sardines (considering that frozen sardine is stored for 4 months) is the fishing and landing stage, which is responsible for more than half of the total impacts, followed by electricity production consumed for freezing and storing the sardine. During the fishing and landing stage (common to the three products assessed), the environmental burdens are mainly associated with diesel production and combustion.

Discussion:

Based on the hotspots identified it is possible to suggest possible measures to decrease the environmental impacts, such as increase of the energy efficiency of the purse seiner fleet and/or use of alternative fuels in the vessels of this fleet. In the case of the canning industry, measures can include the decrease of the amount of oil used and corresponding losses during processing, as well as find alternative packaging materials to aluminium cans.

Literature:

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Internalizing the environmental costs of organic and conventional food production on LCA midpoint and endpoint level

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Abstract

Following scientific and societal consensus, environmental pollution must be reduced drastically. As industrial agricultural activities are one of the biggest polluters globally, the reduction of emissions caused by this sector is of utmost importance. Encouraging a shift in consumers' demand patterns towards more sustainable dietary choices is one auspicious approach to promote more sustainable food supply. Consumers are currently misled towards demand of inadequately priced foodstuff by an insufficient internalization of external costs. These market distortions are followed by a loss in welfare, as well as detriments for ecosystems and human health alike. Therefore, we introduce an interdisciplinary framework that evaluates ecological and social damage economically, according to the polluter-pays principle: we connect the ecological assessment of eleven different food categories with its monetary impact. We also distinguish between different agricultural farming systems (conventional and organic) to differentiate the agricultural production landscape further.

We model the Life Cycle Inventory of various foodstuff of plant and animal origin in SimaPro 9 with i.a. the ecoinvent 3.5 and Agri-footprint 4.0 databases, and a meta-analysis is conducted to adequately model the differences in production between conventional and organic farming from cradle to farmgate. Using the ReCiPe 2016 method for Life Cycle Impact Assessment, midpoint and endpoint level results are then linked with cost factors to adequately adjust food prices regarding

their vast array of unaccounted impacts along the value chain. Lastly, the calculated external costs are put into relation with the foods' current prices resulting in necessary surcharge of each examined product.

Using this framework for the case of food production in Germany, preliminary results, which examine damages from greenhouse gases, reactive nitrogen and energy use, show significant differences between different types of foodstuff as well as farming practices: while organic produce should be more expensive by 42% on average, effects of conventional production resulted in an average necessary surcharge of 129%. Plant-based organic food appears to be the currently most reasonably priced group with an average surcharge of only 6%, whereas animal based conventional foods should be on average more expensive by 94% (milk) to 196% (ruminants).

Overall, these results display the vastly varying gaps between current market prices and the true costs of different food categories. This differentiated approach accounts for the polluter-pays-principle as price levels would rise according to the foodstuff's inherent ecological damage. Our framework can be used as a tool to internalize environmental costs from food production into the market price; the consequentially undistorted market design will – following prevailing economic theory – lead to an economically induced behavioural change of consumers. As the demand for already adequately priced foods increases, the demand for detrimental and, after internalization, more expensive options declines. As a consequence, supply adapts to the changed consumption patterns, eventually developing a sustainable agricultural production landscape. Therefore, the correction of market prices can pose a real chance to achieve global sustainability goals. The price for industrial activities – as of now being 'paid for' by ecological systems and the human health – will fall back into the polluter's arms preventing environmental degradation at the source rather than fighting its symptoms.

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Development and application of an LCA methodology to optimize the coupled nutritional and environmental efficiency of agricultural resource use and product allocation - with a case study of Canadian pea and lentil production

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Abstract

Problem and aim: For the world to eat a “healthy” diet, as per the United States Department of Agriculture guidelines, an additional gigahectare of land (about the size of Canada) is necessary [1]. However, agriculture already occupies 35-40% of terrestrial surface area, with limited potential for expansion [2] and contributes 70-90% of freshwater consumption [3], 95% of nitrogen pollution [4] and up to 30% of greenhouse gas (GHG) emissions [5]. At the same time, poor dietary quality contributes to the paradoxical rising prevalence of both malnutrition and obesity (and related diseases) [6, 7]. Substantial inefficiencies result from current allocations of agricultural land (e.g. between high and low yield crop types) and product usage (e.g. between biofuels, livestock feed, and human consumption). Given the increased demands of a growing population, coupled with the finite resources and limited assimilatory capacity of the environment for anthropogenic emissions [8], identifying viable strategies to maximize both the nutritional and environmental efficiency of land and agricultural product allocation in agri-food systems is imperative for a sustainable and healthy future. The aim of this study was to develop methods to assess the coupled nutrient quality and environmental impacts of agricultural production. These methods were applied to an LCA case study of Canadian peas and lentils, which are economically important crops in Canadian production and considered to be both relatively sustainable and nutrient-rich.

Methods: Literature regarding the inclusion of nutrition into LCA was consulted to develop a nutritional quality index (NQI) that enables normalizing LCA results to an output of nutrients (i.e. rather than weight). For example, Chaudhary et al. [9] proposed a nutrient balance score that considers 27 nutrients in order to compare the carbon footprint of different crops on a nutritionally equivalent basis. In addition, the Combined Nutritional and Environmental Life Cycle Assessment (CONE-LCA) impact assessment framework was applied to evaluate and express scenario results in terms of resource use, emissions-related environmental impacts, and nutritional quality, combined and expressed as Disability Adjusted Life Years (DALYs - a human health metric) [10].

In this study, spatially-resolved LCA models of Canadian pea and lentil production were developed at the reconciliation unit (small-scale), eco-region and provincial scales, based on regionalized data

collected via surveys distributed to Canadian farmers. Agricultural production scenarios were assessed, taking into account the relative environmental impacts and nutritional comparability of pea/lentil product outputs.

Results and Discussion: Within the LCA framework, these scenarios were assessed and presented using both the NQI as a functional unit, and with the CONE-LCA impact assessment framework. The results are presented for each scenario as environmental impacts scaled to nutritional quality, as well as results expressed in DALYs to represent the combined human health impacts of the nutrients supplied and the environmental impacts. This methodology can be used broadly in agri-food production to assess the efficiency of current and alternative patterns of agricultural land and product usage, as a basis for agricultural policy reform.

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Topic 15:
Land and Water Effects

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A spatially explicit approach for estimating Land Use Change-induced Greenhouse Gas Emissions of Agricultural Crops

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Abstract

Problem and aim

Land use change (LUC) from agricultural expansion is a major source of anthropogenic greenhouse gas (GHG) emissions. These emissions are often estimated using LUC statistics at a national level when the exact location of crop cultivation in a country is unknown. This approach neglects spatial variability in LUC and natural carbon stocks at more localised levels. We have developed and applied a spatially-resolved approach for consistent quantification of LUC-induced GHG emissions for crop production with varying levels of uncertainty in the sourcing location.

Methods

Data on approximate location, crop area and yield for 1885 farms, in 33 countries producing 69 agricultural commodities were collected from the Cool Farm Tool (Hillier et al., 2011). These were geolocated (Google Maps Platform, 2019) to derive a spatial boundary containing the expected farm location within the specified geolocation, Figure 1.

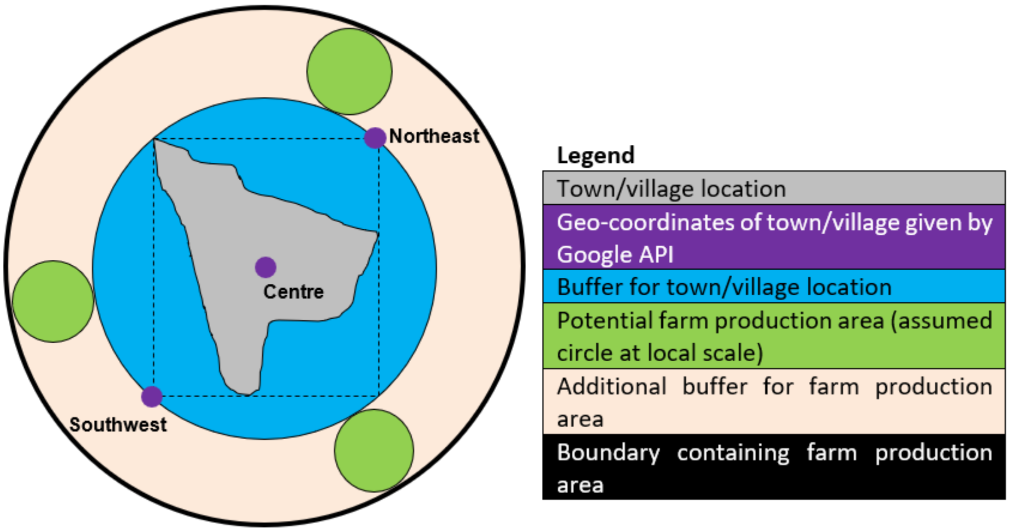

Figure 1. Geographical boundary used to determine LUC for a given crop and farm.

We combined spatially explicit global land cover information (ESA, 2017) with soil and biomass carbon stocks (Chaplin-Kramer et al. 2015; Deng et al. 2016; Ruesch & Gibbs, 2008; Santoro, 2018; Xu et al., 2018) to calculate LUC emissions due to cropland expansion from 1994-2014 for farm-specific crop production. Geolocated results were compared at different spatial scales, namely district, province and country, and with the PAS2050 country scale statistical approach; “country of production known, previous land use not known” (BSI, 2012).

Results

Of the 1,885 farms, 33% were identified to have LUC-induced GHG footprints when estimated at local scale; this percentage increased with coarser spatial scales of analysis and therefore typically overestimated the footprints. There was no relationship between the LUC-induced GHG footprints calculated based on the “country known-previous land use unknown” function (Blonk Consultants, 2017) and our local scale results, when tested using Spearman’s correlation coefficients, i.e. it was close to zero.

Discussion

The approach developed is globally-applicable, consistent and enables the inclusion of more local LUC dynamics to improve the LUC component of GHG footprints, when the exact location of a farm is not known.

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Analysing farm-level greenhouse gas footprints of crops grown for processing

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Abstract

Problem and aim

Analyzing variability of farm-level greenhouse gas (GHG) footprints of crop production and understanding the drivers of this variability can reveal opportunities for improvements in farming practices and enable more targeted GHG mitigation strategies within agricultural supply chains. Here, we quantify the variability and analyze underlying drivers of variability for the GHG footprints of 26 commercially-grown crops.

Methods

Our dataset contained 4565 observations of crop yields and farm management practices, including fertilizer application and energy consumption (Unilever, 2017) of a number of farms, covering the years 2013-2016 and spanning 36 countries and 26 fruit, vegetable, herb, spice and commodity crops, grown in compliance with Unilever's Sustainable Agriculture Code (SAC). Per crop and farm, we first quantified the contribution of four main components of GHG footprints to the magnitude of the GHG footprints. These components were (i) emissions from electricity use, (ii) emissions from on-farm fossil fuel use (petrol and diesel), (iii) emissions from crop residue application, and (iv) emissions from fertilizer production and field application. We then used a linear mixed effect model to assess possible scaling effects of yield and area of production on the GHG footprints of each crop type and to assess possible temporal trends within the sampled dataset.

Results

When considering the total dataset, we found large variability of GHG footprints between crops. Results of a one-way ANOVA revealed that differences between crops contributed to 45% of the explained variance of crop GHG footprints, while the rest were explained by the variability within crops. The fertilizer GHG footprint was the highest contributor to the production-weighted mean GHG footprints for 20 of the 26 crops, contributing between 47% (sugarbeet) and 91% (turmeric). For all 26 crops we found a relationship between footprint and yield. For 24 of the 26 crops (92%), we found a net decrease in GHG footprints across the range in yield. Relationships with area were less clear, as these variables were retained for only 15 crops (~ 58%) and directions of the relationships were more variable. The modelled GHG footprints had a net decrease, net increase and no change across the actual range of years for 12, 9 and 5 of the 26 crops respectively.

Discussion

We conclude that an increase in crop yield is related to a net reduction of the GHG footprint for our dataset. The data analysed in this study relate to crops grown by farmers operating in compliance with Unilever's Sustainable Agriculture Code (SAC), which requires a commitment to continuous improvement in the implementation of best agricultural management practices. The observed decrease in GHG footprints over the respective time period for 12 out of 26 crops is therefore encouraging in terms of the potential effectiveness of implementing best agricultural management practices. However, given that the observed decrease did not extend to all crops studied, further work and longer term monitoring would be required.

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Human Toxicity and Ecotoxicity Impacts of Pesticide Applications in Rice Cultivation in Thailand

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Abstract

Half of the total area in Thailand is agricultural land, with the largest contribution from paddy rice fields. Thailand is a global rice exporter and consumer. Large quantities of pesticides are used in rice fields to increase crop yields and ensure food security. Since pesticides can harm humans and the environment, this study aims to characterize the potential human toxicity and ecotoxicity impacts of pesticides applied to rice in Thailand via Dry Direct Seeded Rice (DD) and Pre-germinated

Direct Seeded Rice (PD). Pesticide application data were obtained from Bayer Crop Science Thailand. Four approaches were followed for assessing pesticide emissions, namely Ecoinvent (Nemecek and Kägi, 2007), US LCI (USDE, 2012), Neto et al. (2013) and PestLCI Consensus (Rosenbaum et al., 2015) to test different assumptions for pesticide dispersion into different environmental compartments. USEtox was adapted for Thailand-specific landscape and consumption parameters to obtain spatially differentiated characterization factors (CFs). This is the first study in Thailand representing the national context and allows the LCA practitioners to assess the potential toxicity impacts both on human health and ecosystem based on various assumptions for emission distributions. Combining emissions and characterization factors yields potential human toxicity impact scores for pesticides from DD and PD productions, which respectively range from 3.32E-06 to 4.44E-05 and from 1.13E-07 to 7.73E-05 DALY ha^{-1} $application^{-1}$, with oxadiazon (CAS RN: 19666-30-9) and tebuconazole (CAS RN: 107534-96-3) as main substance contributors from DD method; while propineb (CAS RN: 12071-83-9) as main substance contributor from PD method. On the other hand, the potential ecotoxicity impact scores for pesticides from DD and PD productions, which respectively range from 3.33E+03 to 6.34E+03 and from 7.89E+01 to 1.95E+02 PDF·m^3·d ha^{-1} $application^{-1}$, with oxadiazon and tebuconazole as main substance contributors in respectively method. The results indicate that the DD method has higher impacts than the PD method for both human toxicity and ecotoxicity when applying the three approaches of pesticide emission quantification except for the PestLCI, which the PD method shows the higher human toxicity impacts than the DD method. However, our results also demonstrate that the ranking of pesticides applied to rice varies with applied emission approaches. The higher the estimated or assumed emission to soil and water, the higher the ecotoxicity impacts. For human toxicity, only PestLCI considers an emission fraction also reaching the rice, which will be consumed and lead to additional human impacts. The emissions to crops are not considered in other approaches (Ecoinvent, US LCI, Neto et al., 2013). In addition, the obtained CFs from adapted USEtox with Thailand-specific data illustrate the difference when compared with the default USEtox ranging from 0.0% to 183.6% for human toxicity CFs and from 0.1% to 160.3% for ecotoxicity CFs. This study helps identifying the main substance contributors of the systems; and highlighting the need for proper emission quantification and for the use of spatially differentiated CFs to increase accuracy. Ultimately, we hope that our study will be useful for policy improvement to administrate and/or advise the Thai rice farmers.

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Don’t water down the whiskey: water footprint and water scarcity impact in distilling

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Abstract

Problem and aim:

Agriculture and subsequent food and drink manufacturing belong to the most water intensive sectors in the UK. Within the beverage industry, alcoholic beverages such as beer and spirits represent a hotspot in terms of water used per product: water consumption in a distillery to produce one litre of spirit reportedly ranges from 7-45 L, even excluding the water required during cultivation of the crops (BIER, 2011).

In the face of climate change and growing population exacerbating water scarcity, this study aims to assess the potential for reducing the water footprint and impact on water scarcity of grain spirits production with whiskey from barley as example. We look at two areas of intervention: 1) process-optimisations on plant level such as closing the cooling water loop and 2) benefits from re-use of waste streams as fertiliser, feedstock or bioenergy resource.

Methods:

The questions will be assessed taking into account primary data from three distilleries in the UK with different production scales. The water footprint will be determined using the methodology described by Hoekstra et al. (2011) and include blue, green and grey water, i.e. quantify consumption and pollution of freshwater. The impact on water scarcity and other environmental impacts such as global warming, acidification and eutrophication from whiskey production will be assessed using Life Cycle Assessment (LCA) methodology from “cradle-to-gate” covering barley cultivation and distillery operations, with the ready but unpackaged whiskey as final product. The water scarcity impact will be assessed using the recently developed AWARE (Available WAter REmaining) method (Boulay et al., 2018) which evaluates water consumption considering water availability in the geographic area of abstraction.

In order to assess benefits from the use of the distillation by-products spent grains, spent lees and pot ales, we expand the system boundaries of the LCA to account for avoided impacts including avoided water use from the substitution of N-fertilisers, feed (direct use of waste streams and conversion to dried distillers' grains with solubles (DDGS)) and natural gas.

Results:

The results will give a full quantification of water used for and determination of water scarcity impacts from grain spirit production from field to plant, showing the major hotspots of the water value chain. They will reveal potential trade-offs between water conservation and reduction of other environmental impacts achieved through the examined process and waste management options. As both water footprinting and LCA-based water scarcity evaluation are applied to the water conservations measures, differences in evaluation outcome will be determined and suitability of the two assessment methods discussed.

Discussion:

The study will enable the recommendation of holistic water conservation measures through process handling and waste management options. Finally, potential water savings will be extrapolated to UK national level and set in context to its food-dependent virtual water footprint.

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Introducing seasonality in the assessment of marine eutrophication impacts due to fertiliser use

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Abstract

Problem and aim

The use of fertilisers in agriculture results in waterborne nitrogen emissions, mainly in the dissolved inorganic nitrogen (DIN) forms of nitrate and ammonia. DIN is transported from agricultural soils to aquifers and rivers and eventually reaches coastal areas, degrading the quality of inland waters and leading to eutrophication and associated biodiversity loss in coasts.

To date, efforts in life cycle assessment have focused on including spatial variation in environmental impacts of DIN emissions, resulting in operational characterisation factors (CFs) at global level at the spatial resolution of watersheds and large marine ecosystem (LME) and temporal resolution of a year (Cosme et al. 2018).

Notwithstanding, seasonality is important when tackling eutrophication-related problems, because algae growth is constrained by factors that follow seasonal cycles, such as river discharge, light availability and temperature. Understanding seasonal patterns of processes involved in coastal eutrophication will allow predicting peaks of potential impacts due to the use of (synthetic and organic) N-fertilisers and introducing corrective measures in agricultural practices accordingly.

The aim of this study is to advance the integration of seasonal aspects in state-of-the-art CFs for marine eutrophication (Cosme et al. 2018) focusing on the fate factor (FF) of the CF.

Methods

The new seasonal FFs have the same structure as in Cosme et al (2018), that is, an inland component and a marine component:

$FF_{i,jl} = f_{Ni,j} / \lambda_l$

$FF_{i,jl}$ [days] is the fate factor for emission route *i* in river basin *j* to receiving LME *l*; $f_{Ni,j}$ models the inland compartment and stands for the fraction of DIN emission to soil and rivers that reaches the coast [dimensionless]; λ_l [days^{-1}] models the marine compartment and stands for the persistence of

DIN in coasts. Conceptually, $FF_{i,jl}$ expresses the amount of time the fraction of the original DIN emission will stay in the coasts, which is the period within which DIN can be transformed in new algae.

For the inland component, we relied on seasonal DIN retention factors from NEWS 2S (McCrackin et al. 2014).

For the marine component, large-scale studies do not give information on seasonal behaviour of DIN. We developed our own estimates of λ_l building upon annual residence times of water on the continental shelves (Sharples et al. 2017) and annual losses of DIN through denitrification given by these same authors, all at 5º resolution. To introduce seasonality on these parameters, we used seasonal, spatially explicit data on temperature and seawater salinity. The influence of other parameters on seasonal patterns of DIN in coasts (e.g. physical properties of the riverine water plume) are under study.

Results

For the inland compartment, the new seasonally resolved FFs show that intraannual changes in runoff and temperature control transport efficiency of DIN to the coasts. For the marine compartment, preliminary trends show how cooler temperatures reduce denitrification rates, resulting in higher FFs.

Discussion/Interpretation

Intraannual changes identified by our preliminary results in DIN fate and transport to the coast as well as seasonal patterns of DIN removal in the shelf justify the need of temporally resolved FFs for a better management of nutrient use in agriculture and reduction of related eutrophication impacts. Our research focuses on the fate component of the CF. Seasonality should be introduced in the other CF's subfactors for a consistent, temporally resolved assessment of the potential environmental impacts of DIN emissions on marine biodiversity.

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First time ever results for footprints of qualified land use and phosphorus towards more conclusive LCAs of food

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Abstract

LCAs of food have been published since about two decades. Still, most of these LCAs covered only the CO2-footprint and only a few the full set of LCA environmental impacts such as greenhouse gas savings, energy depletion, ozone depletion, acidification, eutrophication, photosmog, toxicity and others. Since a few years, some serious environmental impacts related to resource depletion concerning food production have been discussed to supplement the existing LCA impacts set towards a more conclusive picture, namely:

- Water footprint (including water scarcity)
- Land use footprint (including land use quality)
- Phosphorus footprint

All of them address a similar issue: they reflect resources which are in some areas and/or countries very limited, though obviously not all of them everywhere. That’s why complex methodologies are necessary to address these limited resources well in a LCA. From these, only the water footprint has been covered conclusively by the AWARE methodology. Thus, up to date, there is no LCA of food items published, which covers these important impacts seriously and conclusive.

At the upcoming LCA Food 2020 we want to close this gap. Conclusive LCA results of several food items will be presented including the footprints of phosphorus and land use (including land use

quality). They have been performed at IFEU-Institute in 2019 (see some exemplary results KEEKS 2019). The presentation will cover

- An introduction for the need of the inclusion of the land use (including land use quality) and phosphorus footprints
- A short overview of their methodologies
- Detailed results of LCAs of several food items including footprints of phosphorus and land use
- Conclusions and recommendations

The conclusive discussion and presentation of the scientific findings regarding these topics are rounded off by recommendations for science, policy, society and industry.

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A spatially explicit framework to assess the environmental impacts of agricultural production on landscape level

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Abstract

Problem & Aim

Global agriculture is facing immense challenges due to an increasing demand by a growing population that is more (over)consuming and wasting a substantial proportion of the food produced [1] while environmental impacts at local and global scales increase [2-4]. Life cycle assessments (LCA) are widely used to evaluate the environmental impacts of agricultural production, addressing energy as well as material flows and their environmental impacts [5-6]. Despite of recent advancements [7-11], LCA approaches generally measure eco-efficiency without taking into account local ecosystem boundaries or cross-scale interactions and therefore do not allow for a final conclusion on the sustainability of an agricultural production system within its specific local context. Furthermore, LCA neglect the inherent linkages between farming systems (e.g. whey in pig production), which only emerge once analyses cover the entire food system. We address those

needs with the development of a spatially explicit toolbox for assessing nutrient flows and environmental impacts of agricultural production at landscape level.

Proposed methodological framework

The toolbox will be based on a gridded representation of agricultural production (Fig.1 - 1) with a LCA-based farm model applied to each grid cell (2). This model captures within-cell flows of agricultural products, quantifies N/P flows through plant as well as feed and livestock production and considers, through a cradle to farm-gate approach, upstream processes, and external inputs. Hence, it allows for a quantitative environmental evaluation of farms, both per hectare and per kg of outputs. The application of this farm model to each grid cell will facilitate a high degree of spatially resolved farming activity data. A data processing method (3) will centrally manage each grid cell with regard to all physical exchanges with other cells. The biodiversity depletion potential [12] will be calculated for each cell based on agricultural land use intensity and landscape structure parameters, such as presence of semi-natural habitats (4). Additionally, maps indicating water quality as well as other landscape functions and ecosystem services will be integrated (4). Through the combination of this model with a global mass-flow model [13-14], we will quantify off-site effects as well as trade-offs and synergies across different scales (5).

Expected results

The above presented framework will provide a reproducible and innovative modelling approach to assess and optimize agricultural activities in their surrounding landscape. Latter will be firmly linked to their location in ecosystems and consistently embedded in regional to global food system dynamics. The framework will thus allow to explore the regional option space of impact mitigation, including trade-offs and synergies between agricultural land use, ecosystem services, and biodiversity conservation at landscape level. Thus, the approach optimally contributes to regionalised systemically consistent policy making.

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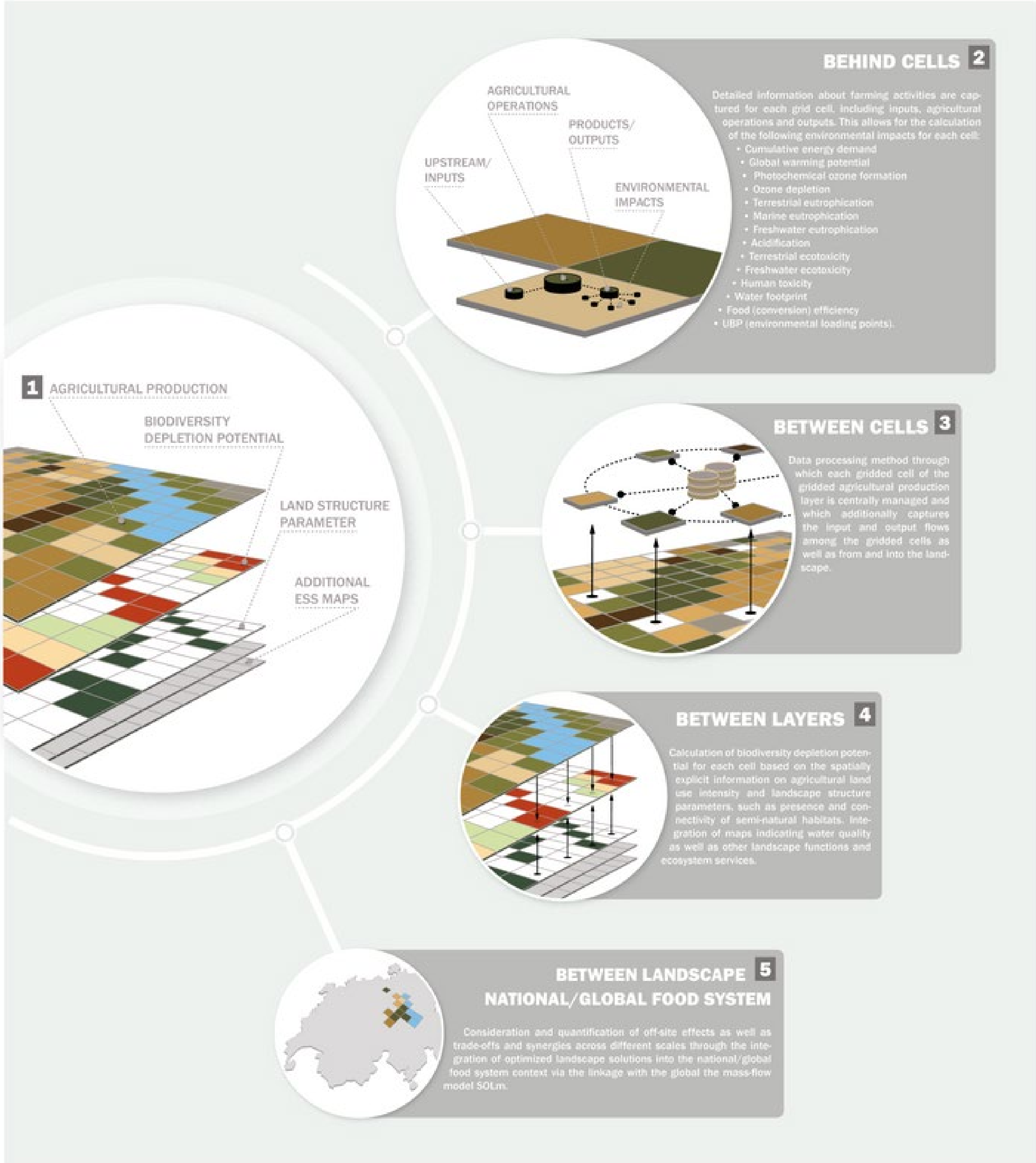

Figure 1: A spatially explicit framework to assess the environmental impacts of agricultural production at landscape level

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Development of a carbon intensity calculator for biofuels in Brazil: RenovaCalc

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Abstract

Brazil is a country with a wide availability of energetic resources, especially due to the country´s favorable weather conditions and extensive land availability. The country has a unique combination of factors such as arable land available for expansion of biofuel production, high productivity, technology of production of biofuels and an established consumer market with great potential for growth. In 2018, renewable energy sources in the vehicle matrix totaled 23%, growth driven by various public policies to promote biofuels, such as The National Alcohol Program (PROALCOOL) in the year 1970, the introduction of flex fuel technology in 2003, and the National Program of Production and Use of Biodiesel (PNPB) in 2005 (EPE, 2019). In 2017, the Brazilian National Biofuels Policy (RenovaBio) was published with the aims to reduce the carbon footprint of the national fuel mix as well as ensuring a long-term demand for low carbon fuels in the country. RenovaBio is a modern agenda and is poised to take a radically new approach to expand biofuels supply in Brazil. In order to calculate the carbon footprint of the biofuels, a calculation tool named RenovaCalc was developed. The aim of this study is to present in detail how the RenovaCalc was constructed and how it operates, using to illustrate a case study of a corn ethanol facility in Brazil. RenovaCalc counts the carbon intensity of the biofuel (g CO_{2eq}/MJ) and compares it to its equivalent fossil fuel (for ethanol, the equivalent is gasoline), generating the Energetic-Environmental Efficiency Score (NEEA), that combined with the volume produced results in an amount of Decarbonization Credit (CBio). The association of NEEA with the volume of biofuel will allow the emission of CBios, which will be traded in the financial market. The carbon intensity of the biofuels is done by using the Life Cycle Assessment (LCA), considering “Climate Change” as the category of environmental impact. The “well-to-wheel” (or “cradle to grave”) scope was assumed, in which all material and energy flows consumed by the production processes and emitted to the environment, from extraction of natural resources, acquisition or production and treatment of biomass, conversion to biofuel, until combustion in engines, including all transport phases. For the calculation, an energy-based allocation was applied and the functional unit is MJ of fuel consumed. RenovaCalc corresponds to a set of spreadsheets in the Excel® platform, containing a database and a specific calculation structure for each type of biofuel. RenovaCalc calculates the carbon intensity of biofuels based on two sets of

data. In the first set, the amount of fertilizers, fuels and other agricultural inputs are added. The second set is the data regarding to the industrial phase of the biofuel product: industrial yields, fuels and electricity. In this research, the amount of agricultural inputs for corn are going to be obtained in RANP 758 (ANP, 2018), while for the industrial inputs and yields, the data will be provided by literature or by interviewing experts in the corn ethanol production. After all the data is inputted, RenovaCalc calculates automatically the carbon intensity of corn ethanol as well as the Energetic-Environmental Efficiency Score (NEEA). Next, the NEEA value is going to be combined with the volume of ethanol produced resulting in the amount of Decarbonization Credit (CBio) for corn ethanol in Brazil.

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