The applicability of LCA to evaluate the key environmental challenges in food supply chains

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ABSTRACT

System analysis was performed to gain an overview of key environmental challenges and pinpoint hotspots causing environmental impacts in three European food supply chains. An overview was obtained based on a review on LCA studies for beef, dairy, orange juice and aquaculture food supply chains. Similarities of the main environmental impacts were identified to rationalize and justify the selection of key performance indicators chosen for a simplified web based LCA tool developed within the EC funded project SENSE (FP7). Life Cycle Assessment methodology covered many of the key challenges identified but will not be sufficient to address all environmental impacts generated from the food supply chains. Especially for aquaculture impacts that are not taken into account with LCA are i.e. nutrient and organic matter releases, impacts associated with feed provision, diseases introduction, escapes, and changed usage of coastal areas. In agriculture land use and biodiversity are issues not well covered.

Keywords: Environmental challenges, agriculture, aquaculture, LCA, key environmental performance indicators

1. Introduction

The food and drink sector is the largest manufacturing sector in the European Union (15%) which directly employs 4.1 million people but it is a highly fragmented sector consisting of 99% of SME's and microenterprises (FoodDrink Europe, 2011) which makes the supply chain from "farm to fork" complex with a multitude of actors involved. This sector is also associated with high environmental impact; a study commissioned by the European commission showed that three areas of consumption – food and drink, private transportation, and housing – are together responsible for 70-80 % of the environmental impacts of private consumption. Food and drink consumption was responsible for 20- 30% of the various environmental impacts of total consumption, and in the case of eutrophication for even more than 50% (Tukker, 2005). Meat products have generally a higher environmental impact than vegetables and fruit (Mogensen *et al.*, 2009; Figure 1) but variations within product groups can be highly depending on production system. Geographical region also influences the environmental sustainability.

Life cycle assessment (LCA) according to an ISO standardized method (ISO 14040, 2006) is generally applied to quantify the environmental impact for a product or service from cradle to grave. LCA is a valuable method but it is difficult to compare one food product to another due to differences in the goals and scopes of the different studies. Defra recently reviewed over 180 LCA studies on food and found that most studies end at the farm gate of the food supply chain, and very few extend as far as the consumer and that there is a shortage of studies which include information on distribution, retail and consumption and waste (Defra, 2011). Due to differences in goals and scopes, methodological approaches, setting of boundaries and assumptions as well as data quality and availability it is often not possible to compare the environmental impact of food products within the same product category and even less so between different product groups.

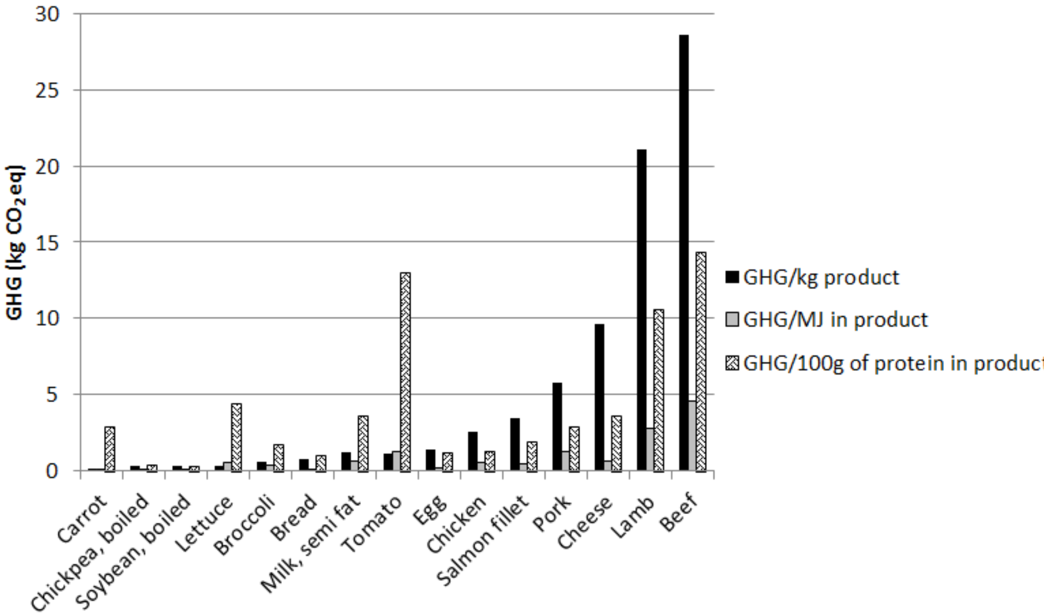

Figure 1. Greenhouse gas emissions of a range of food products per kg of product, per energy content and protein content from farm to retail. The figure is based on the following references: vegetables- Sonesson *et al*. 2010 except chickpea from Gan *et al*. (2011) and soybean from Prudencio da Silva *et al*. (2010); meats (bone free) Cederberg *et al.* (2009) and dairy products Flysjö, (2012). Data on protein content is from the Swedish Food Agency (www.slv.se).

In the SENSE project the aim is to obtain a simplified impact assessment, thus the most relevant impacts that are common in all food supply chains are chosen in order to design a simple LCA based tool, the SENSE-tool. As a first step to gain an overview of challenges in food supply chains in Europe a literature review of existing LCA studies was performed to identify the key environmental impacts as a basis to select key performance indicators that can be used in a simple life cycle assessment tool.

2. Methods

Key environmental challenges in food supply chains were identified based on literature review by selecting as case studies the following food sectors to represent a range of variation of food supplied to the European market:

- Orange juice (Esturo *et al.*, 2013)
- Beef meat and milk (Aronsson *et al*., 2013)
- Aquaculture (salmon) (Olafsdóttir *et al*., 2013)

Published life cycle assessments (LCAs) were chosen as the preferred source of evidence for quantifying environmental attributes of the selected food chains. This is not an exhaustive literature study but key references have been chosen to gain an overview and to compare the impacts in the different food supply chains. The main aim is to demonstrate the similarity and variability of the environmental impacts by giving a range of values reported for the most common environmental impacts assessed by LCA in the respective food supply chains.

3. Results- Environmental challenges

In general supply chain of food products share similarities where food moves from producer to consumer via the processes of production, processing, distribution, retailing and consumption. Each step of the supply chain results in an environmental impact on local, regional or global level (Figure 2 and Table 1). If the environmental hot spots or a key environmental challenge for each step in the chain is known, efforts can be used to focus on these problems and effectively minimize the environmental impact.

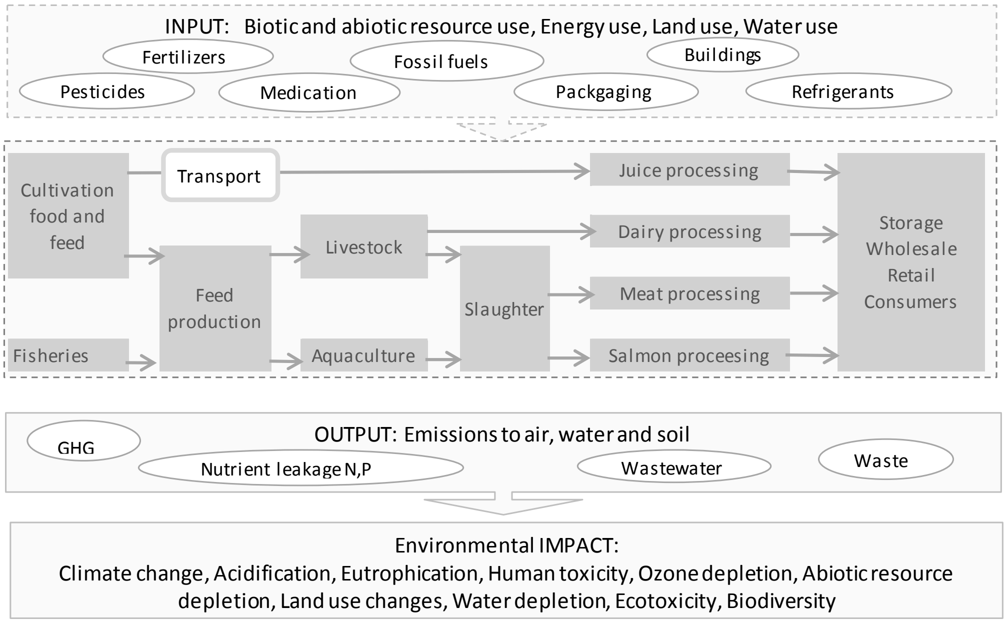

Figure 2. A simplified overview of the common steps in three food supply chain systems (orange juice, meat/dairy and aquaculture) and examples of input resources and output emissions causing environmental impacts.

The environmental challenges of food supply chain systems are typically caused by the use of fossil fuels, water, fertilizers, pesticides and land in the primary production as well as the accumulation of discards from the farm animals i.e. manure and excessive feed in aquaculture. Other challenges in farming are related to the use of feed, medication, the occurrence of escapees and the impacts of the farming on the wild flora and fauna. In the processing steps of food the use of resources, energy, water, packaging and refrigerants, waste and wastewater generation, and the type of facilities like buildings and infrastructure will influence the overall environmental impacts. The choice of technologies is often a key influential factor and the yield, full utilization of resources including the use of by-products is of importance in the overall estimation of the environmental load both in production and processing. In the transport phase the use of diesel is a challenge where the mode of transport can influence the severity of environmental impacts.

Table 1. Identified key environmental categories for the food chain, relevant production steps and challenges.

Impact category	Production step	Challenges
Climate change	Cultivation of biomass, Fishing (feed fish), Feed industry, Animal rearing, Food industry, Transport	Nitrogen fertilizer production, Use of N fertilizer and manure, Enteric fermentation, Manure handling, Use of fossil fuel, Refrigerant leakage
Acidification	Cultivation of biomass, Fishing (feed fish), Feed industry, Animal rearing, Food industry, Transport	Use of N fertilizer and manure, Use of fossil fuels
Eutrophication	Cultivation of biomass, Fishing (feed fish), Feed industry, Animal rearing, Food industry, Transport	Use of N and P fertilizer and manure, Manure handling, Nutrient release from aquaculture, Waste water
Human toxicity	Cultivation of biomass	Use of pesticides
Ecotoxicity	Cultivation of biomass, Feed industry (fishing), Animal rearing, Aquaculture	Heavy metals from fertilizers, Use of pesticides, Use of medicines, Use of antifouling paint
Land use	Cultivation of biomass, Animal rearing (Aquaculture sea surface/floor use)	Land use efficiency
Abiotic resource depletion	Cultivation of biomass, Fishing (feed fish), Feed industry, Food industry, Transport	Use of fossil fuels, Use of P fertilizer
Water depletion	Feed industry, Food industry, Transport	Irrigation, water use
Biodiversity	Cultivation of biomass, Animal rearing	Land use, Use of pesticides, Escapes and diseases in aquaculture

3.1. The beef and milk supply chain

The farm stage is generally the main contributor to the total environmental impact of a food product and for beef and dairy chain the farm stage contributes approximately 80 to 95% percent to the total emissions (e.g. FAO, 2010), with grassland systems having higher emissions than mixed systems (FAO, 2010). Methane is the main contributor with an average of 52 percent of the total emissions. CH_4 emissions from ruminant livestock systems come from enteric fermentation that ruminants produce as a by-product of their metabolism (Crosson et al., 2011) and approximately 6 percent of the energy intake converts to CH_4 but can vary between 2-12 percent depending on the diet. The second largest contributor to environmental impact from beef and dairy systems is N_2O emissions (approx. 27%; FAO, 2010) which can arise as direct emissions from organic manures or inorganic fertilizers applied to soil. In addition, indirect N_2O emissions associated with agriculture arise from volatilization of land applied manures and/or N based fertilizers, and N lost via runoff and leaching from agricultural soils (IPCC, 2006). N_2O emissions also occur upstream when mineral fertilizers are produced. Besides being a potent GHG, N_2O also contributes to ozone depletion. Carbon dioxide emissions contributing to climate change potential and acidification are caused by energy use from operations using fossil fuels and also from production of mineral fertilizers.

There are many LCA studies on beef and dairy production up to farm gate but it is rare with studies that follow the beef and milk to the consumer or grave. Post farm stages for milk and beef production has been estimated to 5-20% of the total environmental impact depending on what life cycle stages are included (Sevenster and de Jong, 2008). Energy use during the processing of milk and the packaging have major influence post farm. Transport often has minor influence but it depends on mode of transport and distances. The processing in the dairy plant results in the highest environmental impact. The separation, homogenization and pasteurization use the most energy (Nilsson and Lorentzon, 1999). However, the cleaning operations have also been identified as a major source of environmental impact (Hogaas Eide, 2003).

Packaging material is important for the environmental impact. Carton packs for UHT milk have been shown to have a significantly better environmental profile compared to HDPE and PET bottles with respect to CO_2 emission, use of fossil resources and consumption of primary energy. Recycling beverage packaging materials as a lower environmental impact than disposal in landfills or incineration plants (Meneses *et al.,* 2012). Up to 17 percent of the total life cycle emissions for energy and 18 percent for global warming potential can be contributed to the manufacturing and distribution of milk packaging consisting of paperboard carton (Hogaas Eide, 2003). The waste management of packaging can contribute significantly to the environmental impact. Packaging design is also an important factor when it comes to product loss in the consumer phase.

No information has been obtained when it comes to the environmental impact of beef and dairy at retail.

At the consumer stage the energy used to refrigerate milk and meat will result in the major environmental impact. There can be large variations in energy consumption of household refrigerators with up to 11.27 MJ/liter and year difference between the lowest and highest energy consuming refrigerator (Sonesson *et al*., 2003). To prepare the meat also demands energy. When it comes to waste in the household there are different kind of losses of milk and meat. In the milk and dairy chain approximately 11 percent of the milk is lost due to wastage (Gustavsson *et al*., 2011). For the meat chain (note, all meats) the wastage is around 20 percent. The consumer stage is the main stage were wastage occur for milk, dairy and meat products (Gustavsson *et al*., 2011).

3.2. The orange juice supply chain

During the cultivation of orange trees high fertilizer rates and large applications of manure concentrated in specific geographical areas lead to significant emissions of ammonia and nitrate, which creates eutrophication and acidification in sensitive aquatic and terrestrial environments and pollution of ground and surface water (EEA, 2009). The use of pesticides affects toxicity both for humans and the ecosystems. Eutrophication caused by agricultural practices has been identified as a serious problem in several Mediterranean countries. Specifically, Comunidad Valenciana region, which is the main orange production area in Spain, is included in the vulnerable zones to nitrate pollution from agricultural sources. Nevertheless, Murcia region and the West of Andalucía are also important orange producing areas. Moreover water depletion effect may be severe in Mediterranean area, where water scarcity is a particularly significant problem. The loss of biodiversity, changes to biotic interactions, and resource depletion in ecosystems are possible impacts of water scarcity.

The main contributor to atmospheric emissions at the processing stage is the energy consumption, mainly for thermal treatments (i.e. pasteurization, evaporation) which is usually related to the combustion in boilers of fossil fuels. Cooling and refrigerated storage of juice have also electricity requirements that implies indirect environmental impacts. Additionally, leakage of refrigerants fluids can be a direct source of GHG emissions contributing to climate change and ozone layer depletion potential. Carton based packaging dominates with 60% of total volume consumed and this type of packaging has been shown to have the lowest environmental impact concerning climate change, energy use and eutrophication when compared to glass and plastic (PET) packaging (Labouze, *et al*, 2008). For the retail and consumption steps of the orange juice value chain very little environmental information exists but it may be concluded that the impact of these steps are small. The main contributors to the environmental impact from the orange juice supply chain are fuel consumption during transport or distribution, followed by the use of fertilisers, herbicides and pesticides and consumption of fossil fuels in agriculture (Beccali *et al*, 2009). Regarding eutrophication potential more than 80% of the total impact is due to the use and production of fertilizers, pesticides and herbicides. The transport and agricultural inputs are the most influential stages of the orange juice value chain.

3.3. The salmon aquaculture supply chain

Environmental challenges in aquaculture which have been in focus are related to the potential loss of biodiversity due to the use of medicine for control of diseases and the salmon lice, and the effect of escapees on the wild salmon. The efficiency of feed and farming systems can have an impact e.g. excess feeding causes eutrophication which influences the benthic ecosystem because of nutrient enrichment of sediments and the water column. Exploitation of forage fish for feed has been a controversial issue, since this puts pressure on fish stocks and may have an impact on the seafloor. The use of soya and other crops for feed has also a considerable environmental impact because of land use changes caused by cultivation and the use of fertilizers, pesticides and water for irrigation. These issues have influenced public opinion and their perception towards aquaculture, which is sometimes a priori negative image.

The salmon production industry is concentrated in Northern Europe, Canada, and Chile and studies on LCA of aquaculture of salmon have focused on the effects of different composition of feed in these countries. While net-pen systems are most common for salmon LCA studies are also available for other rearing technologies like closed system aquaculture and other species farmed in Europe like trout, and arctic charr, as well as turbot and seabass.

Feed production is most often the major contributor to environmental impacts in conventional aquaculture systems (Ellingsen and Aanondsen, 2006; Ziegler *et al.*, 2012), while the impact of energy use is dominating in recirculation systems (Ayer and Tyedmers, 2009). Feed producers source raw materials from diverse fish, crop, and livestock sources globally, each with characteristic resource dependencies and environmental impacts. Fuel use in fishing, and feed production in aquaculture are key contributors to greenhouse gas emission (Ziegler *et al.*, 2012) and the impact of fuel use for global transport involved in sourcing feed is also of concern.

Water use is of importance especially in water scarce areas and land based systems and water use for irrigation in production of crop for feed.

Processing, packaging, transport, sale, consumption and waste management have not been commonly included in life cycle stages in seafood LCAs. This is particularly the case in aquaculture studies, while fisheries studies have often followed products through the transport stage (Ziegler *et al.*, 2012). Results from recent studies which have focused on environmental impacts of the processing and transport steps have shown that they are not significant in the overall impacts for the products when the transport is a short distance to the market within Europe. However, when considering the product type (whole fish or fillets), long distance transport and mode of transport (air or ship) the transport was found to have a large impact on the energy use and GWP and trucking is also an important contributor to GWP. LCAs that have focused on the transportation phase of chilled fish supply chains agree that sea freight is by far more environmentally friendly transportation mode than air freight and therefore it is very important to consider how food is produced and transported to the market and not only where it is produced in terms of environmental performance of products (e.g. Tyedmers *et al.,* 2010; Ingólfsdóttir *et al*., 2010).

The impacts of packaging material and chilling in transportation were the main contributors to environmental impact potentials in a seafood supply chain systems (not including the fisheries) when comparison was made between chilled and superchilled fillets (Claussen *et al.*, 2011). The environmental impact of EPS packaging has been shown to be considerable, where the main contribution is energy use in the production of EPS granulates (Ingólfsdóttir *et al*., 2010).

The impact category ozone depletion is related to the use of refrigerants. However, new refrigerants are being developed where replacement of the HCFC R22 with environmentally harmless refrigerants like ammonia is in progress. According to Ziegler *et al.*, (2012) this change would reduce the carbon footprint of fish products by up to 30% if the right substitutes were chosen.

The aquaculture sector has made considerable efforts to mitigate the environmental effects for example by changing the composition of feed and development of aqua feed, as well as improved aquaculture technologies and good practices. Governmental monitoring and legal requirements in many countries require that aquaculture farms report occurrences of sea lice, escapees, the use of medication and water quality and sediment monitoring in the areas close to the farms. This implies that data on these aspects may be readily available and currently there is an increasing awareness that monitoring data should be accessible in the public domain to enhance the transparency and help building an image of responsibility for the sector.

Table 3 shows reported values from LCA studies for four of the most common impact categories for milk, beef orange juice and salmon aquaculture. Much of the variation in the values is due to differences in goal and scope, if the studies were attributional or consequential or how the metrics were reported (especially for energy use).

Table 3. Examples of reported key values for four impact categories for milk, beef, orange juice and salmon aquaculture.

Impact category	Milk[a]	Beef[b]	Orange juice[c]	Salmon Aquaculture[d]
Climate change (kgCO_2e/kg)	0.5-1.8	20-27	84-112	1.8 – 3.3
Acidification (g SO_2e/kg)	4-7.5	101-510	0,.5-5.5	10.3 -29.7
Eutrophication (g PO^{4-}/kg)	4.8-19	59.2-169	2.5-11.3	31.8 – 74.9
Energy use (MJ/kg)	1-6.9	325-1650	764-952	26,2 – 32,1

[a]Milk: Cederberg, Flysjö and Mattson (2007), Thomassen *et al*. (2008), Meneses *et al.* (2012);
[b]Beef: Casey and Holden (2006), Cederberg *et al*. (2009), Nguyen *et al*. (2010);
[c]Orange juice: Knudsen (2010), Sanjuán (2005), Ribal (2009);
[d]Aquaculture: Pelletier and Tyedmers (2007) Ayer and Tyedmers (2009) Pelletier *et al*. (2009) Ellingsen and Aanondsen (2006) Boissy, et al. 2011.

4. Discussion

4.1. Issues not covered by LCA

There are other aspects that so far are not adequately included in LCA’s studies due to lack of consensus methodology (e.g. soil carbon dynamics) and data availability (e.g. waste percentages). As LCA is a method for assessing the environmental sustainability, socio-economic indicators (e.g. animal welfare) are typically not analyzed in LCA. The inclusion of social impacts will be considered in the SENSE project but these are typically associated with the performance of the enterprises, working conditions and employee rights.

Many of the aquaculture-related environmental impacts are not incorporated in appropriate impact categories in LCA and therefore, LCA methodology for environmental assessment will not to be sufficient to address all of the key global challenges generated from aquaculture i.e. nutrient and organic matter releases, impacts associated with provision of feed, introduction of diseases, introduction of exotic species, escapes, and changed usage of coastal areas (Samuel-Fitwi *et al*., 2012). The indicators and methods applied for chemical discharges and assessment of ecotoxicity are not well developed and their use for environmental impact assessment of aquaculture have been questioned (Ford *et al.*, 2012). Land use for crop production for feed and sea primary production - required to sustain the fish used for salmon feed and the benthic area influenced by fishing gear and methodologies have been suggested to calculate these effects to assess the impacts of feed for salmon (Ytrestöyl *et al.*, 2011). Therefore, when developing a simple tool for environmental assessment like the SENSE tool the limitation and justification for the LCA approach and the methodologies applied need to be addressed.

Some of those aspects that could be addressed in addition to using the LCA methodology are listed here:

- Amount of wastage could be used to measure efficiency in the supply chain. Food wastage reduction has been identified as an important part of EU policies over the last years.
- Feed efficiency in animal rearing can be a relevant indicator to evaluate several environmental impacts. For example, higher feed efficiency results in increased daily weight gain of cattle which means that rearing times can be reduced. This in turn can lower environmental impacts.
- The use of fish for feed is a biotic resource use for which no validated LCIA method yet exists. However, the use of forage fish and the FIFO (Fish in – Fish out ratio) could be used as a basis for an indicator.
- Carbon sequestration can be a positive effect from some systems, e.g. pasture based cattle production, while on the other hand annual cropping can lead to soil carbon emissions. Methods to measure carbon sequestration form different rearing system should be developed.
- Animal welfare is of concern and different opinions exist depending on culture and history in different countries. A production system for animals can be very efficient for the environment but result in poorer animal welfare.
- In some countries esthetical values in the countryside are discussed. Without any grazing animals the biotope will change from agricultural landscape to forests or larger monocultures of arable farming. This can have an impact on the rural communities both for inhabitants and visitors. In this case indicators for eco system services are being developed and could be considered.
- Use of antibiotics versus preventive actions to improve the animal health is very much discussed. Antibiotics can give higher and more efficient production as well as there is a risk for releases to the environment that can introduce resistance to the antibiotics. This is not integrated in LCA.
- How to assess the effects of land use change (LUC) and indirect land use change (ILUC) is very much discussed in the LCA community. There is not yet any consensus on how this should be integrated in LCA.
- Effects on biodiversity are often included in the land use impact assessment methods. It is widely recognized that it is important to assess the land use impact on biodiversity but because of the complexity of the issue there is no widely accepted methodology to use.

5. Conclusion

From the review of LCA studies the main environmental challenges for the three food supply chains have been highlighted and the most important issues can be assessed by LCA based methodologies and included in a simplified LCA web based tool. There are however environmental challenges that LCA methodology does not cover which are important to consider when assessing the environmental sustainability of a food supply chain, especially related to effects on biodiversity. Additionally there are other aspects and challenges that are not environmental, e.g. animal welfare and release of antibiotics to the environment, which are not possible to address with LCA methodology.

6. Acknowledgements

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