PARALLEL SESSIONS 3

3A / Case studies on LCA and the Agri-Food Industry (I) – natural food ingredients

Greenhouse gas emissions of organic and conventional foodstuffs in Austria

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ABSTRACT

The aim of this study was to analyse greenhouse gas emissions (GHGE) of more than 100 foodstuffs from two organic production methods in agriculture as compared to conventional farming in Austria. The system boundaries of the life-cycle study range from agriculture and its upstream supply chain to the retailer, including changes in soil organic carbon (humus) and land use change. In conclusion, all organic products showed lower GHGE per hectare but also per kg of foodstuff than comparable, conventional products. Organic dairy products resulted in 10 to 21 % lower CO_2-eq per kg of product than conventional foodstuffs, organic wheat bread 25 showed % and organic vegetables showed 10 to 35 % lower CO_2-eq per kg of product.

Keywords: organic farming, dairy, vegetables, bread, retailer, LCA, GHG

1. Introduction

The consumer's choice in quality of foodstuffs can influence greenhouse gas emissions (GHGE) from the food sector (Burdick and Waskow 2009). Organic agriculture is contradictorily discussed as a possible way to reduce GHGE (e.g. Hirschfeld *et al.* 2008). However, the mitigating effect on GHGE per kg of organic products is unclear especially under supermarket conditions. The primary goal of the present study was to compare GHGE of organic foodstuffs with conventionally grown ones. All balanced foodstuffs are retail products, processed and marketed by nationwide supermarket companies in Austria.

2. Materials & Methods

To date, 102 foodstuffs from organic and conventional agriculture, respectively, have been subject to comprehensive CO_2-balancing (product carbon footprint, PCF). The PCF includes all relevant greenhouse gases (Carbon Dioxide, CO_2; Methane, CH_4; Nitrous Oxide, N_2O) in CO_2-equivalents (CO_2-eq) according to IPCC (2006) and IPCC (2007) guidelines and is closely based upon the eco-balance guidelines ISO 14040, ISO 14044 and PAS 2050 standard. The system boundaries range from agricultural production to retailers, including the upstream supply chain (e.g., production of fertilizer, pesticides or seeds) as well as processing, packaging, storage and all transports up to and including retail (Figure 1).

Generally, GHGE from dairy products, bread and vegetable products were calculated for three different methods of agricultural production and further processing:

- Organic premium brand „Zurück zum Ursprung" (Bio-ZZU)
- Organic EU-standard, according to regulation (EC) 834/2007 (Bio-EU)

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- Conventional (Conv.)

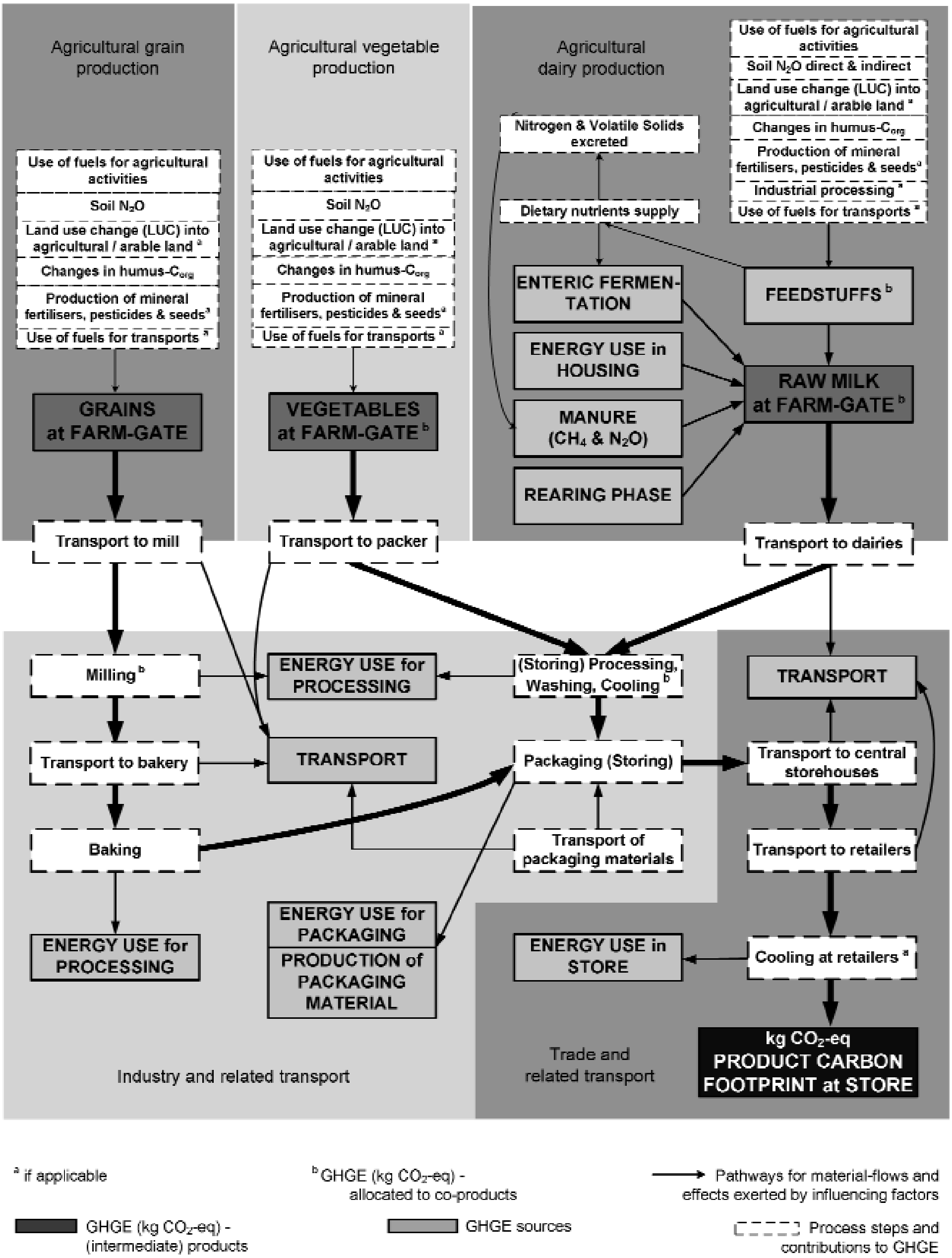

Figure 1: System boundaries for calculation of GHGE for breads vegetables and dairy products .

Modelled farms were assumed to come from the same region as the Bio-ZZU farms considered. As a result, climatic and geographical conditions for production are similar among the production systems. The conventional method of production was modelled with regard to the Austrian agrarian environmental programme.

The organic brand „Zurück zum Ursprung" belonging to the supermarket chain Hofer/Aldi Süd provided primary data, which was the basis for an Austrian-specific „supermarket standard". This includes transport, processing, packaging and distribution being used in the same manner for all three methods of production except the use/technique of partly baked frozen pastries, which is not practiced in Bio-ZZU.

Furthermore, secondary data from GEMIS (2007; v4.42 and v4.5), Ecoinvent v2.0 (Ecoinvent Centre 2007) and approximately 200 relevant national and international publications and statistics were consulted (important statistics and data bases, not further considered/described in this publication, were: BMLFUW 2005, BMLFUW 2006a, BMLFUW 2006b, BMLFUW 2007, BMLFUW 2008a, BMLFUW 2008b, Bokisch 2000, Carlsson-Kanyama and Faist 2000, Hülsbergen 2002, LCA Food DK 2002, LFI 2007, Mäder *et al.* 2002, Niggli *et al.* 2008, ÖPUL 2007, PAS2050 2008, Statistics Austria 2008).

This detailed database enabled the study to take the specific production conditions in Austria into consideration, as well as the current level of knowledge about GHGE. Unlike most PCF found in the literature, two further items land use change (LUC; GHGE-source) and changes in humus (GHGE-source or -sink) were included in the analysis based on Hörtenhuber *et al.* (2010) with minor modifications.

Why consider changes of soil organic carbon (humus)? – The sequestration of CO_2 in soils due to humus increase in organic farmland has been scientifically documented in many cases (i.e. Niggli *et al.* 2009, Fließbach *et al.* 2007) and has been incorporated in the PCF of this study in detail. A study from Bavaria (Küstermann *et al.* 2007) outlined a – for Austria relevant – point of reference: On average 400 kg CO_2 per ha and year were found to be sequestrated in organic farmland. In contrast, conventional farming leaded to a humus decrease of 202 kg CO_2 per ha and year per year (Küstermann *et al.* 2007). In both cases, CO_2 sequestration and release were assumed to proceed only a few decades but were actually related to a 100 year time-scale.

Why consider land use change (LUC)? – Austria imports large quantities of soy, used in conventional animal feed, primarily from Brazil (partially also from Argentina, AGES 2005). On the other hand, the quantity of organic soy imported from South America for organic agriculture is assumed to be small. The organic brand Bio-ZZU does not import any soy from South America. Soy cultivation in tropical regions, particularly in Brazil, contributes to the continued destruction of tropical forests. This causes, inter alia, huge CO_2-emissions, much higher than those caused by the transportation of soy from Brazil to Austria. The GHGE of this ecologically threatening land use change (LUC), contribute to 15-20% of global CO_2-emissions, more than the total emissions of global agriculture (Smith *et al.* 2007/IPCC).

3. Results

All organic products (Bio-ZZU as well as Bio-EU) display lower GHGE per hectare but also per kg of foodstuff than comparable, conventional products:

- Dairy products: 10-21 % lower CO_2-eq per kg of dairy products
- Wheat bread: 25 % lower CO_2-eq per kg of bread
- Vegetables: 10- 35 % lower CO_2-eq per kg of fresh vegetables

3.1 Dairy

Despite the lower milk output of organic cows, 15.7 % lower GHGE (CO_2-eq) per kg of fresh milk are emitted compared to conventional production (Figure 2). The lack or low proportion of soy from South America in organic feed is the main reason for the lower GHGE of organic milk. Transportation causes only a small proportion, ranging from 5 to 8 % of total GHGE in all three considered methods of production.

3.2 Wheat bread

The production of 1 kg of organic wheat bread from Bio-ZZU results in 433 g CO_2-eq and thus in around 25 % lower GHGE than comparable, conventional wheat bread (Figure 2). One kg of organic wheat bread produced following the organic EU regulation also displays 22% lower GHGE. However, the emissions caused by agriculture and baking account for the largest proportion of GHGE. The proportion of GHGE from transport is under 10 %.

Although the yield of cereals and vegetables in organic agriculture is generally one third to one half smaller than in conventional agriculture, GHGE per kg of organic products are still 10-35 % lower. An important reason for this is the lack of nitrogen (N)-mineral fertilizer, as this requires high amounts of natural gas and crude oil during the production processes. Additionally, N-mineral fertilizer use causes considerably higher N_2O-emissions than compared to the mix of organic fertilizing methods with compost and biologically fixed nitrogen by legumes. According to IPCC (2006), the latter does not emit any N_2O.

3.3 Onions

One kg of Bio-ZZU onions causes 139 g CO_2-eq per kg along the entire supply chain and results in a mitigation of 13.7 % of GHGE compared to the conventional product (Figure 2). The example of onions demonstrates the low absolute CO_2-eq-amount of most open land fresh vegetables in contrast to dairy products (see also Fritsche *et al*. 2007).

In the area of agriculture, both organic production methods for onions result in about 40% fewer GHGE than conventional production. Again, the main reason is the lack of N-mineral fertilizer and its consequences on soil-N_2O-emissions.

GHGE from transports show 57 g CO_2-eq per kg and thus exceed the small absolute GHGE from agriculture. GHGE from packaging are relatively high for vegetables (one fourth of total GHGE). The total mitigating effect of both organic production methods across the whole supply chain are 13% (Figure 2).

4. Discussion

Due to environmentally friendly cultivation and the low use of readily soluble mineral fertilizers, GHGE can be considerably reduced in/via organic agriculture. Moreover, through humus accumulation, CO_2 can be sequestrated in soil. This is also apparent in the lower GHGE per kg of product. In terms of dairy, the practice in organic agriculture of (general) disuse of soy from South America results in lower GHGE per kg of organic milk (particularly due to the absence of GHGE caused by land use change in Brazil). Hence the lower output of dairy in organic farms is more than compensated for. The results demonstrate that as a consequence of production and consumption of organic products, GHGE per capita can be reduced considerably. In Austria, these GHGE mitigation effects are presented to consumers through a packaging label on the entire organic product line of Bio-ZZU.

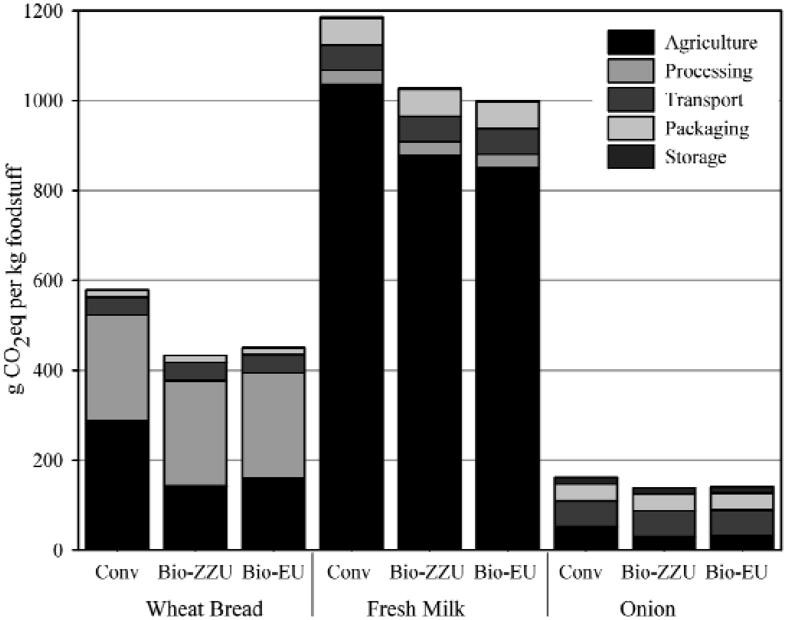

Figure 2: GHGE of each 1 kg wheat bread, fresh milk and onions for the three considered methods of production.

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Environmental impact of organic pineapple production in Ghana: a comparison of two farms using Life Cycle Assessment (LCA) approach

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ABSTRACT

This LCA analysed and compared the environmental impact of producing 1 kg of organic pineapples on farm A to 1 kg on farm B. Environmental impact categories considered were Global Warming Potential (GWP); Acidification Potential (AP); Eutrophication Potential (EP) and Erosion Potential (ErP). Results indicate that farm B was more environmentally friendly than farm A with respect to all impact categories. The environmental impacts per kg product for farm A were between 12% (GWP) and 85% (EP) higher. It is suggested that farm A could improve its environmental performance by (i) replacing its organic fertiliser imported from the Netherlands by locally produced composts and (ii) increasing its yield per hectare. More than 50 percent of the impacts in the categories GWP, AP and EP were due to energy-related emissions. Thus, energy use should be considered when designing certification schemes or assessing the environmental soundness of agriculture production systems.

Keywords: Life Cycle Assessment, eutrophication, acidification, global warming, erosion

1. Introduction

Pineapple (*Ananas comosus* (L.) Merr.) has become one of the successful alternatives to timber and cocoa which have traditionally provided most of Ghana's export earnings. Export of pineapple from Ghana begun when prices of cocoa dropped in the 1980s (Adongo, 2008) and is currently the leading sector in the non-traditional export (GEPC, 2007). Organic pineapple production in Ghana started in the twenty-first century (Adimado, 2008) and is undertaken by large company farms mainly for the export market. However, these farms contract smallholder farmers who produce to supplement the yields of the company farms.

The environmental performance of organic systems is under debate and research. Reported negative environmental effects include nitrate leaching, ammonia volatilisation and high energy use (Pretty, 1995; cited by Rigby & Caceres, 2001). Environmental, health and social aspects are intrinsically related with the particular organic approach to farming, but their evaluation may require great efforts for data collection and analysis. Up to date, there is limited information on the environmental impact of the organic pineapple industry in Ghana. This study addresses this knowledge gap and provides a basis for future studies to compare organic and conventional production systems.

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2. Materials and Methods

The study was conducted in the Eastern Region of Ghana. Farm A is located in the Asuogyaman District while Farm B is located in the Suhum Kraboa Coaltar District. Average temperature for the two districts is in the range 22-37°C and average rainfall is 1200 mm/year. Agriculture is the main occupation in these districts with pineapple as an important crop produced

Cross-sectional information was obtained through a questionnaire, interviews and observations. The questions centred on general farm characteristics, farm inputs and production practices, and harvesting and post-harvest handling. Responses were obtained from the respective directors and farm managers. The following bodies were consulted: Ministry of Food and Agriculture in Ghana, Ghana Organic Agriculture Network (GOAN), Sea-Freight Pineapple Exporters of Ghana (SPEG), Ghana Export Promotion Council (GEPC), EOSTA - the Dutch importer of organic fruits and vegetables, and Memon – a Dutch organic fertiliser production company. Secondary data from records of farmers, government agencies, organisations and literature were also used for this research.

LCA summarises and evaluates the inputs, outputs and environmental impacts of a production system throughout its life cycle (Guinée *et al.*, 2001). Its stages include: *goal and scope definition, inventory analysis, impact assessment and interpretation of results* (Baumann & Tillman, 2004).

This LCA was proposed for developing a product and marketing strategy. The intended audience were farmers, marketing companies, consumers and government agencies. It was to find out the environmental strengths and weaknesses of organic pineapple produced in Ghana. The functional unit was 1 kg of pineapples produced and the approach was "cradle-to-gate". The impact categories used were global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and erosion potential (ErP). Some activities or processes were excluded from the study due to the unavailability of relevant information and data. These include production of capital goods such as machinery, personnel related environmental problems (e.g. transportation), production and disposal of mulch material, and production of boxes for packaging.

The inventory analysis consisted of the collection of data concerning resource use, energy consumption, emissions, and products resulting from each activity in the production system. Each process was analysed in depth, and factors to be included were defined

Collected data were processed, and environmental impacts were computed. Subsequently, environmental effects were assigned to the selected impact categories and quantified in terms of a common unit for that category (characterization). Table 1 shows the impact categories, units, contributing elements and characterization factors. For erosion potential, the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965) was used. The equation is given by

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where A = estimated soil loss (t/ha per year), R = rainfall factor, K = soil susceptibility to erosion factor, LS = topography factor, C = crop management factor, and P = erosion control factor.

Finally, the results were analysed and evaluated, and conclusions and recommendations were made.

Table 1: Selected impact categories with related units, contributing elements and characterization factors

Impact Category	Unit	Contributing Elements	Characterization Factors[1]	References
GWP	kg CO_2-equivalents	CO_2 CH_4 N_2O	1 21 310	Baumann & Tillman (2004)
AP	kg SO_2-equivalents	SO_2 NH_3 NO_2	1 1.1471 0.462	Baumann & Tillman (2004)
EP	kg PO_4 -equivalents	PO_4 NO_2 NH_3	1 0.13 0.35	Baumann & Tillman (2004)

3. Results

3.1. General farm characteristics

Total land area for farm A was100 ha compared to 367.2 ha for farm B but only 30 ha and 50 ha respectively were under pineapple at the time of the research. Land preparation activities are similar for both farms but farm B uses more fuel per hectare. Irrigation was practised on farm A but not on farm B. Farm A uses NPK organic fertilizer produced in Netherlands and imported whiles farm B uses compost produced on-farm. Soil on farm A was sandy loam compared to clay loam on farm B. Yields per ha were 30 and 50 tons fresh weight for farms A and B respectively. The low yield on farm A can be associated with low N (127 kg/ha) and P (30 kg/ha) application which is below the requirements of the pineapple plant (225-350 kg N/ha and 150-225 kg P/ha, respectively; Nakasone & Paull, 1998).

3.2 Global Warming Potential

GWP results (Fig. 1a) indicates that farm A contributes 12% more to global warming than farm B. The contribution of CO_2 on farm A is comparable with that of N_2O, but N_2O contributes more than CO_2 on farm B. The results for methane are negligible. In total, producing a kilogramme of organic pineapple fruits on farm A gives 0.15 kg CO_2-eq compared to 0.13 kg CO_2-eq on farm B.

3.3. Acidification Potential (AP)

AP results (Figure 1b) indicate that farm A has a much larger impact than farm B. No substantial sources of NH_3 emission were identified. In total, the AP per kilogramme of organic pineapple are 8.63×10^{-4} kg SO_2-eq for farm A and 1.43×10^{-4} kg SO_2-eq for farm B.

3.4. Eutrophication Potential

Eutrophication results (Figure 1c) follow the same trend as AP. Farm A gives more NO_2 than farm B, while the emissions of NH_3 are negligible. The total emissions from the two farms are 9.71×10^{-6} kg PO_4-eq /kg fruits for A and 1.45×10^{-7} kg PO_4-eq /kg fruits for B.

[1] With respect to GWP the characterization factors refer to a time horizon of 100 years

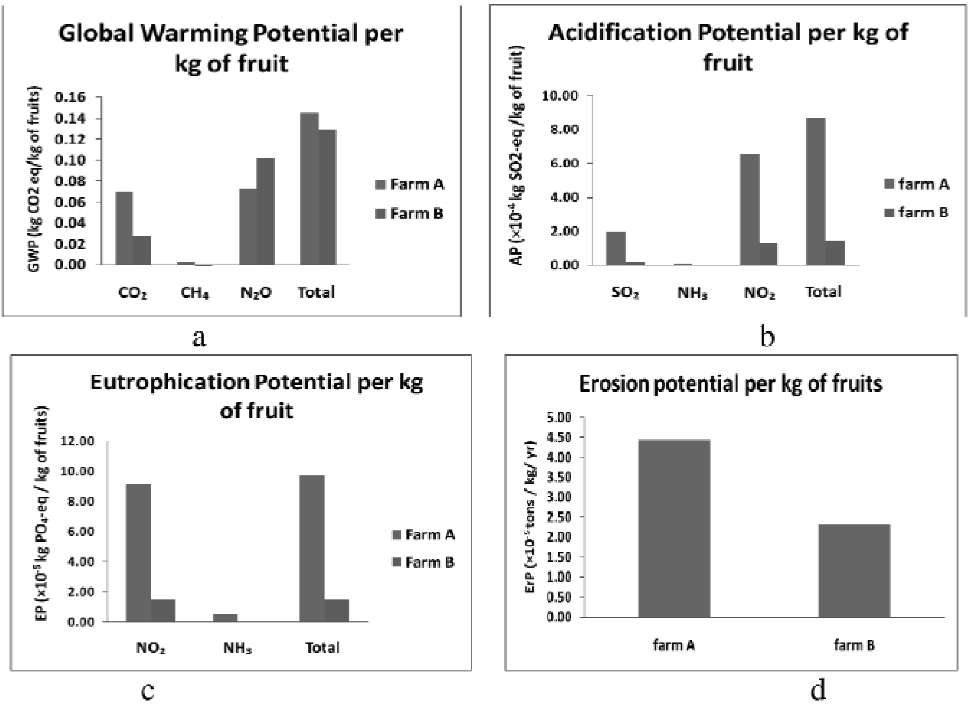

Figure 1. Results of Global Warming Potential (a), Acidification Potential (b), Eutrophication Potential (c) and Erosion Potential (d) per kilogramme of organic pineapple fruits produced.

3.5. Erosion potential

Erosion potential gives an idea on the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. On per hectare basis, farm A is estimated as losing 1.199 tons of soil/ha per year while farm B loses 1.048 tons/ha per year. The production of a kilogramme of pineapple on farm A goes with a significantly higher loss (4.44×10^{-5} tons/kg) of soil compared with farm B (2.33×10^{-5} tons/kg) (Figure 1d)

4. Discussion

4.1. Global Warming Potential

CO_2 and N_2O were mostly from energy usage which accounted for high proportions of GWP in both farms. Studies of Milà i Canals *et al.* (2006) and Dessane (2003) also confirmed energy use as a major contributor to GWP. Farm level differences were due to importation of inputs, irrigation and production of organic fertilizer by Farm A, and yield differences. N_2O emissions from soil due to organic fertilizer and compost application also accounted for substantial portions of GWP. The rate of release of N_2O is dependent on the time of application and the composition of the fertiliser (Milà i Canals *et al.*, 2006). The composition of the fertilizer may have caused some differences between the two farms but the application time is around the same period for both farms. Factors as soil type, tillage operations and weather conditions also affect the release of N_2O (Gärtner & Reinhardt, 2003).

4.2. Acidification Potential (AP)

Relatively high emissions of NO_2 and SO_2 can be explained by high fuel combustion related with mechanised farm operations and transport whereas the relatively small emissions of NH_3 are related with compost and organic fertiliser production. The difference between the two studied farms resulted from the release of SO_2 and NO_2 from the production and shipment of organic fertilizer as well as the shipment of boxes used on farm A. Changing the type of fuel can affect the level of emissions released into the air. Gärtner & Reinhardt (2003) suggested reported a higher AP for bio-diesel than petroleum diesel.

4.3. Eutrophication Potential

NO_2 is the most important component contributing to this impact and its main source is from fuel use associated with transport of inputs and outputs. The difference between the two farms came from importation of organic fertilizer and boxes as well as yield difference.

4.4. Erosion Potential (ErP)

Soil erosion can be very threatening in the tropics due to strong climatic factors, low fertilizer use and conservation activities, fragile soils and strong reliance on the quality of soil for livelihood (Cohen *et al.*, 2005). The susceptibility of a soil for erosion is characterized by the factor K in equation (1) that 'captures' the texture, permeability and structure of the soil caused the difference. Other factors like slope length and rainfall also showed some differences. Generally, the erosion potentials of the two organic farms were limited as a result of the use of plastic mulch materials and ridging across the slope. The ErP is within the range (0.9 – 6.2 ton/ha/yr) given for the savannah ecological zone of Ghana (Asiamah & Antwi, 1988) and at an acceptable low level (Webster, 2001). The values we found are lower than what Dessane (2003) reported (7.67 tons/ha/yr) for organic olive production on plains in Greece.

4.5. Processes excluded from the study

The processes excluded from this study could have changed the results. The production of machinery is a relevant component when assessing environmental impacts of agriculture. Audsley *et al.* (1997) reported that machinery production has a share in total energy consumption of 13-37% in arable systems with different degrees of mechanisation. Milà i Canals *et al.* (2006) also reported a 7-12% share of total energy consumption. The disposal of polythene mulch material by burning releases high quantities of N_2O which has a huge GWP effect since N_2O impacts 310 times as CO_2. Wrobel & Reinhardt (2003) mentioned between 400 and 1500 mg CO_2/g of plastic bag burned. No reliable estimate of personnel-related emissions due to transportation could be made within the framework of this study.

5. Conclusion

Analysis of the environmental impact of an agricultural production process is particularly difficult in developing countries where data are hard to come by. Our study can be considered a good starting point for further studies to assess the environmental impacts of alternative production chains of tropical fruits and vegetables. Our results show that in all the four considered impact categories, farm A has a higher impact than farm B. The reasons being that farm A imports more inputs than farm B, while the output per hectare from A is lower. It was concluded that more than 50 percent of GWP, AP and EP were due to energy-related emissions. Therefore, consumption of energy should be considered when designing certification schemes or assessing the environmental soundness of agriculture.

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LCA in Brazilian agriculture facing worldwide trends

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ABSTRACT

Worldwide demand for setting reliable environmental criteria for food and feed products has brought LCA methodologies to agribusiness. This paper describes the results of our search for scientific literature and governmental documents regarding the application of LCA to agricultural products worldwide, as a way to capture the state of the art in the field and to identify the trends and drivers on labeling and certification requirements in international markets. Considering the agricultural Brazilian status, it would be necessary to adapt the LCA tools to the country environmental peculiarities and technological context, regarding the capacity to answering to the current trends of application of LCA as a tool for analysis of environmental impact. In Brazil, any effort in developing specific methodologies, for both LCI and LCIA, is urgently necessary to remain among the leaders as a food and feed exporter and would be welcomed by the consumers worldwide.

Keywords: Life cycle assessment, Agribusiness, Decision-making, International trade, Food safety

1. Introduction

Worldwide demand for setting reliable environmental criteria for food and feed products has brought LCA methodologies to agribusiness as a way to support the decision making processes regarding agriculture and food production technologies. As a major exporter of food and feed products, Brazil is a country highly concerned with the environmental and food safety issues of international relevance associated to agriculture production and food processing industry. It is the largest South American country with an area of 8.514.876 km² and with a population of over 193 millions (IBGE, 2009). The country leads the world production of orange, sugarcane, coffee, and it is one of the major producer of soybean, corn and beef. Insofar, it is the eighth world exporter of agricultural commodities, like soybean, orange, corn, among others (FAO, 2009).

According to data from the MAPA (Ministry of Agriculture, Livestock and Supply, Brazil) the agribusiness accounts for 33% of Gross Domestic Product (GDP) and 42% of total Brazilian exports (MAPA, 2009). Recent studies show that the total area of crops in the country should go from 60 million hectares in 2010 to 69.7 million in 2020. Brazil will have a 36.7% increase in grain production (soybeans, corn, wheat, rice and beans), equivalent to 47.7 million tons by 2020. There is also forecast growth in the same period for meat production- 37.8% (beef, pork and chicken), sugar - 48.24% and milk - 24.45% (MAPA, 2010).

For answering the new consumer demands for certification and labeling of agricultural products it is critical to Brazilian institutions, academic and governmental ones, to watch for the trends of international markets in using the LCA methodologies and to take the needed steps in qualifying the local institutions for carrying out those analytical procedures properly.

In this paper we describe the results of our search for scientific literature and governmental documents regarding the application of LCA to agricultural products worldwide, as a way to capture the state of the art in the field and to identify the trends and drivers on labeling and certification requirements in international markets. Further we contrasted the data on LCA

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on agricultural products from worldwide sources with the published documents from Brazilian sources. We found that the world literature on the subject is yet relatively scarce and refer to a limited list of products, namely dairy ones, tomatoes, apples, potatoes, olive, wheat, rice, soybean, sugarcane, biomass, forage, maize, beef, fish, pig, poultry, and eggs. The Brazilian sources refer to coffee, orange juice, poultry, aquiculture and oyster.

2. Methods

We noticed that the analytical procedures and units used in the analysis differed accordingly to the products, and to the origins of the publications. Against this background, in this study a literature review on available and recently published life cycle assessment (LCA) studies, including last 10 years, have been analyzed. Data used in this study are obtained from different sources: scientific literature and governmental documents regarding the application of LCA to agricultural products worldwide. Further we contrasted the data on LCA on agricultural products from worldwide sources with the published documents from Brazilian sources.

The data were grouped into a summary table that addresses the evolving profession of LCA in agricultural products around the world, the main products are researched and the most important contributions for this methodology.

3. Results

Apparently, there is a long way before establishing general protocols which would take into account the local conditions while providing valuable comparisons between countries and agricultural products and production systems, useful in supporting international trade official, uni- or multilateral requirements, and consumer decision making as well. Considering the agricultural Brazilian status, it would be necessary to adapt the LCA tools to the country environmental peculiarities and technological context, regarding the capacity to answering to the current trends of application of LCA methodology as a tool for analysis of environmental impact of food and feed products. So far, there are only a few studies on adaptation of description factors related to various critical categories such as biodiversity, land use, and water use. Regarding LCI, no national database is open to access yet, neither related to agriculture, nor to other sectors of industrial activity.

In order to balance the different publications, some tables (table 1, 2, 3 and 4) were as drawn up in a concentrated form that allows a preview of the production of LCA whose variables include: the country of application, issues, functional units, major points, year and authors.

4. Conclusions

There is certainly plenty of room for local efforts in terms of promoting related advanced education, human resources training, infra-structure and institutional build up. In Brazil, any effort in developing specific methodologies, for both LCI and LCIA, is urgently necessary to remain among the leaders as a food and feed exporter and would be welcomed by the purchasers of agricultural commodities worldwide.

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Table 1: International Application of LCA Methodology in Livestock Production

Country	Issues	Functional U-nits	Major points	Year	Author (s)
Australia	water/meat	kg	agricultural systems	2010	Peters *et al*
Spain	LCA/DEA	CO2-eq/kg	LCA + DEA approach	2010	Vazquez-Rowe *et al*
New Zeland	milk	kg N/ha/year; t DM; cows/ha	comparisons with Europe	2009	Basset-Mens *et al*
Canada	grass/confinment	kg milk	environmental benefits	2009	Arsenault *et al*
Czech	dairy and manure	L, ha	environm/health impact	2008	Havlikova *et al*
Brazil / Swe-den	GHG/Land use/energy/beef	kg	energy use/ high land use	2008	Cederberg *et al*
France	dairy chain	gas/elemnt-eq	environmental impacts	2008	Kanyarushoki *et al*
Germany	meat	gas/elemnt-eq	ecology of scale theory	2008	Schlich *et al*
Europe	soybean import	gas/energy	environmental charge	2008	Baumgartner *et al*
Finland	broiler/SCM	gas-eq	grain impact	2008	Katajajuuri *et al*
Netherlands	organic eggs	gas/elemnt-eq	concentration of production	2008	Dekker *et al*
Sweden	organic/intensiv beef production	gas-eq, kg	GHGs and energy consumption	2008	Koneswaran and Nie-renberg
Netherland	convent/org milk	kg of milk	environmental performance	2008	Thomassen *et al*
Japan	beef/cows/calf	calf unit	environmental impacts	2007	Ogino *et al*
Canada	catle	various	nutrient availability	2006	Larney *et al*

Table 2: International Application of LCA Methodology in Grain, Vegetables and others

Country	Issues	Functional Units	Major poits	Year	Author (s)
Switzerld	climate/land	ton	forest/cropland	2010	Müller-Wenk and Brandão
Chile	sunflower/ rapeseed	ton	GHG reduction	2010	Iriarte *et al*
U E	rapeseed/ palm	t CO2-eq.	global warming reduction	2010	Schmidt, J.H.
Brazil	bioethanol	power force/Km	ethanol/oil utilization	2009	Luo *et al*
Canada	supply chain	various	LCAA for decision-makers	2009	Andrews *et al*
Argentina	soy biodiesel	L diesel/km	impacts	2009	Panichelli *et al*
China	biomethanol/ rice straw	kg	beneficial use	2009	Xiao *et al*
China	land/water/ bio-fuel	m3,L, m2	food supply, trade and environment	2009	Yang *et al*
Italy	Rice	various	communication	2009	Blengini and Busto
Argentina	soybean meal	kg	consequential LCA	2008	Dalgaard *et al*
Spain	fresh apples	Gas,elemnt-eq	environmental impacts	2008	Soler-Rovira and Soler-Rovira
Germany	bioenergy/ biomass	kg	organic integrated production	2007	Kagi *et al*

Table 3: International Application of LCA Methodology in Animal Products

Country	Issues	Functional Units	Major points	Year	Author (s)
Germany	footprints	gas-eq/kg	emission reduction	2009	Flachowsky and Hachenberg
Norway UK/Chile/C anada	salmon farm	MJ,gas, elemnt-eq	comparative impacts	2009	Pelletier *et al*
N.Z./U.K.	energy/ GHG/Dairy	various	production efficience	2007	Saunders and Bar-ber
New Zeald	logistics	various	production efficience	2006	Saunders *et al*
Spain	milk	L	methane occurrence	2003	Hospido *et al*

Table 4: Brazilian application of LCA Methodology

Theme	Goal	Functional Units	Results	Year	Author (s)
Poultry	stages of poultry production impacts	Ton	logistic performance of chains	2008	Silva *et al*
Oyster	stages of production analysis	Unit	water consumption, CO2 emission, solid waste	2008	Alvarenga *et al*
Frozen con-centrated o-range juice	energy use	kg	GWP related to non-renewable energy	2008	Coltro *et al*
Aquiculture	human-environmental context	undefined	enviromental licensing	2007	Eler and Millani
Green Coffee	production inventory data	MJ , kg and ha	agricultural practices	2006	Coltro *et al*

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Product category range of environmental performance for EPDs: example of Costa Rican pineapple

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ABSTRACT

A process-based farm-to-shelf LCA of fresh pineapple was conducted in cooperation with an anonymous set of farmers, packers and exporters from Costa Rica, to inform the future creation of product category rules (PCRs) for environmental products declaration (EPD) program. All impacts are presented in respect to the functional unit of 1 USDA serving of pineapple. LCIA indicators were selected to cover both the most common food-system related impacts (energy use, water depletion, global warming, human and eco-toxicity, soil erosion, eutrophication, acidification, ozone depletion). Ranges of environmental performance (RoEP) were constructed for each indicator based on variation in yields, inputs and emissions using uncertainty propagation formulas and Monte Carlo simulation. The RoEPs are used to view the impacts for an example pineapple relative to the range present in a sector, which is suggested to be used with to facilitate interpretation and encourage better management.

Keywords: range of environmental performance, LCA, fruit, serving, product category rule

1. Introduction

Large retailers and end consumers of foods make purchasing choices that create environmental consequences. These consequences differ not only by product category but within product category and they arise from complex production chains and often have regional impacts far from the point of consumption, which has been demonstrated in various studies of the environmental impacts of food systems (e.g. Jungbluth, 2002; Roy *et al.* 2008; Sim *et al.* 2007). The consequences of purchasing choices are typically not transparent to retailers and consumers. Environmental product declarations (EPDs) offer a mechanism for presenting impacts of products quantified in an LCA, in the form of an ISO-standardized Type III environmental label (ISO 14025). A significant advantage of EPDs over single product LCA is the ability to communicate the environmental performance of products in comparison to other products in the same category. Some authors (Christiansen *et al.*, 2006; Steen *et al.*, 2008) have recognized that presenting product data in the form of tables of pure performance values without normalization or comparison to other products is not readily comprehensible nor easily used for environmentally preferable purchasing. A more user-friendly way of presenting that information in EPDs is through graphical formats that permit comparison with other products.

Direct comparison of environmental performance between products within a category depends upon data that often does not exist. While LCA category-wide characterization of agricultural products is uncommon overall, it is particularly rare for agricultural products from non-OECD countries that are part of North American and European diets. A background LCA of a product category is a recommendation of the ISO 14025 standard. Although the value of the background LCA is not elaborated in ISO 14025 other than to gener-

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ally inform product category rule (PCR) making, a sector-wide LCA can potentially provide the information for comparing products within a category.

Successful non-Type III labels depicting product performance comparisons can be templates for displaying comparative product environmental performance results in EPDs. The graphical format used for depicting energy consumption information on labels for large household appliances (refrigerators, water heaters, etc.) in the US is the EnergyGuide.[1] The Energy Guide label presents a *range of comparability* for energy consumption for all products in the same category and locates the labelled appliance along this range. The EnergyGuide program, originally mandated in 1980, has undergone extensive internal and independent review and was revised in 2007 with a new label design that was better understood in studies on public perception (FTC, 2007).

A new method for presenting LCA-based environmental performance information for a food product is introduced here using the results of a farm-to-shelf LCA of fresh pineapple from Costa Rica. Costa Rica provides approximately 85% of the fresh pineapple available to consumers in the US and 71% in Europe (FAO, 2009). The scope, inventory, and impact methods of this LCA are described in detail in a manuscript in preparation. Here the methods used to characterize performance across the Costa Rican fresh pineapple sector are summarized and farm-to-shelf results of an example pineapple are presented in a format designed for EPDs in which performance is indicated in the context of the range of performance of all Costa Rican pineapples supplied to an arbitrary location in Florida.

2. Methods

2.1. Summary of LCA methods

A farm-to-shelf LCA of fresh pineapple was conducted in cooperation with an anonymous set of farmers, packers and exporters from Costa Rica. The LCA was designed to inform the development of PCRs for pineapple for a future ISO 14025 environmental product declaration program in Costa Rica, which was investigated and proposed in a prior study (Ingwersen *et al.*, 2009). Primary data was collected through questionnaires from farmers, packing plants, and exporters and through field surveys of participating farms; generic data for international transport and distribution to a retailer in Gainesville, Florida was used to model the life cycle from port-to-retailer. Data represented producers and exporters in all three primary pineapple growing regions, including conventional and organic farms from 1 to 150 ha, and covered approximately 10,000 tons of pineapple (0.6% of national production) and 540,000 boxes exported. Input data was matched with equivalent processes in Ecoinvent v2.0 or used to create new processes comprised of inputs drawn from Ecoinvent. Methods used to model emissions and impacts included: non-renewable fossil cumulative energy demand as implemented in SimaPro; product carbon footprint for global warming using the PAS 2050 standard; stress-weighted water footprint for farm and process evaporated water; PestLCI and USETox for pesticide emissions and related human toxicity and freshwater ecotoxicity; and TRACI for eutrophication, acifification, ozone depletion, and smog formation. An original impact method was incorporated for soil erosion: the RUSLE2 soil erosion model (Foster *et al.*, 2008) was parameterized for pineapple production in Costa Rica and adapted for use in LCA. The RUSLE2, PestLCI, USETox, and TRACI eutrophication models were customized for Costa Rica with regional climate, topography, soil, crop, geographic, and demographic data.

[1] See http://www1.eere.energy.gov/consumer/tips/energyguide.html for an example of an EnergyGuide label.

2.2. Product category range of environmental performance

The agricultural processes that contribute to food systems can be considered some of the most significant and variable contributors to environmental performance, due to the variability in growing conditions, management, and yield among and between farms that provide raw products for foods (Roy *et al.*, 2009). Especially in the case of international fresh produce supply chains, the transportation and distribution processes can also differ significantly in environmental performance particularly due to location and mode of storage and transport (Sim *et al.*, 2007). Capturing the range of environmental production in the fresh produce industry depends on characterizing[2] the variability in cultivation, processing, and distribution of the produce.

In order to characterize the range of environmental performance for fresh pineapple produced in Costa Rica and provided to a US consumer, the variability and uncertainty of inputs, yields and emissions from the participating farms and packing companies was combined with variability in distribution to the port of departure to generate a range for environmental performance (RoEP) in the sector. The RoEP for each environmental category was modelled by combining input, yield, and emissions variations in all life cycle stages.

The 99% confidence interval for the baseline scenario generated by Monte Carlo simulation in SimaPro of each impact category was used to create ranges of comparability of farm-to-shelf performance for Costa Rican pineapple sold at an arbitrary location in the US (Gainesville, Florida). A variation of the style used by the EnergyGuide label is used to depict the range of comparability for each environmental impact category. Performance by category for a specific fresh pineapple (pineapple X) based on individual LCA results is then located along this range of comparability for all Costa Rican fresh pineapples.

3. Results

Table 1: Ranges of environmetal performance for 1 serving* of fresh Costa Rican pineapple at a FL retailer.

No.	Category	Min (0.5%)	Max (99.5%)	Co. of Variation
1	NR fossil cumulative energy demand (MJ)	0.98	1.60	12.6%
2	Stress-weighted water footprint (L H_2O)	0.28	0.85	26.3%
3	Carbon footprint (kg CO_2-eq)	0.09	0.58	43.2%
4	Potential soil erosion (kg soil eroded)	0.0004	0.73	221.0%
5	Eutrophication potential (kg N-eq)	0.001	0.01	77.3%
6	Freshwater ecotoxicity (potentially affected fraction/m^3/day)	0.06	0.67	52.6%
7	Human toxicity (cases)	5.31E-11	5.82E-10	46.5%
8	Ozone depletion (kg CFC-11-eq.)	7.19E-09	2.24E-08	23.2%
9	Acidification (H+ moles-eq.)	0.032	0.051	11.1%
10	Smog formation (kg NOx-eq.)	0.0004	0.0008	13.9%

*1 serving pineapple = 165 g edible fruit (USDA, 2009); 1 kg pineapple = 3.07 servings

[2] Here and elsewhere 'characterization' is used in the conventional English language (syn: to describe) and does not refer to the LCA-specific use of the term defined in ISO 14040.

The ranges for each category of farm-to-shelf environmental performance for pineapple at a retailer in Florida are presented in Table 1. For impacts dependent on the diversity of conditions present in Costa Rican pineapple fields and the regional environment, such as soil erosions and eutrophication, the range of comparability is relatively large in comparison with other impacts for which management and regional conditions are less variable (e.g. acidification and smog formation). A graphic presentation of the environmental performance of a pineapple from one of the participating pineapple producers is presented in Figure 1.

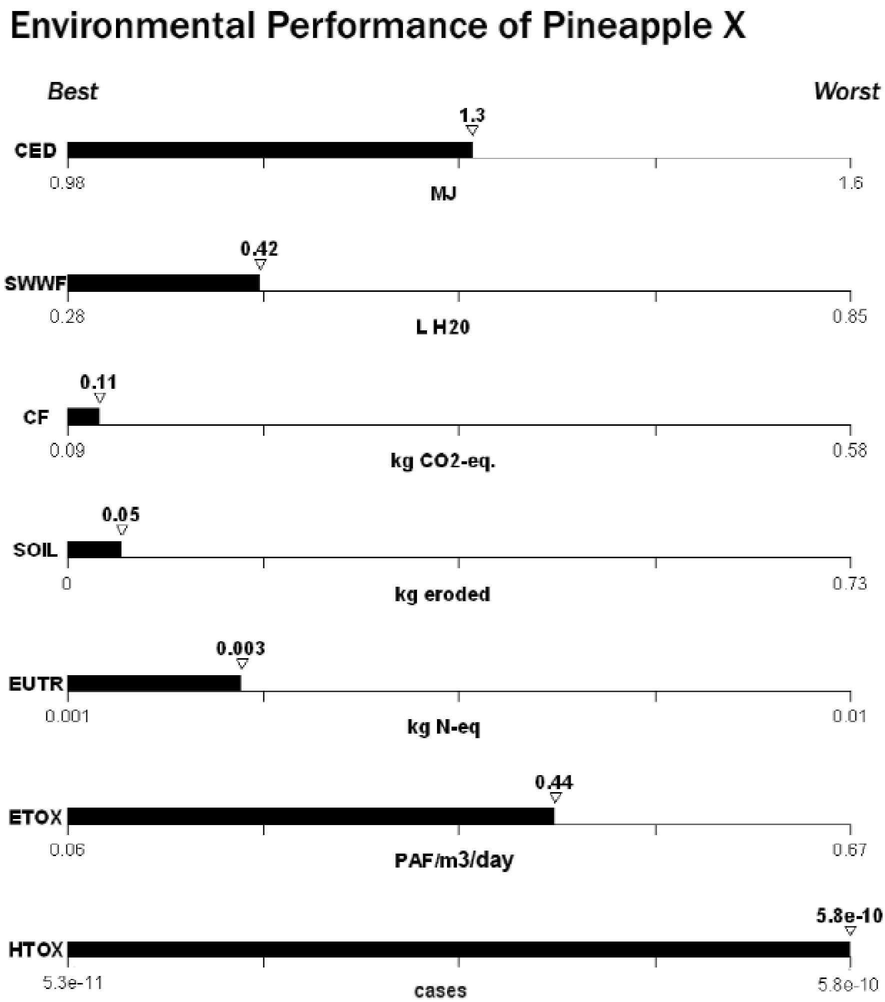

Figure 1: Example label showing comparative farm-to-shelf environmental performance of a 1 serving of pineapple X at a retailer in Florida. CED = NR fossil cumulative energy demand; SWWF = Stress-weighted water footprint; CF = carbon footprint; SOIL = Potential soil erosion; EUTR = Eutrophication potential; ETOX = Freshwater ecotoxicity; HTOX = Human toxicity.

4. Discussion

Characterizing the range of environmental performance for a food product derived from a large set of farms using distinct management practices and spread across different geographic regions and countries presents challenges for LCA. Product characterization has typically been represented with average performance based on aggregated data, with variation represented only qualitatively (e.g. Ecoinvent data). Such aggregation does not permit comparison of products against the full range of performance for a product category, or comparison of products with those in other categories that serve the same function. Here a method is presented to characterize the range of LCA-based environmental performance for a fruit product, using a set of representative primary data.

A selected set of the most environmentally relevant categories for fresh pineapple are presented in Figure 1. Global scale impacts including energy use and carbon footprint are assumed relevant for all products and the remainder are particularly relevant for agricultural products. Combining the different categories of performance was not done here, as the indicators were individually selected and/or designed to quantify impacts of this product system and weighting factors do not exist to combine these categories.

The ranges resulting from this method are statistical approximations of performance for fresh pineapple from Costa Rica and not based on the outcomes of individual LCAs of each pineapple in the sector, which would be impractical to expect given the diversity of actors in the production chain, beginning with thousands of farms in Costa Rica. The use of the 99% confidence interval of the distribution resulting from a Monte Carlo analysis can be considered a conservative estimate of the performance range. Nevertheless the impact range produced in the Monte Carlo depends upon a complex set of factors, including emissions of other pesticides, downstream production efficiency (e.g. factors effecting the pineapples per box, portions per pineapple, etc.) among others, and as a consequence, the combination of these factors may result in confidence intervals that do not represent all products in the category. In the case of pineapple X, human toxicity was slightly greater that the maximum value in the range, thus the range was expanded with the new maximum being the human toxicity value of pineapple X.

Because the function defined in this study is to provide the consumer with a serving a fruit,[3] performance is reported in relation to other fresh pineapple from Costa Rica using the functional unit of 1 serving (Figure 1). Although Costa Rican pineapple dominates fresh pineapple supply in the US and EU, pineapples of other origin were not included in the range of comparability, but, in principle, should be included in a range that represents pineapples available to consumers. Such information would permit large produce buyers and/or end consumers in the US and EU to see where one pineapple falls in comparison with the performance of other pineapples.

Christiansen *et al.* (2006) recommend EPDs also show an additional performance comparison (beyond the same product category) with an alternative purchase that would reflect consequences the choice in a wider context, suggesting comparison against an equal monetary amount for another consumer good. More relevant for food items would be a comparison against a wider groups of foods that serve the same nutritional function. In this case that would translate to a presentation of a pineapple along a range of comparability for all products that provide a serving of fruit, using a selection of impact indicators relevant to all those products. This range of comparability would capture performance of other fresh fruits, dried fruits, frozen fruits, fruit juices, and other foods products providing this function. Thus buyers and consumers would be able to contrast a fruit product against all alternative fruit products.

[3] The USDA recommends at least 2 servings of fruit per person per day. Any foods that provide a fruit serving have the same function according to this definition.

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Evaluating life cycle impacts of soybean production

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ABSTRACT

Consumers and governments have express interest in understanding the life cycle impacts of the agri-food sector. The United Soybean Board (USB) which represents soybean farmers in United States has responded to that interest by commissioning Omni Tech International, Ltd. and Four Elements Consulting LLC to update the existing life cycle data associated with growing soybeans and converting them into food and industrial products. A Life Cycle Assessment (LCA) was then performed to measure environmental impacts. The main objective of this study was to provide "cradle-to-gate" life cycle information to life cycle practitioners who wish to conduct modeling of downstream soy food and industrial products and possibly compare those results and impacts with those of other food and industrial products. To ensure credibility of the data and results, the study was peer reviewed by an international panel. This paper describes key findings and how the study was conducted.

Keywords: Life Cycle Assessment, LCA, soy meal, soybean oil, biobased

1. Introduction and objectives

The past decade has witnessed an increased consumer and government interest in understanding the life cycle impacts of the agri-food sector. The United Soybean Board (USB) which represents soybean farmers in the United States has responded to that interest by commissioning Omni Tech International, Ltd. and Four Elements Consulting, LLC, to conduct a comprehensive study to update the life cycle data associated with growing soybeans and converting them into food and industrial products. This data was then subjected to a life cycle assessment (LCA) to measure environmental impacts. A main objective of this study was to provide "cradle-to-gate" life cycle information available to LCA practitioners who wish to conduct modeling of downstream soy food and industrial products and possibly compare those results and impacts with those of other food and industrial products. To ensure credibility and objectivity of the data and results, this study was peer reviewed by an international panel to ensure conformance with ISO 14040 and 14044 (ISO 2006a and 2006b) requirements.

2. System Boundaries and Modeling

The unit processes included in the modeling for this paper are soybean growing/ agriculture, crushing into crude soybean oil and meal, and refining into refined soy oil feedstock, as shown in the following figure.

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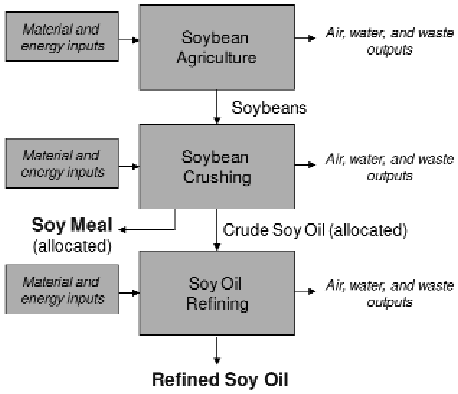

Figure 1: System Boundaries: Cradle-to-Gate of Soy Feedstocks

2.1. Accounting for Carbon Sequestration

The sequestration of carbon has been taken into account since the system is cradle-to-gate, and downstream fate of that embedded carbon (i.e., potential biobased carbon neutrality) is out of the system boundaries. The amount of carbon uptake has been based directly on the quantity of biomass carbon in the feedstocks, as shown in the table below.

Table 1: Biobased Carbon Content in (1000 kg per each output)

Product	**% Carbon** (calculated or estimated by Omni Tech)	**Biomass carbon (kg)**	**Corresponding biomass CO2 (kg)**
Meal	48%	480	1760
Refined oil	80.6%	806	2955

3. Data Updates and Sources

To conduct a credible LCA, it is critical to use current mass balance data on raw materials, processing aids and energy used to produce a product since this is the platform for LCA modeling and results generation. In the case of soybean agriculture and processing, existing LCI databases contained information that was, in many cases, more than 10 years old and/or used default data based on hypothetical assumptions. For this update, thanks to collaboration with industry stakeholders, it was possible to obtain actual operating data for producing refined soybean oil and soy meal. Updated information is provided in the next sections; the data, along with more detailed descriptions, can be found at www.soybiobased.org.

3.1. Soybean agriculture

Data for the agricultural processes is based on average U.S. soybean production practices in the U.S., and data are based mainly on the years 2000 through 2007. Soybean agriculture data includes use of farm tractors; irrigation; fertilizer inputs and associated air emissions and water effluents; agrichemical inputs and associated air emissions and water effluents; other energy and material inputs including seedlings; and transportation of the material inputs to the farm. Data was updated from 1990's soybean growing data in National Renewable Energy Laboratory's (NREL's) LCA study on biodiesel use in an urban bus, which was updated by Omni Tech International and other experts in 2003.

3.2. Soybean processing

The data for soybean processing were collected and aggregated by the US-based National Oilseed Processors Association (NOPA, 2009). The resulting data reflect information on 50 of the 60 soybean processing plants that NOPA represents, and data received were provided as full-facility inputs and outputs on a per-soybean input basis, and cover soybean processing via solvent extraction through crude oil degumming. Transportation of materials to the crushing facility has been accounted for.

The products from soybean crushing/processing include degummed soy oil and soybean meal. Since there are multiple product outputs (or co-products), the process inputs and outputs have to be divided or allocated between all products in some way to fairly assign environmental impacts to both products. Allocation based on the mass of the products was used for the baseline results, and a sensitivity analysis based on economic value was performed (economic value as of December 2008). It should be noted that this data on crushing and processing, made public, is presented as unallocated data, so that the LCA practitioner is able to decide upon an allocation rule appropriate for his/her study. Allocation is discussed later in this paper.

3.3. Crude Soy Oil Refining

All data except energy is based on an NREL study on biodiesel production since it contains information on the alkaline refining processes occurring prior to transesterification into biodiesel (Sheehan *et al.*, 1998). Typical soy oil refining electrical and steam energy were provided by a large agro-processor in the U.S.[1] For the economic allocation, the oil was given an allocation percentage of 100 since soap stock has a minimal value, especially relative to oil. Transportation of materials to the refining facility has been accounted for.

3.4. Sources of data in LCA model

The LCA model, using the updated data, was built in SimaPro 7, a commercially available LCA software product (Pre Consultants, 2006). Data for energy and transportation came from the U.S. LCI database (National Renewable Energy Laboratory). Data for materials are from secondary sources from the following databases (in order of preference and data availability): the U.S. LCI database, the EcoInvent database (Swiss Centre for Life Cycle Inventories), and the SimaPro database which contains data sets with varying levels of data quality in terms of representativeness of technology, age of data, and geography of the processes.

4. Allocation

Mass allocation was used as the main allocation rule for the baseline analysis and economic allocation was used to assess the sensitivity of this modeling decision, with the following factors for each:

[1] Company name not released for confidentiality purposes.

Table 2: Soy Oil and Meal Economic Data

	Portion from 1 kg soybean (kg)	**Mass allocation**	**Dec. 2008 economic value ($/kg)**	**Total in system ($)**	**Economic allocation**
Crude oil	0.195	**19.5%**	$0.78	$0.15	**38%**
Meal	0.805	**80.5%**	$0.30	$0.24	**62%**

The debate as to which is the best allocation decision for soy-based products will continue but factors favoring mass allocation include:

- The physical breakdown of soybeans into oil and meal is a relatively constant percentage while the economic value of oil and meal can vary significantly due to market conditions; and
- If using economic allocation, LCA results may have to be updated fairly often to capture current market conditions which may not be feasible for most organizations. Results for a mass-based allocation are not subject to these economic market fluctuations.

System expansion was also evaluated for its feasibility, but results were negative in many cases so were not intuitive for the user. Another feasible choice that was not used for this study is allocation based on energy content of the co-products, which was used by the European Commission in its Renewable Energy Directive that incorporates minimum GHG emission targets for biofuels (EU, 2009). While this current study did not evaluate the systems based on energy content, the allocation percentages were similar to the economic allocation (crude soybean oil: 36% for energy allocation; 38% for economic allocation). In fact, because the economic allocation allocates a higher percentage relative to the energy allocation for crude soy oil, results for the economic allocation are actually a worse-case scenario for the refined soy oil. For more discussion on this topic, the reader is encouraged to see the published main report.

5. Results and discussion

The Building for Environmental and Economic Sustainability (BEES) impact methodology was used because it was appropriate for this U.S.-based study: the BEES framework and impact categories are used for U.S. government programs such as the U.S. Department of Agriculture's BioPreferred program. BEES also has a recognized and accepted methodology and its comprehensive set of impacts meet ISO's requirements for a range of impact categories. The following table presents the cradle to gate impacts of soybean agriculture and an analysis of its components.

Table 3: Soybean Production and Contribution Analysis (1000 kg output)

Impact category	**Unit**	**Total Soybean Production**	**Direct Impacts %**	**Upstream Materials Prod'n %**	**Energy %**	**Transportation %**
Global warming potential	kg CO2 eq	-1.2 E+03	87%	8.5%	4%	0.2%
Acidification Potential	milmole H+eq	9.4 E+04	21%	36%	42%	1%
Eutrophication Potential	kg N eq	2.9 E+00	15%	83%	1%	0%
Water Intake	liters	5.1 E+04	100%	0%	0%	0%
Criteria Air Pollutants	microDALYs	2.5 E+01	3%	61%	35%	1%
Smog Formation Potential	g NOx eq	2.0 E+03	25%	13%	60%	2%
Total Fuel Energy	MJ	1.8 E+03	0%	44%	54%	3%
Note: 0% means less than 0.1%, and percentages may not add to 100 due to rounding.						

The GWP result is a net negative. As mentioned previously, the CO2 uptake due to growing soybeans has been accounted for. For soybean production, the benefit of the carbon sequestration more than offsets the CO2 from burning fossil fuels. 87% of the GWP is part of the "direct impacts" component which includes uptake of carbon dioxide and N2O release on the field. The water intake value represents the water use for the irrigated land averaged over all the hectares planted. Use of energy and upstream materials account for most of the other impact categories, and transporting fertilizers and agrochemicals to the field have very little influence on the final results.

The next tables present the cradle-to-gate results for soy meal and refined soy oil in terms of the percentage contribution of the major unit processes defined above.

Table 4: Cradle-to-Gate Results for Meal Production (1000 kg output)

Impact category	Unit	Total Cradle-to-Gate Soy Meal Production	Soybean Agriculture	Crushing
Global warming potential	kg CO2 eq	-1.3 E+03	90%	10%
Acidification Potential	milmole H+eq	1.6 E+05	59%	41%
Eutrophication Potential	kg N eq	3.0 E+00	99%	1%
Water Intake	liters	5.2 E+04	99%	1%
Criteria Air Pollutants	microDALYs	4.6 E+01	54%	46%
Smog Formation Potential	g NOx eq	2.8 E+03	74%	26%
Total Fuel Energy	MJ	3.9 E+03	47%	53%

Table 5: Cradle-to-Gate Results for Refined Soy Oil Production (1000 kg output)

Impact category	Unit	Total Cradle-to-Gate Refined Soy Oil Production	Soybean Agriculture	Crushing	Refining
Global warming potential	kg CO2 eq	-2.5 E+03	94%	6%	0.4%
Acidification Potential	milmole H+eq	1.7 E+05	58%	40%	3%
Eutrophication Potential	kg N eq	3.1 E+00	99%	1%	0.05%
Fossil Fuel Depletion	MJ Surplus	4.2 E+02	49%	47%	4%
Water Intake	liters	5.4 E+04	99%	1%	0.3%
Criteria Air Pollutants	microDALYs	4.9 E+01	53%	44%	3%
Ozone Depletion Potential	kg CFC-11 eq	1.9 E-06	44%	56%	0.3%
Smog Formation Potential	g NOx eq	3.0 E+03	73%	25%	1%
Total Fuel Energy	MJ	4.2 E+03	45%	51%	4%

As shown in these two tables, the agriculture impacts are for the most part the largest. The results for the economic sensitivity analysis are as follows (see USB, 2010):

For meal, in all categories but GWP, the results using the economic allocation decrease since in the mass allocation, the meal co-product accounted for nearly 80% of the allocation (including crushing and upstream soybean agriculture). The economic allocation brings this value down to almost 60%. The GWP category is higher because much of the GWP value stems from the carbon embedded in the product. The allocation change only affects the non-biomass CO2 impacts.

For oil, in all categories but GWP, the results using the economic allocation increase. This makes sense, since the crushing and soybean production impacts are nearly doubled, from 20% allocated to nearly 40%. The GWP category is lower, as much of the GWP value stems from the carbon embedded in the product. The allocation change only affects the non-biomass CO2 impacts.

IMPACT 2002 methodology was used as an alternate method to assess the results. The European-based methodology is more health focused than BEES and uses different characterization factors, thus the two methods cannot be directly compared. However, despite these differences, the sensitivity result outcomes were similar for both the mass and economic allocation comparisons. See complete study for specific results.

6. Conclusions

This updated life cycle inventory information should be a great aid to anyone wishing to perform an LCA on a product made with a soybean derived ingredient or to compare environmental impacts with another crop. The individual life cycle stage data for soybeans and their downstream feedstock products are largely based on actual operations data rather than theoretical assumptions, as was the case with the previous data. The updated environmental profile for the soybean production and processing stages has shown overall improvement when compared to the inventory data previously available. The favorable global warming potential impact of raising soybeans remains a positive factor for considering soybean oil or meal derivatives as a feedstock for food or industrial products.

It is important to mention to the reader that the *application* of the soy products in this paper has not been evaluated. These results are cradle-to-gate, so depending on the use and end of life phases of the products, results would change. This aspect was beyond the scope of this current work. Also, the reader should be reminded that allocation choice also may affect the outcome of the results, so careful consideration should be paid to this modeling aspect. That said, the allocation decisions and methodology used for this study are being applied to other crops. But since co-product modeling has always been controversial, the reader is cautioned to always carefully consider the co-products and their fate so that allocation is done properly. Examples of items to consider include the fate of crop residue, the value (both economic and nutritional content) of the meal, and other potential crop outputs (i.e., corn stover as a biofuel).

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Simplified Life Cycle Assessment of cod fishing by Basque fleet

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ABSTRAC

Cod fishery is an important activity in the Basque Country. During 2007 about 500 tonnes of cod were caught, which represents 5% of the total caught value in the Basque Country. But cod is overexploited specie, mainly due to the high TACs set by the European Commission which exceeds the recommendations of ICES. Life Cycle Analysis had been performed to analyse the impact of cod fishing, which includes the main inputs and outputs of the system, taking into account fuel consumption, anti-fouling paints, leaching of cooper and spill of evisceration processes, stock exploitation rate, among others. As expected, the impact analysis shows that fuel consumption is the most significant stage, so more features are planned aimed at reducing that consumption. However, it was also conducted a feasibility analysis of cod stocks.

Keywords: LCA, seafood, fisheries, cod, environmental impacts

1. Introduction

Cod is one of the most representative species of international fisheries, especially in countries like Norway. In Spain, the fishing quota (TAC = Total Allowable Catch) in 2007 was 14,000 tonnes (4.14% of total) for cod in the Barents Sea. With regard to the Autonomous Community of the Basque Country, cod is a fish traditionally highly valued by consumers and is part of the typical cuisine in many dishes. Catches of cod by the Basque fleet, although not very numerous, represent, approximately, 5% of the economic value of the total catch.

Currently, there are 3 ships catching cod in the fleet of Pasajes' Port. Fishing takes place in the Arctic, in ICES areas I and II (IIa and IIb). According to the ICES recommendation, biological reference points have been introduced for safeguarding a sustainable management of resources in this area, restricting the number of catches. However, in 11 of the last 14 years the European Commission has set higher TACs than those recommended by ICES. In 2007, ICES has recommended 309,000 tonnes, but the Russian-Norwegian Committee which regulates fishing in the Barents Sea area, has established a TAC on 424,000 tonne.

Therefore, in recent years, cod stocks have suffered a severe decline in the coast of Norway where, traditionally, most of the catches of the Basque fleet are carried out. In fact, the Norwegian Institute of Marine Research believes that the situation is critical and the cod fishing should be closed or limited to allow recovery.

This overfishing is due to the introduction and proliferation of equipment and technology that increased the volume of landed fish. Besides overexploitation, fishing activity contributes to the environmental impact with fuel consumption (Hospido and Tyedmers, 2005).

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To face this problem, the main objective of this study was to define the stages with greatest environmental impact of the cod fishing, and propose actions for the reduction of these impacts.

2. Methodology

2.1 Functional Unit

It has been established 1 tonne of gutted fresh cod ready for distribution as functional unit.

2.2 Scope and system description

Figure 1 describes the system boundaries assumed in this study. Main inputs and output are described below.

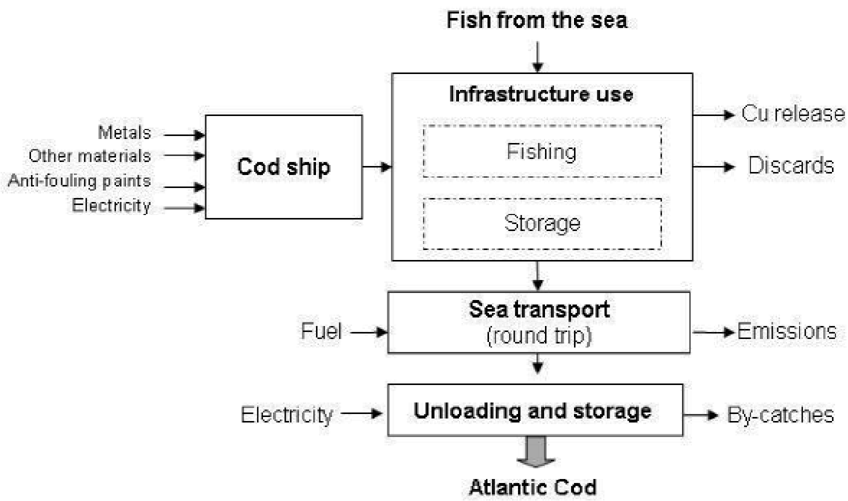

Figure 1: System boundaries

Main inputs of the system are:

- Ship, including steel, iron, wood, plastics, anti-fouling paints and energy needed for the manufacture.
- Cod fish and by catches
- Fuel requirements for the trip and for the auxiliary tasks
- Cod storage: Hoisting and cooling in the port

Main outputs are:

- Spill of N, P and COD from evisceration processes
- Leaching of copper due anti-fouling paints.
- Combustion gases
- Fish discards

The following aspects were not considered into the system:

- Fishing gears: nets, hooks and other utensils.
- Cardboard boxes necessary for the storage of cod on board
- Infrastructure required for storage.

2.3 Life Cycle Inventory

The main assumptions taken are the following (table 1):

The trip: The distance travelled during the work of fishing is around 8,000 miles along, and 4,000 miles round trip, for a total of about 12,000 miles. The trip takes place in summer (May to August) and lasts about 3 months (16 days of round trip, plus 2 ½ months of fishing activity). The total fuel consumption is 5Tn per day. The 90% of fuel is used for transport and the remaining 10% approx. is used for auxiliary tasks, such as maintenance of cold freezing tunnels.

For land use data, information obtained in the study by SINTEF (Ellingsen and Aanodsen, 2006) has been used, which estimates an occupation of 384 m^2 trawl / cod kg.

The ship: The average length of vessels is about 56m and lifespan is around 25 years. The ships have a tunnel freezer system and process the cod on board. Remains of viscera and trimmings are thrown into the sea.

Antifouling paints are used in order to prevent the growth of flora and fauna in the hull. However, substances such as copper, which prevent the growth, are causing considerable marine pollution. The cooper leaching depends on the content of cooper into the paints, type of binder, type of sea water, type of ship, speed, thickness of the layer of paint, etc. (Schiff et al., 2003) Initially used paints were based on tin (TBT - tributyltin), but their high polluting effect forced its ban in 1990. The diffusion rate of copper in the paint has been calculated with the following equation (*Pinturas Nervión* enterprise, no date)

- Copper content in paint of 50% and a thickness of 300 microns, with a diffusion rate of 10 µg Cu cm^2 d^{-1} for 3 months of travel.

The cod: Within the subsystem "Fish from the sea", by-catches and discards have been also taken into account.

- By-catches or non-target species, account for about 5% of Pasajes fleet (AZTI-Tecnalia, 2008) and are mainly composed of haddock, black halibut, norway haddock, wolf fish, american flounder or coalfish. Therefore, for an average catch of 500 tons / trip, the 95% (475 tons) correspond to the cod, while the other remaining 25Tm correspond to other species.
- Discards are approximately 3% and correspond to non-commercial species. These catches are returned to the sea along with the remains of evisceration.
- Viscera are on average 10% of fished cod (AZTI, 2008)

Landing: Upon reaching port, manually classified cod is prepared in boxes and hauled to port by crane. The download time may last up to 5 working days (8 h / day). Then, the cod is stored refrigerated (0 ° to 5 ° C) in the same port.

Considering all, the main flows of the inputs and outputs of the system are the followings:

Table 1: Data introduced to SimaPro 7.1.

Product		
Atlantic cod (fished by Basque fleet)	**1**	**Tm**
Assembly		
Ship (construction and maintenance)	8,42E-05	p
Fish from the sea	1,1	T
Processes		
Electricity	14,2	kwh
Fuel Consumption	947	L

2.4 Allocation rules:

All the inputs and outputs are allocated by mass, 95% to the cod and 5% to y-catches.

2.5 Data Quality

The data on fisheries were obtained from internal data, supplied by the Marine Research Division of AZTI-Tecnalia and a ship-owner dedicated to cod fishing. The energy data required for the manufacture of a fishing vessel have been estimated from the values given in the database Ecoinvent for other ships of the same or similar magnitude.

3. Life cycle impact assessment

The method used for the impact assessment is "CML 2 baseline 2000 v2.04". As expected, the LCA results performed with the software SimaPro 7.1. showed that the use of fuel in the boat is the aspect of fishing which produces the greatest impact (figure 2). The main stages of this process are production of diesel, which impacts mostly in abiotic depletion and ozone layer depletion; and air emissions of diesel combustion, which affect mostly in acidification, global warming and eutrophication.

Regarding to the "cod fishing system" showed in figure 1, it should be mentioned that the main cause of terrestrial and freshwater aquatic ecotoxicity is the steel production for the ship construction. For marine aquatic toxicity, the diesel extraction is the most important stage, however; the release of copper from antifouling paints has an important impact (25%). Nevertheless, toxicity categorization in CML methodology is highly questioned because it is not complete, and ignores many substances, such as dioxins (Ziegler *et al.*, 2003)

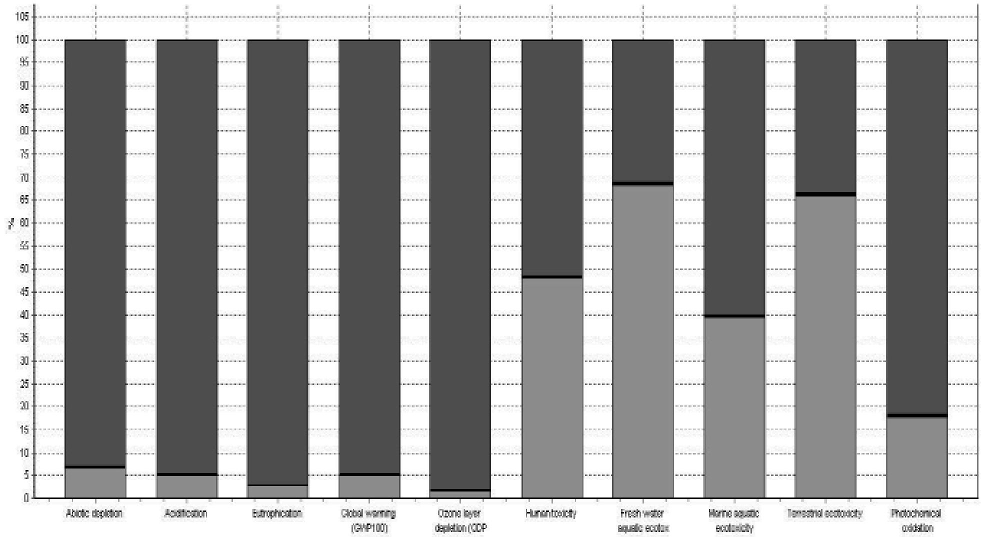

Figure 2: Impact assessment of the life cycle of cod fishing. Legend: Grey: "Cod fishing system" which included the materials needed for the ship construction and maintenance; Black: electricity requirement and, Dark Grey: Fuel consumption.

Concerning the impact of the removal of individuals from their environment, up to now there is no agreed methodology for measuring this impact with the LCA methodology. Therefore, it is necessary to develop a new impact category to assess the effect of fishing in the marine environment, or, at least, take into account the contribution of fishing to the status of the target stocks by other current fishing indicators.

To face this challenge, the Atlantic **cod stock exploitation** rate has been selected as additional environmental impact category for the fishing process. Recruitment data, landings and total biomass of cod in the last 20 years were selected among the existing fishing pressure indicators (ICES, 2007)

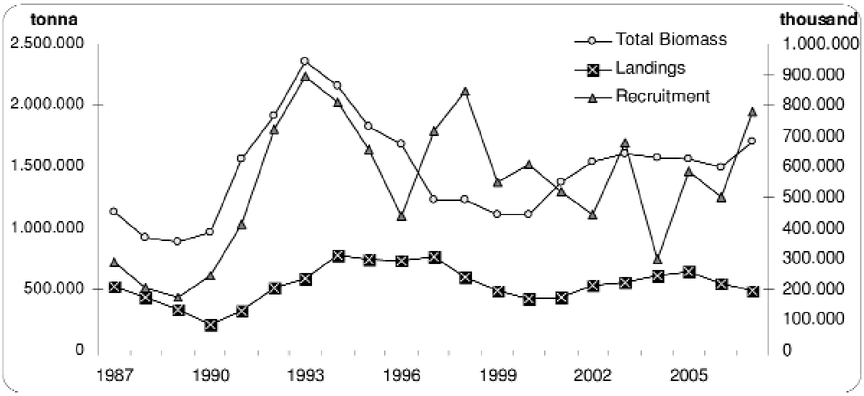

Figure 3: Fluctuation of recruitment (thousand), total biomass (tonne) and landings (tonne)

The evaluation results have shown that the cod stock is within safe biological limits, while fishing mortality is above the reference limits of effort (figure 3). This means that although the population is above the minimum of viable biomass and, therefore, at safe levels, the effort exerted on the population is not sustainable in the long term, and is far from guaranteeing the maximum sustainable yield (AZTI - Tecnalia, 2008).

Additionally, there is no clear consensus on the environmental effect of seafloor use. Some researches (Fossa, 2002) estimated that trawling and dredging the seabed are responsible for up to 50% of the damage caused to coral reefs in the Northeast Atlantic. Some researchers compared the effect of acid rain on deforestation. However, Huse *et a.l* (2002) concluded in a research made in a marine protected area of Bear Island in the Barents Sea in 2000 and 2001, that changes in biodiversity attributed to the fishing gears are generally low, especially in areas exposed to natural stress waves, currents or changes in levels of eutrophication and salinity.

4. Discussion and conclusions

Once the fuel consumption has been identified as the most significant stages of the life cycle of the cod fishery, several potential improvements were proposed based on existing literature. These proposed improvements can be: Optimization of the fuel use efficiency by improving the performance of engines, improving the design of the hull and propeller, reducing fishing nets resistance, optimizing routes and fuel management or using renewable energy.

However, overexploitation and fish discard should be faced by:

– Diversification of target species to reduce the pressure on overexploited species.
– Valorisation of discards by using it as novel food products and animal feed.

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