POSTER SESSION D
Animal production

Life cycle assessment of Australian egg production

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ABSTRACT

The Australian government and community are demanding more information on the environmental impacts of food products produced in Australia. Few data are available on the environmental and resource efficiency parameters (water use, energy use, and greenhouse gas emissions, or global warming potential – GWP) of egg production. Life Cycle Assessment was used to collate preliminary information on these for three Australian egg production supply chains, with the focus being at the farm level. All results for layer hens are presented as a capacity based indicator (hen place per year). Preliminary blue water use for egg production was in the order of 77 to 114 L/hen/yr, with drinking water contributing 56 to 79% of water use. Preliminary energy related GWP ranged from 1.8 – 3.1 kg CO_2-e/hen/yr (farm only), with manure handling, storage and application ranging from 4.3 – 4.7 CO_2-e/hen/yr. A streamlined assessment for an aggregated full supply chain showed emissions were in the order of 1.6 kg CO_2-e / kg eggs.

Keywords: Eggs, Layer, GHG, Water

1. Introduction

The egg industry in Australia is predominantly characterised by intensive, modern highly efficient production systems. With on-going improvements to production efficiency in the industry, it is expected that egg production will also be environmentally efficient, though to date few research projects have investigated the environmental performance of the whole supply chain. The industry has set environmental priorities to quantify and improve performance in the key areas of water usage, primary energy (PE) usage and greenhouse gas (GHG) emission intensity, reported as global warming potential – GWP. These areas are in line with national environmental priorities and are also of interest to the general public. The Australian egg industry has commissioned a project to address the issues of resource usage and impacts based on data from commercial production systems. This paper reports on preliminary results of a rapid Life Cycle Assessment (LCA) to 'footprint' greenhouse emissions and water and energy usage associated with Australian egg production.

Life cycle assessments in Australian agriculture have been completed for a number of industries over the past 10 years, including major studies for dairy (Lundie *et al.*, 2003), red meat (Peters *et al.*, 2010a, Peters *et al.*, 2010b), grains (wheat, barley, canola - Narayanaswamy *et al.*, 2004), (maize - Beer *et al.*, 2005) and pork (Wiedemann *et al.*, 2010a). However, LCA studies of eggs and egg products in the literature are limited. A literature review revealed only three detailed studies (Dekker *et al.*, 2008, Mollenhorst *et al.*, 2006, Williams *et al.*, 2006) and one study of egg packaging (Zabaniotou andKassidi, 2003). These studies investigated either free range, free range organic, conventional caged production or all of these systems. All the studies reviewed were performed in Europe. Table 1 provides a summary of these studies including main production parameters and results.

The studies covered several production systems prevalent in Europe, including conventional caged production, deep litter (barn) production, free range and organic free range pro-

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duction. The three studies used slightly different system boundaries. For all studies, the focus areas were feed production and layer farm production. All studies included pullet rearing in the assessment. Only one study (Williams *et al.*, 2006) explicitly mentions the inclusion of parent flocks for breeding chicks, though Dekker *et al.* (2008) did include the hatchery. It was not always clear from the studies where primary data were collected from to compile the assessment. The UK study (Williams *et al.*, 2006) covered multiple species and covered the whole of the UK, including all production system types. Data were generated from integrated farm models. As such the results are based on nation-wide averages rather than specific commercial production farms.

Mollenhorst *et al.* (2006) and Williams *et al.* (2006) present data comparing alternative production systems used in their respective countries. Both studies concluded that caged hens produce the lowest GWP and require the lowest amount of energy per kilogram of eggs. This is mainly related to the superior feed conversion efficiency for caged hens compared to free range and free range organic hens. All studies appear to have used IPCC emission estimation methods for calculating emissions related to feed production and manure. All studies identified feed production as the major source of GWP and energy usage for egg production. Of this, the primary emission source in nitrous oxide emitted during grain production.

Table 1: Summary of International Egg LCA literature

Reference	**Mollenhorst *et al.* (2006)**	**Williams *et al.* (2006)**	**Dekker *et al.* (2008)**
Study country	The Netherlands	UK	The Netherlands
Production system	Cage, deep litter (barn), barn + outdoor run and aviary + outdoor run	Cage, perchery (aviary), free range outdoor	Organic free range with two shed types – single and multi-tiered
Global Warming Potential (kg CO_2-e / kg eggs)	Cage = 3.9	Cage = 5.5	Organic free range = 4.0
	Deep litter = 4.4	Free range (non organic) = 6.2	
	Deep litter with outdoor run = 4.6	Organic = 7	
	Aviary with outdoor run = 4.2		
GHG emissions by stage	Manure management= 7-9% Feed production = 78-82%	NR	Feed production = 75%
Energy Use MJ/kg eggs	0.0013 – 0.0014[b]	Non organic cage =13.6; Non organic free range =15.4; Organic=16.1	13.1
Co-product handling	Economic	Economic	Economic

[a] Values interpolated from results spreadsheet released with the project – not directly reported. [b] values originally presented in kJ/kg egg. Considering the very low values compared to other studies these values may be subject to a reporting error in the original reference.

2. Materials and Methods

A preliminary assessment of energy and water usage, and direct GHG emissions was made across three modern caged layer production systems in the northern region of Australia. The assessment was based on historical data (winter/spring 2008 to winter/spring 2009) collected at the farm. The three farms collectively house over 1 M birds, and all farms utilise modern, environmentally controlled sheds for the layer hens. All farms included pullet rearing and layers. Estimation of GHG emissions were based on energy and bird production records. Farms varied in the bird genetics they used and the management of the birds. Variation was found in the length of laying period, with end-of-life varying from 74-80 weeks. In order to present 'like-with-like' results for benchmarking purposes, all farms were balanced to present results on for a laying period from 18-76 weeks. This was done by calculating total bird-days and averaging resource usage on a bird-day basis. Data were then multiplied by the number of bird days in the 'standardised' housed period (18-76 weeks = 406 days). The exact age of housing for pullets varied between farms and between flocks on farms. As a target, all farms aimed to house pullets by 17 weeks. Pullets were also reared in different management systems across the three farms, including caged and floor rearing. This was found to influence both performance and resource usage.

Energy usage covered electricity, gas usage and liquid fuel usage for the pullet and egg production systems. Electricity is used in the egg production system to operate extractor fans, lighting and feed / water supply systems. Electricity usage is known to vary greatly through the year depending on fan operation times, as is gas usage (depending on seasonal heating requirements). Liquid fuel (petrol and diesel) is used on most egg farms for management and maintenance vehicles used on-farm.

Water usage is made up of two main requirements, drinking water and cooling water. Drinking water is fairly well understood in the industry and is published by some breeding companies for their particular genetic strain. However, water requirements for evaporative cooling in environmentally controlled pullet or layer sheds is not well documented.

Egg production is expected to be a low GHG emission intensity industry when compared with other intensive agricultural sectors because of the high productivity and low natural emissions associated with poultry. According to Australia's tier 2 GHG estimation methodology (DCC, 2007), direct emissions are limited to manure management and soil emissions from spreading of manure, depending on practices employed on individual farms. These emissions are in the form of methane (CH_4) and nitrous oxide (N_2O) and may be lost in the shed, from manure stockpiles or from soils after spreading manure. To understand and accurately estimate these emissions, attention must first be given to accurate estimation of the primary substrate (excreted manure).

When considering greenhouse gases, the two characteristics of interest are volatile solids (the bio-degradable organic fraction of the manure) and nitrogen excretion. To calculate the excretion of manure components (volatile solids and nitrogen) a manure mass-balance estimation spreadsheet was developed. Life cycle inventory data were modelled in Simapro 7.1 to provide a preliminary assessment of the supply chain emissions and hotspots for GWP (measured in kg of CO_2-e).

3. Results and Discussion

All results for layer hens are presented as 'per hen place per year' (a capacity based indicator). Average electricity usage for the three farms is shown in Table 2.

Table 2: Preliminary electricity usage for three egg production operations

Production system	Units	Farm A	Farm B	Farm C
Caged layer hens	kwh / hen / yr	2.19	3.00	1.69

Energy usage varied by 66% between the highest and lowest user, suggesting opportunities may exist for efficiency improvement.

Water usage consisted of drinking and cooling water. Cooling water data were calculated as total water usage less drinking water usage, and includes minor amounts of cleaning water. Table 3 shows drinking and cooling water per hen / year. Not surprisingly, drinking water was similar across the three farms for layers, suggesting that birds are highly responsive to climate control with respect to drinking water demand. Cooling water data are presented for two farms and represented 21-44% of total water usage.

Table 3: Preliminary water usage (drinking and cooling) for layer and pullets for three farms

Production system	Units	Farm A	Farm B	Farm C
Drinking water	L/hen/yr	60	65	64
Cooling water	L/hen/yr	16	NR	50
Total	L/hen/yr	76	*	104

[1] Cooling water not reported for Farm B

The direct farm emissions associated with energy usage and manure handling (only) are presented in Figure 1 for per hen housed/yr across three farms. These data show that aggregated waste stream emissions represent the largest proportion of total emissions. As a weighted average across the three layer farms, manure emissions represent 64% of total GHG, compared to energy emissions of 36% on a per hen basis.

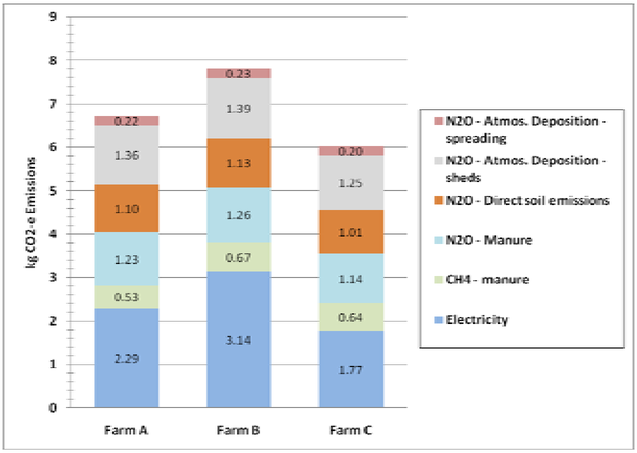

Figure 1: GHG emissions for three environmentally controlled egg farms (kg CO_2-e / hen / year)

A preliminary hotspot analysis for GWP of the whole supply chain was conducted using a simplified LCA methodology, based on standard international methods for LCA (ISO 14040-2006), with some omissions in the data collection. Omissions included egg packaging and resource usage associated with capital infrastructure (i.e. housing). Farm production data, energy usage, waste stream emissions and feed inputs were included (averaged across the three farms presented above). Feed inputs were analysed using a desktop study of diet inputs, based on the same dataset used by Wiedemann *et al.* (2010a, 2010b). The hotspot analysis used the functional unit ‘1 kilogram of eggs produced to the point of wholesale distribution’.

The hotspot analysis showed supply chain GWP was in the order of 1.6 kg CO_2-e / kg eggs. The majority of emissions were contributed by feed production for the layers and pullets (67%), electricity consumption (16% - this represents electricity consumption from the feed mill, pullet production and egg production (layer farm) and the manure management system for the layer farm (7% - methane and nitrous oxide from the shed and surrounds as per the Australian tier 2 methodology for GHG assessment).

Considering the relative contribution to overall impacts, these results correspond reasonably well to the literature, though the overall emissions are considerably lower. Feed production contributed slightly less to overall emissions in percentage terms than the studies reviewed in the literature. However, in actual terms the emissions from Australian feed production are considerably lower (see Table 4).

Table 4: GWP and contributions from feed production comparing Rapid LCA results and literature values

	Mollenhorst *et al.* (2006)	**Dekker et al. (2008)**	**Williams *et al.* (2006)**	**This study**
Total GWP (kg CO_2-e /kg eggs)	3.9 (cage)	4.04 (Organic)	5.52 (cage)	1.64 (cage)
GWP contribution from feed (kg CO_2-e /kg eggs)	3.1 (80%)	3.02 (75%)	3.6 * (65%)	1.1 (67%)
Contribution from all other sources (kg CO_2-e /kg eggs)	0.8	1.0	1.9 *	0.5

* Value interpolated from results based the breakdown of GHG gases and values reported in the feed grains section of the same study.

Feed production is likely to contribute lower emissions under Australian conditions because of lower nitrous oxide emissions in crop production. A similar finding was made in the recent Australian pork LCA (Wiedemann *et al.*, 2010a). Contributions from other areas in the supply chain were dominated by electricity usage and nitrous oxide manure emissions.

4. Conclusions

These preliminary data focus at the farm level, and can be used as a benchmark for resource usage and GHG emissions against productivity. Energy usage data were found to range substantially from one farm to the next, suggesting that progress may be made in the area of energy efficiency in this area.

Water usage for egg production was in the order of 77 – 114 L / hen / year. Of this, drinking water contributed 56 – 79% of total water usage, with the remaining water being cooling and sundry uses. Cooling water data were available for two farms only and a weighted average was not collated for water usage until further data is available.

Greenhouse gas emissions for energy emissions (electricity only) ranged from 1.8 – 3.1 kg CO_2-e/hen /yr, while manure emissions ranged from 4.25 – 4.68 CO_2-e/hen/ yr.

Results from the hotspot analysis show that feed is the major contributor to supply chain GWP, though the magnitude of emissions from this source are considerably lower than evident from other studies. While preliminary in nature, it is believed that the lower emission feed inputs will contribute to lower GWP in Australian egg production.

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Environmental impacts from capital goods in LCA of meat products

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ABSTRACT

As a part of an ongoing research project, one of the aims is to develop and improve standard methods for LCA of different categories of food products. An important issue is whether the environmental impact of capital goods should be included in the LCA of food products. The contributions of capital goods are calculated in a case study of chicken fillet. The following capital goods are included: transports, agriculture machines, animal housing and industrial plant. The results show the relative importance of the environmental impacts from capital goods. Since capital goods in some case contribute significantly to the total impacts of the product life, they should be included by doing a screening LCA in the beginnings of a project. Then it is possible to put an extra effort to gather specific data for the most important unit processes. Capital goods are always important to include in comparative LCA of products where the amount of investment is clearly different.

Keywords: LCA, capital goods, system boundaries, housing

1. Introduction

Capital goods are means of production and include factories, machinery, tools, equipment and various buildings which are used to produce other products for consumption. Capital goods are products which are not produced for immediate consumption, but they are objects that are used to produce other goods and services.

Whether to include or exclude the environmental impact of capital goods in a Life Cycle Assessment (LCA) has been discussed. For accounting LCAs, the guiding idea is often that the study should be as complete as possible and then production and maintenance of capital goods should be included (Baumann, 2004). Anyway, this is neglected in many studies. Capital goods have been excluded due to lack of data and too little awareness of how they can affect the results.

2. Background

In PAS 2050 it is stated that GHG (Green House Gas) emissions from capital goods shall be excluded, and that the rule shall be considered further in future revisions (BSI, 2008). In the Basic Module PCR for meat of poultry (EPD-system 2010) developed in the International Environmental Product Declaration system, it is stated that the manufacturing of production equipment, buildings and other capital goods shall be excluded.

However, in some case studies it is found that capital goods can give be an important contribution to some impact categories. Different housing systems for dairy cows and fattening pigs have been compared in a study from cradle to farm gate (Erzinger et al., 2003). It was found that the feeding regime was the most important factor, but also the building infra-

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structure was relevant, especially for energy consumption. In another study, different organic and conventional production systems are compared (Williams et al., 2006). The study does not give results of the importance of capital goods, but it contains detailed data for different machinery and buildings. It is then possible to compare the environmental impact from different buildings. The data show a lower impact from a low cost housing system than a conventional building.

A case study of rice compares alternate agricultural food chain managements systems (Blengini & Busto, 2009). The study shows a strong correlation between the number and size of machinery per hectare and the farm size. The relative contributions from capital goods were 6% on energy requirement and less for the other impacts categories studied.

A paper discussing LCA methodology describes the relative importance of including capital goods (Frischknecht et al., 2007). This is assessed by using the ecoinvent life cycle inventory database for different sectors and showing results when respectively including and excluding capital goods. The study is based on several hundreds of cradle-to-gate LCAs of heat and electricity supply systems, materials, agricultural products and transport and waste management services. The result shows that the capital goods gives substantial contribution in three or more environmental impact categories for all products and services analysed in the paper (except metals). Therefore it is sensible to include capital goods by default in any case. When focusing on the relevance of capital goods in agriculture, it seems that the share of capital goods on total impacts differs from that of typical industrial processes. The agricultural production is characterised by seasonal and weather conditions and therefore some machinery is used only a few times during a year. This can also be the case for animal buildings which are empty during grazing periods. In the study mentioned above (Frischknecht et al., 2007) the capital goods contribute 20% of the total impact of fossil energy use, but as for global warming potential and eutrophication it is substantially lower. This is explained by the high direct field and farm emissions, which make the relative impact from capital goods less important.

3. Description of case study

The scope of this paper is to document the relative importance of environmental impact of capital goods in LCA of meat products. A case study is used as an example for documentation of the consequences of different methodological choices, which in this context are capital goods as a part of setting the system boundaries.

Figure 1 show the life cycle of a food product. Each transport process has direct emissions from the use of fossil energy input and indirect emissions from the fuel production. The transport process also contributes by production and maintenance of the vehicle itself. Also the machines, housing and industrial plants have direct and indirect emissions from the use of energy, as well as emissions from the production and maintenance of the installation itself.

The contributions of capital goods are calculated in a case study of chicken fillet. The impact of the broiler house is allocated to the chicken fillet by using the service life of the buildings (depreciation) and the yearly production volume to calculate the contribution normalised to the functional unit. In this broiler house example a service life is 30 years, and a yearly production volume of 100 000 broilers is used.

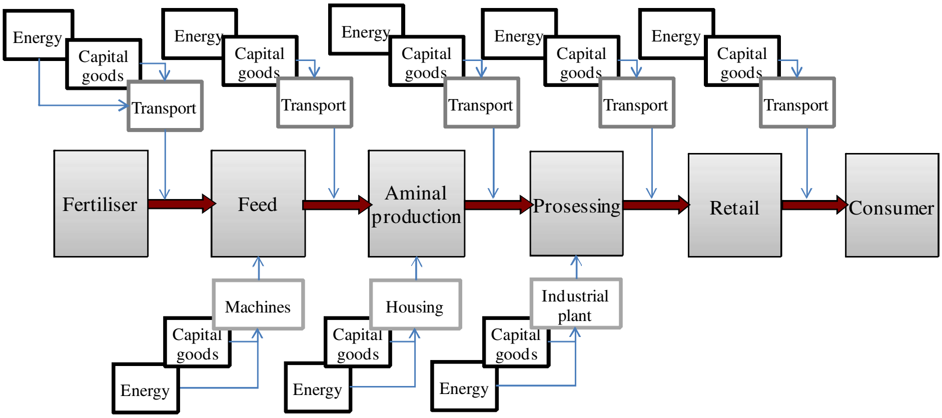

Figure 1: Life cycle of a food product, showing direct and indirect process units

The technical sheets for the broiler house give information of how much of each building material that is used. Emissions connected to operation of the housing or the machines (i.e. energy related emissions) are not defined as a part of capital goods, but as production related emissions.

Databases are used for emissions from other capital goods in the life cycle of chicken fillet. The emissions from capital goods in the slaughterhouse are calculated by using general data for a processing plant and normalise the contribution to the functional unit by using data for the depreciation time, yearly production volume and the size of the building.

4. Results

The result from the case study for GWP (global warming potential) is showed in figure 2 and the use of energy in figure 3.

The relative importance of capital good is approximately 6% for GWP and 9% for use of energy. For both impact categories it is the life cycle stages of production of feed and animal production that gives the greater part. The contribution for feed production comes mainly from machines, and for animal production the contribution comes from the broiler house. The processing unit has a small impact from capital goods, i.e. the slaughterhouse. This is explained by the big volume produced in the plant, which makes the normalised contribution from the capital goods relative small.

5. Discussion

Since capital goods in some case contribute significantly to the total impacts of the product life it should be included by doing a screening LCA in the beginnings of a project. Then it is possible to put an extra effort to gather specific data for the most important unit processes.

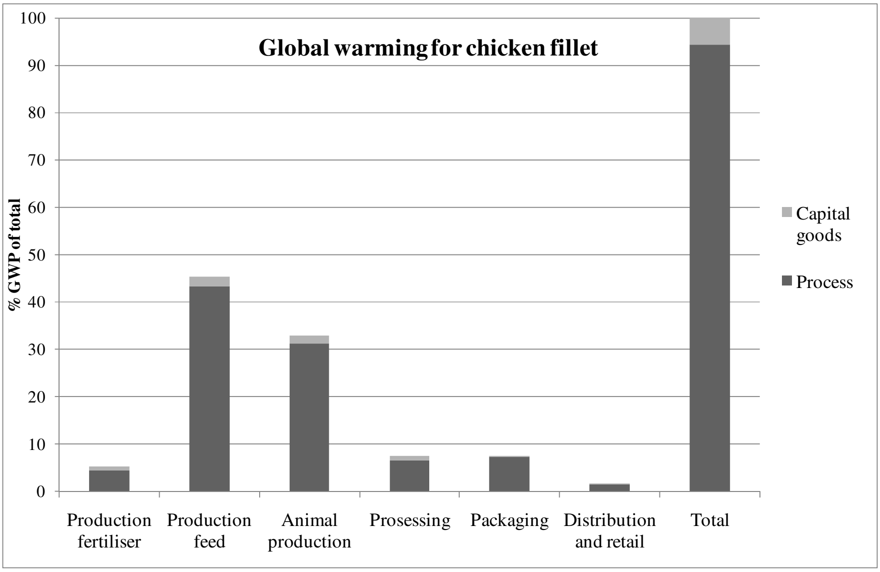

Figure 2: Global warming potential for chicken fillet – relative effect of capital goods

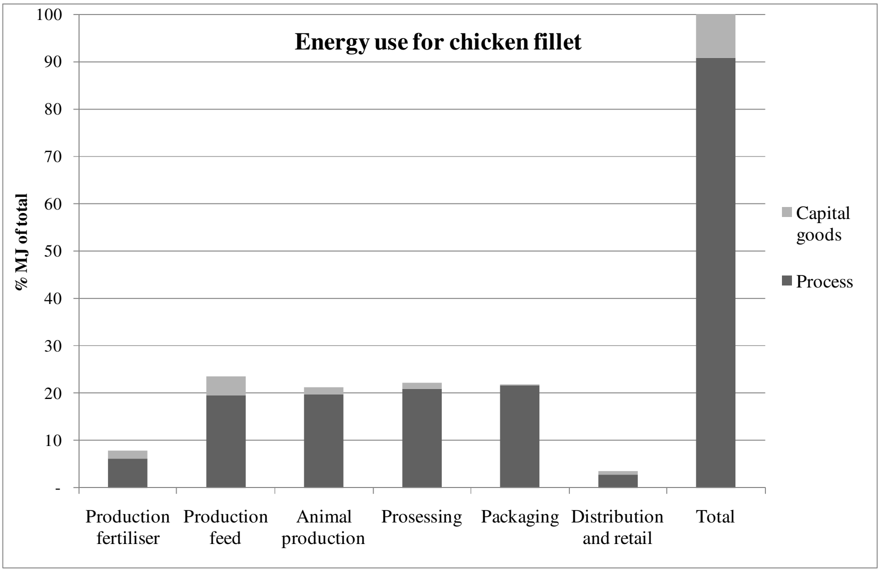

Figure 3: Energy use for chicken fillet – relative effect of capital goods

Capital goods are always important to include in comparative LCA of products where there is a clear difference in the investment in capital goods. One example can be pig production in a conventional pig house compared to outdoor pig production. When doing a cradle to farm gate LCA, the relative importance of machinery and buildings can be even more important than in a product LCA. The argument is that the machinery is only used a few times during a year, and the relative contribution per produced unit is higher, as described in an earlier section.

6. Conclusion

Even though most of the Carbon Footprint and LCA standards and methods do not specific include capital goods, results have shown that capital goods can give be an important contribution to some impact categories. It is therefore recommended to carry out a screening LCA including capital goods when starting a LCA of food products. Then it is possible to find the relative impact of capital goods and gather specific data for the most important contributions. It is also important to put an effort on including data for capital goods where the investment is high compared to the total production value.

When comparing food products from production systems where the amount of investment is clearly different it is also recommended to include capital goods.

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Life cycle assessment of cow and goat milk chains in France

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ABSTRACT

Stakeholders of milk chains in the Poitou-Charentes (PC) region (central western France) worked together to analyse the environmental impacts of regional dairy chains to identify improvement options. Fifteen cow farms and six goat farms were analysed and compared to cow farms in the Bretagne (B) region. Per 1000 kg of milk, goat milk had higher impacts than cow milk, while impacts of PC cow milk were higher than those of B cow milk. Per ha of land occupied, impacts of B cow were similar to those of PC cow, while goat farms had higher impacts, except for climate change. For all impacts except energy use, farm operation contributed most to impacts of butter and its co-products and goat cheese, impacts associated with farm inputs came second. For energy use farm inputs contributed most, depending on the product farm operation (butter, cheese), packaging (crème fraîche) or transport (skimmed milk) came second.

Keywords: cow milk, goat milk, butter, cheese, Life Cycle Assessment

1. Introduction

Cow and goat milk chain stakeholders in Poitou-Charentes (PC) region (central western France) worked together in a 3 year (2007 - 2009) research and development project called PaRMEELI (http://www.btpl.fr/page.php?r=4&p=44) to analyse the environmental impacts of regional dairy chains in order to identify improvement options. Most published results of Life Cycle Assessment (LCA) studies on milk chains report a predominance of the impacts of the farm stage compared to the other stages of the milk chain.

The LCA approach was used to quantify for each impact the contribution of each stage of the milk chain: production and supply of inputs to farms, farm operation, milk transport, milk processing and the transport of dairy products to retailers. The presentation of the potential impacts of the chain's sub-systems is likely to increase awareness of each stakeholder and may emphasize the need to work together to improve the environmental performance of the regional milk industry.

2. Method / Approach

The PaRMEELI project involved a wide range of stakeholders associated with PC cow and goat milk production and transformation chains. The main stakeholders in the project were cow and goat farmers, dairies, and organisations involved in dairy farm development, training in milk technology, agronomic research and technical advice to farmers.

LCA was used to assess the environmental impacts. Because most of the project partners were neither familiar with LCA, nor convinced of its relevance, we adopted a "participative"

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approach. This involved a seminar at the beginning of the project where the LCA method was explained, and meetings in which partners contributed in shaping the inventory data collection tools. Preliminary LCA results and need for additional data collection at the farm and dairy level were discussed, and partners were involved in deciding on subsequent project stages.

This study was conducted in a pilot area in PC, the “Pays Thouarsais”, in the north of the Deux-Sèvres département, hosting around 54 cow and 41 goat specialised dairy farms. Among these, 15 cow farms (Cow T) and six goat farms (Goat T) were compared to a group of 41 dairy cow farms (van der Werf et al., 2009) in the Bretagne region in western France (Cow B). All of these farms produced forages and most of them cash crops.

LCA calculations at the farm level were performed with EDEN, a Microsoft® Excel-based tool (van der Werf et al., 2009). EDEN estimated farm emissions of CH_4, CO_2, NH_3, N_2O, NO, NO_2, NO_x, SO_2, NO_3, PO_4, Cd, Cu, Ni, Pb, Zn, and non-renewable energy and land occupation. Estimated CO_2 emissions do not include dynamics of soil carbon stocks. EDEN calculates potential impacts for eutrophication (EU, kg PO_4 eq.), acidification (AC, kg SO_2 eq.), climate change (CC, 100-year horizon, kg CO_2 eq.), terrestrial toxicity (TT, kg 1,4-DCB eq.), non-renewable energy use (NRE, MJ), and land occupation (LO, m^2.year). EDEN distinguishes “direct” impacts originating on the farm site, from “indirect” (off-farm) impacts associated with the production and transport of inputs to the farm.

EDEN applies a cradle-to-farm-gate analysis. The farmer’s house, farm buildings, farm roads and drainage networks are not included in the system, nor are chemicals and veterinary products. For pesticides, non-renewable energy use and impacts associated with production and supply are considered, but impacts associated with the use of pesticides (toxic effects) are not considered, due to lack of appropriate characterisation factors. A dedicated version of EDEN for goat farms was developed.

Impacts were compared using two functional units (FU): a) 1 t of fat- and protein-corrected milk (FPCM)[1] sold and b) on-farm plus estimated off-farm hectares utilised. For the FU “1 t of FPCM sold”, a first version of EDEN allocated impacts among milk, animals, and crop products according to the proportion of total revenue generated by each product type. This allocation method was challenged by project partners when discussing preliminary results as well as by one of the reviewers of a paper on EDEN (van der Werf et al, 2009).

It was argued that this choice might introduce artefacts, as environmental interventions associated with the animals (e.g. methane emissions) will be partially allocated to crop products and vice versa. We therefore decided to avoid allocation between animal and crop products and separated the farms in two parts: production of crop products not used for animal production and all other farm processes. In the final step, economic data was used to allocate impacts between milk and animal production (88 and 97 % to milk for cow and goat production, respectively).

Regarding the post-farm dairy chain for cow milk and goat milk (from farm-gate to the retailer entrance gate), our results are based on data for two dairy plants in Poitou-Charentes, a medium-size dairy which transforms cow milk into butter, crème fraîche and skimmed milk, and a small goat cheese dairy. Butter and crème fraîche are packaged and delivered to retailers at average distances of 200 and 300 km, respectively. Skimmed milk is bulk transported, most of it to Spain (940 km). Goat cheese is packaged and transported over an average distance of 224 km to retailers (50% to Paris and 50% to Western France). Hypotheses on the emissions and resource use associated with the on-farm production of the milk that is transformed in these dairies were based on: a) average data for the milk from the 15 Cow T farms,

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[1] FPCM is fat and protein corrected milk, i.e. 0.337 + 0.116 × %fat + 0.06 × %protein × kg milk sold (Thomassen and de Boer, 2005)

b) average data for the milk from the 6 Goat T farms. For cow milk, allocation of impacts among butter, crème fraîche and skimmed milk was done according to the milk dry matter in products. Transformation of goat milk yielded a single product, so no allocation was needed.

We divided the cow and goat milk chains in five stages: 1) production and delivery of farm inputs, 2) farm operation, 3) transport of milk to and operation of the dairy plant, 4) packaging of products, 5) transport of products. Construction and maintenance of the dairy's buildings and equipment were not included in the system. The use of energy carriers (electricity, fuel oil), packaging materials and chemicals (detergents) was considered. Data for these processes and for transport were from the Ecoinvent database v2.0. Temporal coverage was a period of one year, corresponding to the period used in the bookkeeping for the farms and dairy. Life cycle impacts assessment methods used were as in van der Werf et al. (2009).

3. Results

3.1. Characteristics of dairy farms

Dairy farms examined in this study differed with respect to mean values for farm structure, input use and output level (Table 1). Relative to Cow B farms, Cow T farms had a larger usable agricultural area (UAA) (59 vs. 87) and Goat T had a smaller UAA (47 ha). The percentage of fodder crops and grass in UAA followed the same pattern (75 vs. 87 and 66%). Livestock density was similar for the three groups. Use of concentrated feed per kg FPCM was higher for Goat T and Cow T than for Cow B (684 and 184 vs 97 g kg FPCM^{-1}), total N input was similar for Cow B and Cow T, but higher for Goat T (152, 171 and 227 respectively). Diesel use was similar for Cow T and Goat T, but slightly lower for Cow B (119 and 116 vs 105 kg ha^{-1}) and electricity use was higher for Goat T and Cow T than for Cow B (616 and 550 vs 339 kWh ha^{-1}). Mean annual FPCM production per cow or goat was 7678 kg for Cow B, 8507 for Cow T, and 753 for Goat T. The proportion of milk sales in total farm animal product sales was lowest for Cow B (82%) and highest for Goat T (97%). Surplus of the N farm gate balance (N inputs – N outputs) was lowest for Cow B (88 kg) and highest for Goat T (183 kg).

Table 1: Mean values for characteristics of dairy farms (cash crops excluded), Bretagne cow farms (Cow B, n = 41), Thouarsais cow farms (Cow T, n = 15) and Thouarsais goat farms (Goat T, n = 6).

Characteristic	Dimension	Cow B	Cow T	Goat T
Farm structure and management				
Useable Agricultural Area (UAA)	ha	59	87	47
Fodder Crops and Grass in UAA	%	75	87	66
Stocking density	LU ha^{-1} FCG	1.5	1.5	1.4
Pasture residence time	Days year^{-1}	198	78	0
Inputs				
Concentrate feed use	g kg FPCM^{-1}	97	184	684
Total N input	kg ha^{-1} UAA yr^{-1}	152	171	227
Diesel use	kg ha^{-1} UAA yr^{-1}	105	119	116
Electricity use	kWh ha^{-1} UAA yr^{-1}	339	550	616
Output				
Milk production	kg FPCM cow^{-1} or goat^{-1} yr^{-1}	7678	8507	753
Milk fat content	%	4.3	4.1	3.7
Milk protein content	%	3.4	3.3	3.2
Milk-sales portion of total sales	%	82	88	97
Surplus of N farm-gate balance	kg ha^{-1} UAA yr^{-1}	88	129	183

3.2. Impacts of cow and goat dairy farms

When expressed per 1000 kg of FPCM and relative to Cow B, impacts for Cow T were 13 – 58% higher, and impacts for Goat T were 27 – 164% higher, while relative to Cow T, impacts for Goat T were 13 – 88% higher (Table 2). Contribution of indirect impacts ranged from 10 to 12% for EU, from 15 to 30% for AC, from 15 to 32 % for CC, from 13 to 28% for TT, from 71 to 81% for NRE and from 16 to 24% for LO. When expressed per ha of land occupied Cow B was similar to Cow T for AC, CC and NRE, while EU and TT were lower for Cow B than for Cow T. Impacts for Goat T were similar to Cow T for TT, CC was lower for Goat T than for Cow B and Cow T, but EU, AC and NRE were higher for Goat T than for Cow B and Cow T (Table 2).

Table 2: Mean impacts (1) per 1000 kg fat and protein corrected milk (FPCM) and (2) per ha of land occupied for cow farms in Bretagne (Cow B, n = 41), cow farms in Pays Thouarsais (Cow T, n = 15) and for goat farms in Pays Thouarsais (Goat T, n = 6). Values in brackets indicate the contribution in percent of indirect impacts (i.e. associated with off-farm inputs) to total impacts.

		Per 1000 kg FPCM			**Per ha of land occupied**		
Potential impact	**Units**	**Cow B**	**Cow T**	**Goat T**	**Cow B**	**Cow T**	**Goat T**
Eutrophication	kg-eq. PO_4	7.1 (10)	9.5 (12)	15.3 (10)	39.8	50.1	63.9
Acidification	kg-eq. SO_2	7.6 (30)	8.6 (19)	16.2 (15)	48.1	45.5	67.9
Climate change	kg-eq. CO_2	1037 (15)	1174 (20)	1322 (32)	6271	6305	5509
Terrestrial toxicity	kg-eq. 1.4-DCB	1.8 (13)	2.9 (17)	3.9 (28)	11.8	19.9	19.2
Non-ren. energy use	GJ	2.8 (71)	4.2 (74)	7.4 (81)	18.9	22.3	30.4
Land occupation	$m^2\ yr^{-1}$	1374 (16)	1992 (21)	2504 (24)			

3.3. Impacts of the cow dairy chain

For butter, NRE was mainly due to farm inputs (64%), farm operation (22%) and dairy operation (9%) (Table 3). For crème fraîche, farm inputs (52%), packaging (20%) and farm operation (18%) contributed most to NRE. For skimmed milk, NRE resulted mainly from farm inputs (43%), transport (35%) and farm operation (15%). Farm operation contributed most (69-78%) to CC for the three products, farm inputs came second (17-19%). Other stages of the product chain contributed less than 2% to CC, except for transport, which contributed 11% for skimmed milk. Farm operation contributed most (86-88%) to EU for the three products, farm inputs came second (12%), other stages contributed very little.

Table 3: Contribution of milk chain stages (in %) to total non-renewable energy use (NRE in GJ), climate change (CC in t CO_2-eq.) and eutrophication (EU in kg PO_4-eq) per 1000 kg of butter, crème fraîche and skimmed milk.

Stage of milk chain	**Unit**	**Butter**			**Crème fraîche**			**Skimmed milk**		
		NRE	CC	EU	NRE	CC	EU	NRE	CC	EU
Farm inputs	%	63.7	19.5	12.0	51.9	19.2	11.9	43.3	17.3	12.5
Farm	%	22.3	78.0	88.0	18.1	76.4	88.1	15.2	69.4	86.1
Dairy	%	9.4	1.9	0.0	7.9	1.8	0.0	6.4	2.0	0.0
Packaging	%	2.9	0.2	0.0	20.4	2.1	0.0	0.0	0.0	0.0
Transport	%	1.7	0.5	0.0	1.9	0.5	0.0	35.1	11.2	1.4
Total	See caption	35.0	8.43	68.7	21.6	4.33	34.6	5.33	0.98	7.2

3.4. Impacts of the goat dairy chain

NRE was mainly due to farm inputs (55%), dairy operation (28%) and farm operation (13%) (Table 4). Farm operation contributed most (66%) to CC, farm inputs came second (31%). Farm operation contributed most (90%) to EU, farm inputs came second (10%), other stages contributed very little.

Table 4: Contribution of milk chain stages (in %) to total non-renewable energy use (NRE in GJ), climate change (CC in t CO_2-eq.) and eutrophication (EU in kg PO_4-eq) per 1000 kg of goat cheese.

Stage of milk chain	**Unit**	NRE	CC	EU
Farm inputs	%	55.3	31.3	10.0
Farm	%	13.3	66.4	89.9
Dairy	%	27.5	2.2	0.1
Packaging	%	3.6	0.1	0.0
Transport	%	0.3	0.1	0.0
Total	See caption	71.3	8.35	99.7

4. Discussion and conclusions

Per 1000 kg of FPCM produced, Goat T impacts were higher than Cow T impacts, which were higher than Cow B impacts. For AC, EU and NRE differences between Cow T and Cow B were much smaller than differences between Cow T and Goat T. Thus Bretagne cow milk farms show the lowest impacts, impacts of Thouarsais cow milk farms are intermediate, and Thouarsais goat farms show the highest impacts. This trend is also found for the importance of indirect impacts, goat farms had highest percentage of indirect impacts for CC, TT, NRE and LO, Bretagne cow farms had the lowest percentage and Thouarsais cow farms where intermediate.

These contrasting findings result to a large extent from the characteristics of the three dairy farm samples (Table 1), especially those related to farm management and input use, such as annual pasture residence time (198 d for Cow B, 0 d for Goat T), concentrate feed use per kg milk (97 g for Cow B, 684 g for goat T), total N input (152 kg ha^{-1} for Cow B, 227 kg ha^{-1} for goat T) and electricity use (339 kWh ha^{-1} for Cow B, 616 kWh ha^{-1} for Goat T). Relative to Cow B farms, input use is higher for Cow T farms, and much higher for Goat T farms.

For both milk chains and all impacts, the processes up to the farm gate contributed most to overall impacts. This confirms findings in the literature (Berlin, 2002; Foster et al., 2006; Guignard et al., 2009). For NRE, farm inputs contributed much more than farm operation, for the other impacts the inverse was true.

For the post-farm cow milk chain, the dairy stage contributed 6 – 9% to NRE and 2% to CC, and very little to other impacts. For crème fraîche, the contribution of packaging to NRE was important (20%), whereas for skimmed milk transport contributed 35% to NRE. Skimmed milk makes up 94% of the mass of the dairy's output, therefore its contribution to the overall NRE of the dairy is large. Reducing the transport distance of skimmed milk would greatly reduce the dairy's impact.

For the post-farm goat milk chain, the dairy stage contributed 27% to NRE and 2% to CC, packaging contributed 4% to NRE. Post-farm stages contributed very little to other impacts. The higher contribution to NRE for the small-scale goat milk diary relative to the medium-size cow milk dairy has two causes. First the cow milk dairy had fuel oil as its main source of energy, whereas the goat milk diary relied on electricity as its sole source of energy. Secondly the goat milk dairy uses its energy less efficiently, probably due to its smaller size.

The search for options to reduce impacts associated with these milk chains should neglect none of the five stages. At the farm stage, reducing input use, in particular concentrate feed, and increasing grazing will help reducing impacts of the Thouarsais goat and cow farms. For all stages of the milk chains energy saving strategies should be implemented, in particular the goat milk dairy plant and the transport of skimmed milk should be priority targets.

Due to the complexity of the agricultural sector, a call for the methodological innovation of LCA methodology was made by one of the partners, to widen its scope and integrate in the analysis the multifunctionality of agriculture which, besides producing food and biomass, contributes also non-tradable goods such as environmental and landscape services.

The participative LCA approach brought a methodological improvement for the allocation of impacts between dairy farms products, by avoiding allocation between animal and crop products and separating the farms in two parts: production of crop products not used for animal production and all other farm processes.

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Transport energy for Swedish locally produced dairy cow feed

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ABSTRACT

The present study aimed to analyze the use of transport energy for five different yearly feed rations for Swedish dairy cows. Three of these had a higher share of locally produced feedstuffs than normal, when 'locally' was interpreted as Swedish. The transport energy included both transport of raw material crops and feed products. Only one feed ration substantially lowered its transport energy use (from 3.4 GJ to 1.9 GJ); one other feed remained almost at the initial transport energy (3.2 GJ) and a third feed increased it use to 4.6 GJ per yearly feed ration. The conclusions of the study was that transports only contributed up to a quarter of the total energy use and that the concept of locally produced feed need to be interpreted in a quite narrow perspective in order to reduce the use of transport energy.

Keywords: Energy use, Feed, LCA, Milk, Transport,

1. Introduction

Locally produced feed is often regarded as an important factor for sustainable animal production. The potential advantages relate to low energy use due to short transports, nutrient cycling from on-farm feed production, avoidance of imported feedstuffs with a poor environmental record, etc (Emauelson et al., 2006). The present study aimed to analyze the use of transport energy in relation to total energy for a set of feed rations for Swedish dairy cows, in order to gain knowledge on the importance of feed transports for an energy efficient dairy feed supply. This study is part of a larger study entitled *Life cycle assessment of locally produced feed for dairy cows* (Wallman et al., 2010), where also other parts of the feed production as well as the animal metabolism of the feed were examined.

2. Material and methods

The functional unit of this study was a yearly feed ration for one dairy cow with an average yearly milk production of 9000 kg energy corrected milk (ECM). The context of the case study was a 100 head dairy farm, with on-farm production of roughage feed only, situated in the county of Västra Götaland, Sweden (the county with highest numbers of dairy cows in Sweden). Five different feed rations were compared (see Table 1); feed 1 was a normal, conventional feed; alternatives 2, 3 and 5 had a higher content of locally produced feedstuffs than the normal feed when 'locally' was interpreted as Swedish; and feed number 4 was included in the study due to its content of the new and promising maize silage, but also had a higher inclusion of soy meal to satisfy protein requirements (thus, being less "local" than the normal feed).

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The methodology used was attributional lifecycle assessment, with economic allocation to assess by-products. Each feed ingredient was in the main study tracked from production of input materials up to and including transport from fodder plant to farm, where the latter was assumed to be 100 km by a 40 ton's truck with 70% load rate. The results are presented as primary energy, i.e., where also the production of the energy carrier is included. For transport energy, also production of vehicles and infrastructure was included as these data were taken form Ecoinvent as implemented in SimaPro 7.1 (PRé consultants, 2010).

The total energy results include several parts of the feed production lifecycle, such as mineral fertilizer production, field operations, feed processing and transports, whereas the transport data is a sub-set that include only transport of raw material crops and feed products. Roughage feed was produced on-farm and thus not relevant to include in the transport energy results.

In this auxiliary study transport energy data for each feed ration was set in relation to the corresponding total energy data of the feed in the main study, so that the effect of changing to a more locally produced feed on transport energy use could be clarified. As the transport energy for transporting wet ensiled beet pulp (Feed 4 and 5) from the sugar plant in southern Sweden to the milk farm in the typical milk region of Västra Götaland (400 km from the sugar plant) turned out to be so high, a sensitivity analysis was set up, where a new assumption was made on the farm location, this time 100 km from the sugar plant.

3. Results

The transport energy results for each feed ration are presented in Table 1, also showing the contribution from each feed stuff. Figures 1 and 2 illustrates the transport energy in relation to the total energy use for each feed ration, for two cases – when the distance between the farm and the sugar plant was 40 km and 10 km respectively.

The resulting transport energy use for a yearly feed ration varied between 10 and 28 % of the total primary energy use; the typical normal feed (Feed 1) scored 15% (see Figure 1). All three locally produced feed rations (Feed 2, 3 and 5) lowered their total energy use compared to the normal feed, although to different extents (97%, 83% and 74% of the base case, for alternatives 2, 3 and 5 respectively). Feed 3 (High quality silage) had the lowest transport energy use, due to a high share of on-farm feed crops, whereas Feed 5 (Clover, Rapeseed and Peas) had the lowest total energy use, despite its relatively high transport energy use. The latter was mainly caused by transportation of wet and bulky beet pulp but also by domestic transportation of cereals, rape seed products and peas. Feed 4 scored the same total energy use as the normal feed, but used a higher share of this for transportation. This was due to a higher inclusion of concentrate feed/soy meal and wet and bulky beet pulp.

The sensitivity analysis of Feed 4 and 5 (investigated due to their inclusion of the wet beet pulp) resulted in a lower transport energy use and a corresponding lower total energy use. The relative share of the transport energy was reduced from 28% for both feed 4 and 5 to 22% for feed 4 and 19% for feed 5, respectively when the distance between the farm and the sugar plant was reduced to a quarter (see Figure 2).

Table 1. Feed rations for dairy cows producing 9000 kg ECM-milk per year [kg product, unless indicated as dry weight], and their corresponding use c transport energy [MJ primary energy]. *Italics = sensitivity analysis.*

Transport energy[1] [MJ primary energy per kg product]	Feed ingredient	**1. Base case**		**2. Distillers dried grains (DDGS)**		**3. High quality grass silage**		**4. Pressed beet pulp, maize silage**		**5. Clover silage, rape-seed, peas**	
		kg feed	MJ transport	kg feed	MJ transport	kg feed	MJ transport	kg feed	MJ transport	kg feed	MJ transport
on-farm	Roughage feed, dw	3367		3346		4499		2150		2989	
1,5	*Ensiled Sugar Beet Pulp (200 km, 90% load rate), dw*								*641*		*732*
5,2	Ensiled Sugar Beet Pulp (650 km, 55% load rate), dw							427	2220	488	2538
0,6	Cereals	1620	921	1373	781	1007	573	1818	1034	1278	727
0,8	DDGS			549	426						
1,1	Dried sugar beet pulp pellets	275	294	275	294						
1,4	Rapeseed meal									204	294
1,4	Rapeseed cake									400	577
0,6	Peas									881	501
4,4	Soybean meal							85	371		
1,9	Concentrate feed, Unik 52	1196	2225	924	1719	726	1351	1473	2741		
	Sum [MJ per feed ration]		**3441**		**3220**		**1923**		**6366**		**4637**
	Sensitivity analysis: farm instead situated in sugar plant region										
	Sum [MJ per feed ration]								*4786*		*2831*

[1] Ref: Wallman et al., 2010.

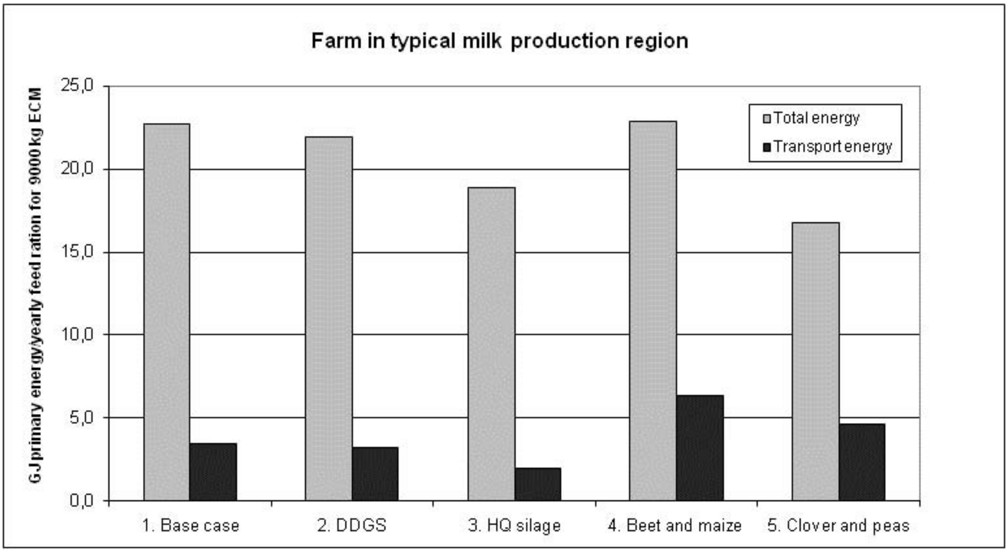

Figure 1: Transport energy use compared to total primary energy use for production of five different feed rations for dairy cows milking 9000 kg ECM annually, when the farm was situated in the typical milk region of Västra Götaland 40 km from the sugar plant.

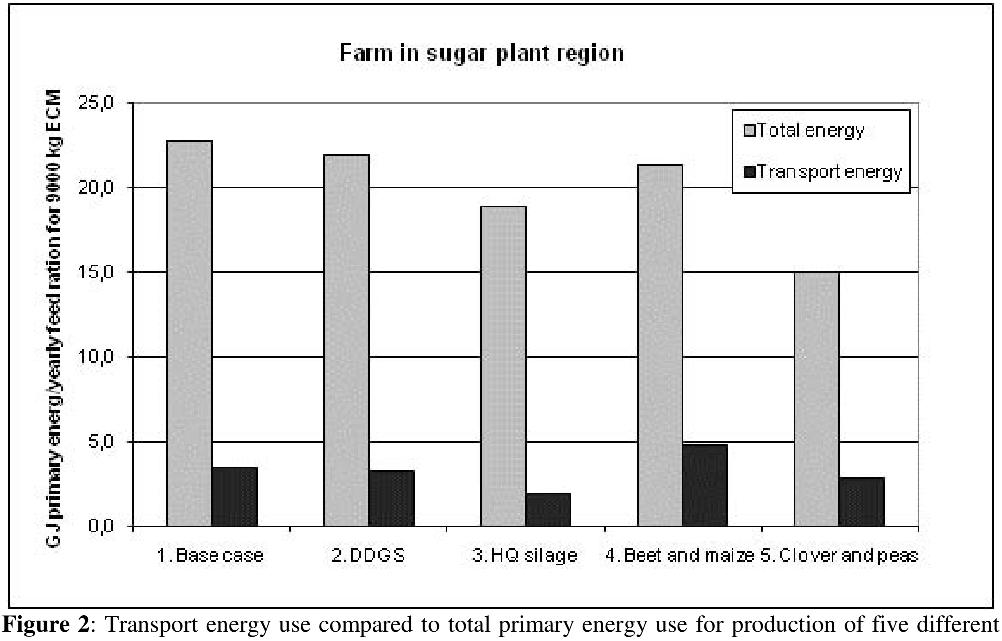

Figure 2: Transport energy use compared to total primary energy use for production of five different feed rations for dairy cows milking 9000 kg ECM annually, when the distance to the sugar plant was reduced to 10 km.

4. Discussion

When comparing the transport energy use with the total energy use, it becomes clear that other phases of the feed production life cycle, such as mineral fertilizer use, contribute more to the total energy use. However, the transport energy use, which contributed to approximately up to a quarter of the total, may be more feasible to change. Reducing transport energy use have been pointed out as one of the possibilities for increased energy efficiency in the food supply system (Wallgren, 2008).

Scrutinising the results in Table 1 gives that the transport energy use was mainly related the use of concentrate feed, except when wet ensiled beet pulp was transported relatively far. The concentrate feed of the study included soybean meal and palm kernel meal, which both used large quantities of transport energy per kg feed (ca 4 MJ/kg). There is thus a potential to reduce the use of transport energy by excluding these long-distance feed ingredients.

The other obvious reduction potential lies in the avoidance of transporting bulky feeds like the ensiled beet pulp. It was much more energy efficient to off-set the wet beet pulp in the same region, as shown in the sensitivity analysis.

The only feed with a markedly low transport energy use (Alternative 3, High quality silage) had a high share of on-farm feed. The transportation of cereals, rapeseed products and other Swedish feed ingredients also resulted in use of transport energy, especially since these ingredients were use in large quantities in feed 1, 2, 4 and 5. Since feed 2, 3 and 5 all can be entitled “more locally produced” if this term is to be interpreted as Swedish feedstuffs, the concept of “locally produced” is no guarantee for low use of transport energy. It seems that the interpretation needs to be more narrow, such as on-farm or adjacent to farm if it should give a clear indication of low transport energy use. However, locally produced feed interpreted as Swedish or European can have other advantages, such as less environmentally disturbing production and land use, but that has not been investigated in this study.

Viewing the results from another perspective, it is important to acknowledge that three quarters or more of the energy use was related to other factors than feed transportation, mainly mineral fertiliser production (Wallman et al., 2010). There is thus a need to aim for a reduction of this in order to reduce the total energy use. One example of a model that takes into consideration energy use from many of the farm operations and production energy for mineral fertilisers is the Canadian Holos model by Little et al (2008). However, transport energy of feeds to and from farms is not included. This may underestimate the total energy use in that model (depending e.g., on the share of on-farm feed production).

5. Conclusions

One conclusion of the study was that feed transports only contributed up to a quarter of the total energy use for feed supply, but may still be important in the process of creating a more energy efficient dairy production since it is a factor that is relatively easy to control. Another conclusion was that the concept of locally produced feed need to be interpreted in a quite narrow perspective in order to give a clear indication of low transport energy use.

As more life cycle assessment data of various feed stuffs becomes available for feed designers, the possibilities increases to design feed rations with low energy use. The results from this study indicated that the transport energy use can be reduced by choosing locally produced feed stuffs, where consideration has to be taken to the share of on-farm feeds and farm location in relation to feed suppliers, especially for bulky feeds.

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The challenges of comparing the environmental impacts of butter and margarine in Western Europe

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ABSTRACT

Life cycle assessment is a tool commonly used to compare the environmental performance of products. When conducting an LCA there are a number of decisions that need to be taken which can potentially affect the outcome. This paper will discuss the key decisions taken in a recent LCA study where the environmental impacts of butter and margarine were compared and margarine proofed to be environmentally preferable to butter. In particular, the paper will focus on the challenges arising from the different nature of the two products and their production systems. These decisions are explored from an academic as well as a business perspective.

Keywords: butter, margarine, Life Cycle Assessment, comparison

1. Introduction

Life Cycle Assessment (LCA) is a widely used tool to assess the potential environmental impact of products and services across the value chain. The insights gained help to improve the general understanding of the environmental performance of products, for instance, by identifying hotspots or by understanding differences in the life cycle when comparing products. In a business context, insights from an LCA study can provide useful information which will help the business to become more sustainable.

Unilever is a consumer goods manufacturer with a strong reputation for its work in the area of sustainability. The company's portfolio covers a wide range of household care and food products. Within Unilever, LCA and other environmental tools have been used for more than ten years to help understand the environmental impact of products, identify hotspots across the life cycle and to estimate the environmental benefits of innovation projects. From an assessor's point of view the wide range of products (e.g. different variants of margarine) and the global scale of the business can be challenging especially when assessing food products due to the different local conditions and practises for agricultural processes.

In this paper we explore the challenges in LCA when comparing two product types - butter and margarine - in Western Europe the thinking behind choices made in the approach from an academic as well as business angle. This LCA study was conducted in 2008 (Nilsson et al., submitted) to better understand how these two products compare environmentally. Although a number of Life Cycle Assessments on margarine and milk have been conducted in the past (e.g. Nielsen *et al.*, 2003; Cederberg & Flysjö, 2004; Thomassen *et al.*, 2008) only few studies have examined the impact of butter across the whole life cycle (Nielsen *et al.*, 2003).

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2. Case study

In 2008 SIK and Unilever conducted an ISO-compliant study (Nilsson *et al.*, submitted) comparing the environmental impact of butter and margarine in Western Europe. Seven products were assessed in total, the leading margarine and butter stock keeping unit in the UK, Germany and France as well as a spreadable butter, which contains a high percentage of vegetable oils. Details can be seen in Table 1.

Table 1: The seven studied products in three key markets

	Margarine	**Spreadable Butter**	**Butter**
UK	38% fat Sold in 500g units Polypropylene tub	80% fat (25% is rape seed oil) Sold in 500g units Polypropylene tub	80% fat Sold in 500g units Butter wrapper
Germany	70% fat Sold in 500g units Polypropylene tub		80% fat Sold in 250g units Butter wrapper
France	60% fat Sold in 500g units Polypropylene tub		80% fat Sold in 250g units Butter wrapper

The following impact categories were included, selected on the basis of their importance for the food production systems:

- Primary energy use (PE)
- Global warming potential 100 years (GWP)
- Eutrophication potential (EP)
- Acidification potential (AP)
- Photochemical ozone creation potential (POCP)

Land use, biodiversity and ecotoxicity whilst relevant were excluded due to lack of robust methodology, however, land occupation (m^2*a) was included as crude proxy for potential land use effects.

The system boundary for the margarine and butter system, as shown in Figure 1, is drawn from cradle up to the first distribution centre in each country. In addition waste treatment of packaging is included in the system boundary. Storage at the distribution centre, transport to and storage at the retailer as well as the consumer use stage (transport, storage) were not included since these will be the same for both margarine products and butter products.

The results show that there are large differences in the environmental impact of butter and margarine, independent of market (see Figure 2). The difference is least when considering energy use but in all countries the margarine products require less energy than butter products. The largest differences between the products occur for the GWP impact category. The GWP impact of margarine does not exceed 20% of that of butter, independent of the country. The only environmental impact that is higher for the margarine products is POCP. This is due to the use of hexane in the oil extraction process. There is no similar process in the butter production system.

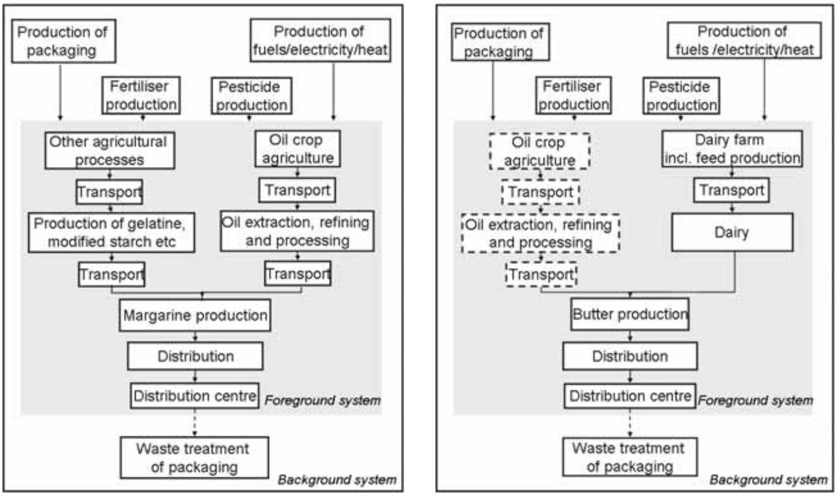
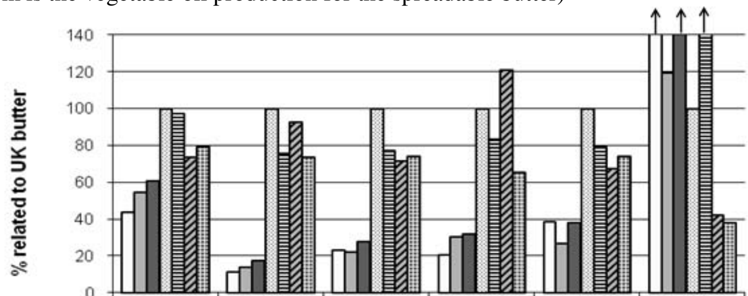


Figure 1: System boundary for margarine (on the left) and butter (on the right). The dotted processes in the butter system is the vegetable oil production for the spreadable butter)



	PE	GWP	EP	AP	land competition	POCP
UK margarine	44	11	23	20	38	289
DE margarine	54	14	22	30	26	119
FR margarine	61	17	28	32	38	487
UK butter	100	100	100	100	100	100
UK spreadable	97	76	77	83	79	257
DE butter	73	93	72	121	68	42
FR butter	79	74	74	65	74	38

Figure 2: Results for the relative impact of all seven products compared to UK butter

3. Key decisions

As in all LCA studies a number of decisions had to be taken when conducting this study. The challenge is to identify what the critical decision points, what the options, and what the consequences are for each of the options. Some of these points can be addressed as part of a sensitivity analysis. At the same time a balance has to be found between challenging every decision and the time and efforts put into the study. In the following examples some of the key decisions taken in the course of the study are explained in detail.

3.1 Product choice and Functional Unit

The aim of the study is to compare margarine and butter in general, rather than comparing a specific brand to another. Therefore, the key selling products in three major Western European markets were chosen, namely the UK, Germany and France. While there are only little differences between butter products in the three countries, there are clear differences in margarine products, predominately the fat content. While in Germany the most popular margarine contains 70% of fat, the UK brand has only 38% fat content.

This fact is also important when choosing the functional unit. As with many other products margarine and butter products fulfil more than one function. Both, margarine and butter can have several applications, from bread spread to use in cooking and baking. However the latter is only possible with products with high fat content. This is not the case for all products within the scope of the study. For this reason the functional unit refers to products that are used as a spread, e.g. to act as a barrier to stop sandwiches going soggy, to make toppings stick to the bread or simply to improve the eating experience. For this type of application we assumed the same amount of either butter or margarine is needed. The recommended serving size for margarine is 10 g (IMACE, 2008). However, for simplicity a functional unit of 500 g of packed margarine/butter was chosen.

The use of margarine and butter for other purposes, e.g. cooking, provision of nutrients or calories were explicitly out of scope. However, since the fat content is a key driver for the environmental impact a sensitivity analysis was performed where products of the same fat content were compared.

3.2 Data and sources

Since the study was commissioned by the manufacturer of all three margarine products within the scope of the study proprietary data was available for many oils, manufacturing, product specification, and packaging. However, the same level of detail was not available for the butter products. Therefore, the impact from butter was calculated from literature data. Since dairy practises vary from country to country (or even region to region) care needed to be taken to reflect these in the data sources (i.e. relevance to the source for the butter).

For the commissioner of the study, Unilever, the choice of consultancy for this project was highly influenced by the fact that SIK has experience in conducting LCA studies on the dairy sector. This knowledge helped to ensure that relevant data sources were used and it allowed data sources to be indentified and analysed quickly and efficiently. Besides, having an independent and competent third party institution conducting this study, increased credibility in the results, and thus the value to the business.

3.3 Allocation

There were several processes in the two systems which generate more than one (useful) product output, e.g. extraction of vegetable oils which generates both, oil and meal, or rearing of cows which yields both milk and meat. In order to understand the influence the allocation method has on the results a sensitivity analysis was carried out using different allocation approaches. As the base scenario economic allocation was considered. Care was taken to identify allocation methods that are focusing on the type of ingredients in question; these were:

- Mass allocation for the vegetable oil extraction
- Allocation according to the causality between the supply of energy and protein to cover the diary cow's milk production (allocated to the milk) as well as her maintenance and pregnancy (allocated to meat) according to Cederberg & Mattsson (2000)
- For dairy an alternative allocation method according to the allocation matrix developed by Feitz et al. (2007) was applied. This is based on milk solids content and average resource use (e.g. energy, water) of the different dairy products.

The sensitivity analysis showed that the results of the study were robust.

3.4 Palm oil

Unilever is actively promoting the development and sourcing of sustainable palm oil through the Round Table for Sustainable Palm Oil (RSPO) initiative. Although palm oil and palm kernel oil are only two of several ingredients in margarine, due to the specific environmental issues in connection with palm oil production special care was taken to ensure all aspects were adequately considered. Therefore a sensitivity analysis was performed to ensure the robustness of the results considering three scenarios

a) base scenario: The data sets as used in this LCA study. No greenhouse gas emissions due to land use change, cultivation on peat soils or from waste fraction palm oil mill effluent (POME) are considered.

b)midway scenario: 40% of the oil comes from transformed land (rainforest converted to palm plantation), 4.1 % is cultivated on peat land in Malaysia (Schmidt 2007) and 80% of methane from POME is emitted (20% recovered as biogas)

c) worst case scenario: 100% of oil comes from transformed land, 100% of emissions of the POME fractions are emitted and 4.1% of palm is grown on peat land in Malaysia.

In all three cases (base scenario, midway scenario and worst case scenario) the GWP for all three types of margarine is less than 50% that from butter.

3.5 When is a product better than another?

This is an important question when comparing different products (see e.g. ISO 1999, European Commission, 2009). In this study the interpretation was conducted so that if there was a difference of 50% or more between the products being compared, this was interpreted as a significant difference. We appreciate that this is a high percentage, but it was chosen in order to have certainty that there was a significant difference between the products despite uncertainty and variability around the used data.

In this study margarine products in all three markets (UK, Germany and France) are significantly better than butter products for GWP, EP and AP. Primary energy and land occupation are less for margarine than butter although not as significant as for the other impact categories. These findings are also valid when comparing margarine and butter between the markets. For this reason they are likely to be of general relevance for other Western European countries where similar margarine and butter production systems are found.

In addition a sensitivity analysis was performed on key issues, i.e. fat content (assuming same fat content in butter and margarine), allocation methods, data sources for oils data (including the above described palm oil scenarios), data sources for milk data and on energy use at dairy for butter production.

Since the outcome of this LCA may be used in external communications and it is comparative an externally peer review according to ISO 14 040 and 14 044 (ISO 2006 a, b) was conducted - a summary of this report is currently submitted for publication (Nilsson et al., submitted). In this way the quality of communicated information is ensured without disclosing the actual study which contains propriety information.

4. Conclusions and recommendations

With the strong driver of integrating sustainability into business practise, LCA can be a useful tool to help understanding the environmental impact of products. However, LCA studies are also time and resource intensive tasks. The study described here took about one year from commissioning SIK until the final report. A detailed LCA approach was chosen to compare margarine and butter to ensure robustness of the evidence and results (i.e. margarine shows environmental benefits over butter). However, there are also limitations to LCA and these need to be considered. A thorough sensitivity analysis is therefore essential which is customised to the purpose of the study. Including aspects of public concern into the sensitivity analysis makes an LCA study more valuable for business purposes because public concerns can be proactively addressed (e.g. sensitivity analysis around palm oil). The added value for the business in having credible external partners and reviewers when results are communicated needs to be stressed.

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LCA of high quality milk: main indicators and benefits due to company environmental improvement

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ABSTRACT

During recent years Granarolo, one of the biggest Italians dairy player, has encompassed life cycle thinking into the definition of its environmental policies and communication activities. This paper tackles the LCA approach applied to high quality pasteurised milk packaged in PET bottles. The system boundaries analyzed in the LCA include the entire supply chain, from cattle breeding to the delivery of pasteurized milk to GRANAROLO's distribution platforms. The LCA also allows the evaluation of the improvements associated with the environmental programs developed at reducing company impact. An example is given by the wrap-up issue in which the main actions are aimed to reduce bottle and cap weights, increase the number of bottles per pallet and reduce the thickness of the film used in the palletizing phase. These actions contributed to reduce Granarolo's carbon footprint of about 4.500 tons of CO_{2eq} per year.

Keywords: milk pasteurization, environmental improvement, packaging reduction, cattle breeding, carbon footprint.

1. General information

Granarolo, in cooperation with Life Cycle Engineering, in recent years has developed several studies based on LCA approach (Baldo, Marino, Rossi *et al.*, 2008); these focus on:

- comparing different yogurt packaging materials in terms of environmental impact;
- evaluating the environmental impact related to the various stages of milk production and processing (breeding, milk collection, pasteurization, packaging, etc…);
- publishing several Environmental Product Declarations, following the international EPD system requirements (International EPD Cooperation *et al.*, 2008) as effective tools to provide consumers with information on the environmental performance of different types of fresh milk.

With regard to the last item, the first experience fostered concerns the EPD based on the results of the Life Cycle Assessment applied to the production of High Quality fresh Milk packaged in a PET bottle. The study was performed considering every element of the milk production chain starting from activities relevant to livestock, industrial treatment (handling, processing, pasteurization, and packaging) and services (storage and distribution).

The study followed specific product rules published within the EPD requirements, whose main highlights are:

- the system boundaries include the entire supply chain from the cattle breeding to the delivery of bottled milk to GRANAROLO's distribution platforms;
- the breeding phase was assessed using primary data collected in a selected sample of farms, increased year after year;

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- the production phase, which includes pasteurisation and packaging activities, takes place in 5 production plants that are involved in primary data collection. The average plant based on the annual production was considered for the calculation of environmental indicators.

Through the LCA and the EPD, Granarolo has presented both the environmental performance related to milk production, and the improvements achieved through its environmental programs. In particular, the LCA has allowed quantification of carbon footprint reduction related to the main actions implemented by Granarolo in relation to High Quality Milk. These include the reduction of cap and PET bottle weight, increase in the number of bottles per pallet and thickness reduction of the plastic film used for the palletizing phase.

2. Goal and scope

Granarolo has developed a specific LCA study of fresh High Quality milk packed in PET bottle with the following objectives:
- examine the total life cycle of fresh milk and identify the production phases with the greatest environmental impacts;
- evaluate the improvements associated with the environmental programs developed in order to reduce company impact;
- develop and publish the Environmental Product Declaration for use as a communication tool.

3. System description

The system boundaries investigated are shown in Figure 1 and include the following phases:
- production of raw milk at farms; the main aspects considered in this phase are energy, water and detergent consumption (farm management), field cultivation of feed given to animals breeding (included production and use of fertilizer and other chemicals), emissions to air and soil due to management and direct use of cow slurry/manure;
- milk pasteurization and packaging at plants;
- production of primary, secondary and tertiary packaging;
- transportation of the finished product to distribution sites.

4. Methods

The quantification of environmental performance in relation to the production of 1 litre of High Quality Milk bottled in PET was performed, as provided by both the General Rules of the EPD system and the specific group of PCR products - Product Category Rules (PCR 2006).

The assessment tool employed is the methodology of Life Cycle Assessment (LCA - Life Cycle Assessment) is governed by international standards ISO 14040 series.

The LCA has been developed using Boustead Model as a basic component as well as some LCA databases such additional supporting tools for the secondary data treatment.

The primary data used to elaborate the LCA study related to High Quality fresh Milk were collected in direct collaboration with farms, manufacturers and suppliers involved in the production chain.

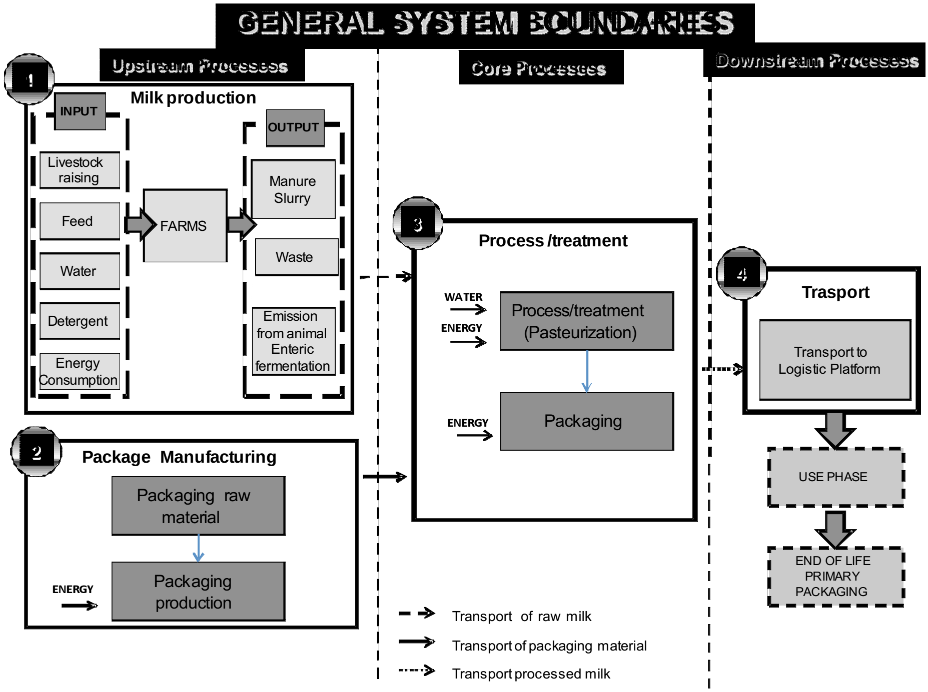

Figure 1: System boundaries related to LCA of High Quality Fresh Milk packed in PET bottles

Considering that the farms which supply milk to Granarolo are multiple and rather different in terms of size and productivity, a representative sample of the livestock farms was selected; the sample (11 farms) was defined considering different ranges of daily production of fresh milk, in order to perform a circumscribed LCA.

Based on the data gathered in the farms sampled, Granarolo has defined an "Average Farm" assigning specific weighing factors to the various farms involved; weighing factors were calculated on the basis of the percentage of milk produced by all of the farms divided by bands of daily production.

Adopting this methodological approach has ensured data representativeness for over 90% of crude milk delivered to Granarolo (ENEA LCA-lab *et al.*, 2006).

The inputs and outputs related to the farms sampled were allocated totally to milk production considering that the mass of meat deriving from slaughtering and from the animals calved is negligible compared to the total quantity of milk produced during the service period of the cow.

With regards to the process of pasteurization, packaging and transport of milk, the data considered is derived primarily from the records of the business management system implemented in the four Granarolo facilities located in Italy, where High Quality Milk packaged in PET bottles is produced.

When the milk production plant generate more than one product (such as cream, yogurt, cheese), the inputs and outputs of the system were partitioned among the different products through the application of mass allocation procedure.

Granarolo has defined an ideal "average plant", which is composed on the basis of the weighted average of impacts associated with individual plants compared with annual volumes of production.

Finally from the point of view of PET preforms and closures, data used in the LCA model were collected directly from producers through special questionnaires.

5. Results

With regards to the results obtained in the LCA, an interesting indicator is constituted by overall system energy consumption in terms of Gross Energy Requirement. This indicator includes:

- directed energy (energy consumed directly for milk processes)
- feedstock energy (share of energy contained in the materials used as input by the process as such and not as fuel)
- indirect energy (energy to produce directed energy feedstock and energy)
- energy associated with transport.

The results are shown in Figure 2 which shows that the most energy-intensive phases are represented by the production of crude milk at farms (energy consumption related to the cultivation and production of feed given to cows) and production of packaging.

By focusing on environmental impact, Figure 3 reports the results obtained with reference to the potential greenhouse effect (Global Warming Potential Indicator- GWP_{100}).
The chart highlights that milk production during the farming phase lends highest contribution to the potential greenhouse effect, especially in relation with the emissions of methane resulting from digestive process of cows (methane has a greenhouse potential of approximately 20 times that on the CO_2). However, milk packaging is not negligible since it contributes for a share of about 10%.

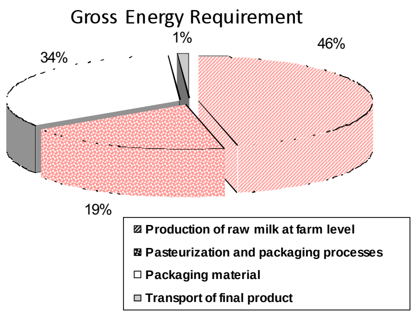

Figure 2 – Gross Energy Requirements related to the production of 1 liter of Granarolo High Quality Milk packaged in PET bottle

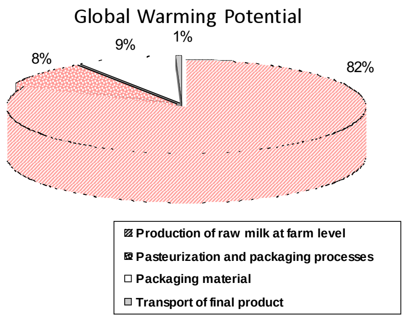

Figure 3 - Breakdown of GWP_{100} between the various stages associated with the production of 1 liter of Granarolo High Quality Milk packaged in PET bottle

The elements directly influenced by Granarolo (relating to the processing and handling of milk) characterized by greatest impact are energy consumption for the pasteurization phase and the production of packaging (e.g. PET bottle production is characterized by a significant consumption of energy resources).

It must be considered that Granarolo, besides operating on pasteurization and packaging equipment to make these more efficient in terms of energy consumption, has designed specific programs to reduce the environmental impact associated with the packaging phase.

The actions developed in reference to High Quality Milk packaged in PET are illustrated in Figure 4; they have contributed to reduce the 2009 Granarolo carbon footprint[1] of about 4.500 tons of CO_{2eq} per year; this quantity is equivalent to CO_2 emissions associated with the lighting of a town of 45.000 inhabitants for 1 year[2].

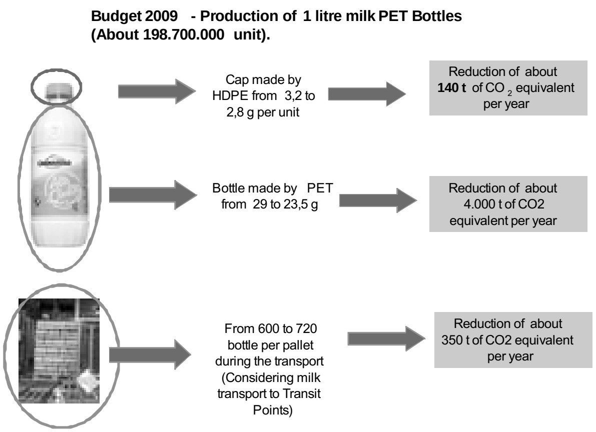

Figure 4 – Improvement actions developed by Granarolo in order to reduce the environmental impact of Fresh High Quality Milk packed in PET Bottle.

[1] Carbon Footprint represents the total amount of greenhouse gases (GHG) produced in direct or indirect support of human activities, usually expressed in equivalent tons of CO_2 with the relative indicator, commonly called "global warming potential. For more details see www.pcf-world-forum.org/

[2] Calculated assuming the consumption of lighting energy of 120kWh/(yr inhabitant) and forecast production 2009 of milk bottles from 1 liter PET AQ.

6. Conclusion

The LCA study and the Environmental Product Declaration EPD related to Granarolo High Quality Milk packed in PET bottles represent a useful means of dissemination and environmental communication for the Company, as well as an effective tool for sustainability. The LCA study has helped Granarolo to identify (in light of the life cycle of entire milk production process) some potential actions for environmental improvement.

In support of the above expression it is interesting to note that this experience has enabled Granarolo to obtain a series of recommendations to apply within the enterprise management system in order to implement strategies finalized at reducing corporate environmental impact.

In particular, Granarolo has focused attention on the milk packaging phase through specific activities (the most important is the PET bottles weight reduction) that have made it possible to reduce the company's carbon footprint at 2009 of a share to 4.500 tonne of $CO_{2\ eq}$.

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Life Cycle Assessment applied to two French dairy systems

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ABSTRACT

The environmental assessment of dairy systems has firstly focused on nitrogen flows and losses, then on other environmental concerns (phosphorus, pesticides, use of energy…), and it is now necessary to perform a more global environmental assessment of livestock systems. A Life Cycle Assessment (LCA) tool designed for the dairy sector was applied to two experimental dairy farms in western France, representative of the dairy systems currently in place in these regions. The total impacts, per 1000 litres of milk are similar on both sites, with the exception of terrestrial toxicity and the use of non-renewable energies. The differences between these two farms can be explained by the level of productivity and the fertilizer management.

Keywords: Milk, Life Cycle Assessment, Dairy system, Environment

1. Introduction

Productive dairy systems have negative impacts on the environment. Over the last 15 years, most studies and assessments performed in France and Europe have focused on nitrogen flows and losses. In recent years, a larger number of environmental concerns have been raised, including water pollution (nitrates, phosphorus, pesticides, pathogens, etc.), air pollution (ammonia, greenhouse gases, etc.), soil pollution (heavy metal accumulation, etc.) and the use of resources (energy, water, etc.). Experimental farms are very useful tools to provide such detailed environmental references for different production systems.

There is now a need to perform a more global environmental assessment of livestock systems. To meet this challenge, Life Cycle Assessment is appropriate and should provide keys to compare dairy production systems and analyse environmental efficiency.

This paper describes the application of LCA to two experimental dairy farms in western France.

2. Equipment and methods

The EDEN tool (Dairy Farm Sustainability Assessment) was used. It has been developed as a part of an Agro-transfert project by the INRA and the Brittany Chambers of Agriculture (Kanyarushoki, 2006) and aims at performing environmental evaluations, based on the life cycle assessment framework. The method focuses on direct pollutant emissions from farms and indirect emissions associated with the inputs used. These emissions were assessed, based on emission factors applied to the flows in question. They were then translated into impact

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indicators: eutrophication, climate change, acidification, terrestrial toxicity, energy, surface occupation).

This LCA method was applied to two experimental dairy farms in western France (Derval in the Loire Atlantique region, and Trévarez in Finistère), for the years 2003, 2004 and 2005. As the variability of the data over the three years was low (no major modification on farm management), average data were used. Those farms have been followed by Institut de l'Elevage for several years, providing references concerning their technical and environmental running. Indicators at farm level, such as nitrogen surplus (input/output balance), measured nitrate leaching or input purchase, are then available for these farms. They are representative of the dairy systems currently in place in western France. Stocking rates and dairy production per hectare are moderate. Dairy herd management is economical in Trévarez but much more intensive in Derval.

To assure the relevance of the results, a comparison was made with those obtained in a sample of 41 commercial similar dairy farms in western France (van der Werf *et al.*, 2009). They were also compared to a publication from New Zealand (Basset-Mens, 2006) where dairy systems are different.

3. Results

Table 1 summarizes technical characteristics, environmental classical indicators and impacts results obtained for the two farms studied, for the western France and the New Zealander dairy systems.

Regarding the environmental indicators, the farms studied are optimised overall, particularly in terms of nitrogen management (concentrates and fertilizers). Nitrogen surpluses measured at farm level are moderate (below 100 kg/ha). However, the nitrogen losses measured are relatively high and represent a significant proportion of the nitrogen surplus (more than 70%). The leaching estimated by the EDEN method, based on the surplus, is close to that measured on the basis of nitrogen residue analyses performed during the winter on the dairy farm's paddocks. Phosphorus flows are moderate with, as a result, low estimated losses by surface runoff (<1kg P_2O_5/ha). Direct and indirect energy consumption appears to be close to those recorded in other studies. Taking into account the use of herbicides on fodder corn, pesticides pressure per hectare is significant.

The total impacts, per 1000 litres of milk, calculated on the basis of these flows and emissions, are similar on both sites. Almost 80% of most of the impacts are linked to flows occurring on farm site (Table 2). The major differences, in terms of impacts and contributions, appear for terrestrial toxicity and the use of non-renewable energies. The application of pig manure and a lower dairy productivity per hectare in Trévarez, respectively explain these gaps.

The impacts observed appear to be very similar to those obtained in 41 commercial dairy farms in western France (van der Werf *et al.*, 2009). In contrast, the environmental impact of these dairy systems seems greater than that observed in dairy systems in New Zealand, based on grazing, in particular for eutrophication and energy use (Basset-Mens *et al.*, 2009). Nevertheless, Global Warming potentials are very close between the situations.

Table 1: Flows, emissions and impact indicators of different dairy systems

	Trévarez	**Derval**	**Commercial farms Brittany**	**Average Dairy farm New Zealand**
	This study	This study	Van der Werf *et al.*, 2009	Basset-Mens *et al.*, 2009
Dairy system studied				
% Fodder Area/AA	91	86	75	100
% Maize forage/Fodder Area	31	39	30	0
Stocking rate (LU/ha FA)	1.5	1.4	1.5	2.74
Concentrates (kg/cow)	520	1573	761	0
Milk produced (kg/cow/year)	6579	8488	7500	3763
Milk produced (kg/ha AA)	5951	7169	5300	11300
Nitrogen flows (kg/ha AA)				
Mineral fertilizer	45	31	60	114
input/output balance [1]	89	77	90	-
N leached measured [2]	64	54	-	31
N leached EDEN [3]	65	52	-	-
N emissions into air	39	36	-	41
Phosphorus flows (kg P/ha AA)				
Mineral fertilizer	8	8	-	49
Total values (fertilizers + wastes)	30	28	-	-
Input/output balance (kg/ha AA)	15	10	-	
P runoff [4]	0.30	0.28	-	
Energy consumption (MJ/ha)				
Direct energy (electricity, fuel)	8 484	9 165		-
Indirect energy (fertilizer, conc.)	7 267	7 840		-
Use of pesticides				
Product application (g AI/ha AA)	1020	623	777	-
% herbicides	99	95	-	-
Total impact [5](per 1000 l milk)				
Eutrophication (kg eq. PO_4)	7.1	4.8	7.1	2.8
Acidification (kg eq. SO_2)	9.6	6.6	7.6	7.7
Global Warming (kg eq. CO_2)	892	737	1037	884
Terr. toxicity (kg eq. 1-4 DCB)	12.9	6.7	-	-
Energy use (MJ)	4121	3084	2800	1436
Surface occupation (m^2/year)	1662	1437	1374	1084

[1]: nitrogen balances on the farm excluding atmospheric deposition
[2]: N leached based on residue analyses performed Oct-Feb
[3]: N leached estimated on the basis of the nitrogen balance - nitrogen losses into air
[4]: P runoff: 1% of soil values (fertilizers + wastes)
[5]: based on characterisation factors in Guinée et al., 2002

Table 2: Direct and indirect contributions to each environmental impact (per 1000 l milk) and identification of the main sources

	Trévarez		**Derval**		**main sources**
	indirect	**direct**	**indirect**	**direct**	
Eutrophication	13%	88%	14%	86%	fertilizer (nitrate leaching)
Acidification	21%	79%	18%	82%	housing and manure spreading
Global Warming	20%	80%	25%	75%	enteric fermentation and manure (buildings and storage)
Terr. Toxicity	28%	72%	58%	42%	organic fertilizer
Energy Use	73%	27%	71%	29%	energy for fuel and electricity
Surface Occupation	18%	82%	23%	77%	farm area

4. Discussion

This initial application of the LCA offers a more integrated vision of the environmental impact of dairy systems. These results underline the fact that LCA, applied to several dairy production systems, can supply differentiated results for a range of impact categories. This is provided by detailed and appropriate technical data, and the use of relevant simulation models to estimate the emissions to the environment. The differences between these two farms can be explained by the level of productivity and the fertilizer management. However, it is advisable to repeat the exercise in relation to more mixed systems in order to explore and understand the variability of the results. This variability may be linked to the diversity of the systems and the production conditions across countries, as illustrated in Table1. The use of concentrates and mineral fertilizers on the one hand, and the part and productivity of forage areas on the other hand, explain most of the differences between the systems. This is particularly well illustrated by the differences between French and New Zealander contexts. Both are intensive production systems, but in New-Zealand the use of permanent grassland, high stocking rates and the non use of concentrates, bring to lower impact expressed per 1000 liter of milk. First results of carbon footprint obtained for some types of cattle systems common in France underline the variability and the major effect of the animal productivity and the forage system (part of grassland and concentrates) on the results (Dollé *et al.* 2009). This approach should now be extended to other environmental impacts. Applying LCA to a large sample of farms and production systems should then provide a new key to the analysis of the system variability in the French context.

LCA also makes it possible to identify the main sources of emissions and the contribution to the impacts studied. In dairy systems, most of the mitigation options are on farm and concern herd and fertilizer management improvement. But these options have to be adapted to each system context.

To analyse and explain the results obtained, it is necessary to use environmental indicators that are more familiar to farmers, such as nitrogen surplus or fertilizer use. These are the indicators useful for advising, to identify mitigation strategies and to allow farmers to move towards practices more respectful for the environment. Beyond the system approach, the variability may also occur from a farm to another, in a same production system, as already determined in Switzerland by Rossier *at al.* (2001). This demonstrates the necessity of individualised advice to provide targeted strategies in order to decrease the environmental impacts of farms.

This environmental improvement is also the condition to supply the market with agricultural products with a reduced environmental footprint. This is particularly relevant in France, in the perspective of the application of the “Grenelle de l’Environnement” law, which plans both an environmental labelling of products and the improvement of the whole production and distribution chain of products.

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Using environmental constraints to formulate low-impact poultry feeds

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ABSTRACT

Eutrophication (E) and Climate Change (CC) impact were used as environmental constraints to formulate low-impact poultry feed. Our simulations were focused on fast-growing broilers, slow-growing broilers (i.e. quality label) and laying hens feeds, and on three contrasting feed-cost situations (January 2006, December 2007, March 2009) by using a linear programming tool. The effects of using these constraints on feed cost and the use of feed components was investigated. For a feed production plant in Bretagne (western France), environmental impacts of poultry feed increased with the energy and protein content of the formula and were affected by the relative costs of feed components. The search for a minimum level of E and CC of the formula decreased its impacts by 1-8% and by 1-12% respectively, and increased its cost by 2-8%, depending on the type of feed and the economic situation. Impact reduction was obtained by partial substitution of soybean meal and cereals by rapeseed meal, grain legumes and co-products (wheat bran, gluten). Furthermore, almost two thirds of the potential reduction of the E and CC impacts could be obtained at a modest (1-3%) increase in the cost of the formulas.

Keywords: Eutrophication, climate change, environmental constraints, formulation, poultry feed

1. Introduction

Feedstuff production is considered as one of the major contributors to the environmental impacts of animal production systems (Basset-Mens and van der Werf, 2005). Katajajuuri *et al.* (2008), using the Life Cycle Assessment (LCA) method, found that feed production accounted for 25% of primary energy demand, 36% of global warming, 25% of acidification and 65% of eutrophication associated with all production phases from parent stock and production of farming inputs to product distribution and sales in retail stores of a typical broiler chicken fillet product in Finland. Linear programming (LP) aims to find the least-cost combination of ingredients satisfying a specific level of nutritional requirement and regulatory constraints. The question is whether there are feed formulation strategies, in a specific economic situation, which can reduce environmental impacts of concentrate feed for poultry. The aims of this study are (1) to assess the environmental impacts of poultry feed formulas using an LCA database of feed components and a linear programming tool for three contrasting feed-cost situations and (2) to analyze the effects of using environmental constraints to formulate low-impact poultry feeds on feed cost and the use of feed components.

2. Materials and methods

2.1. LCA of poultry feed components

The present LCA study does not deal with the entire life cycle of poultry feed. Only the production on the farm, the subsequent drying and processing (e.g. extraction of oil), and the

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transport of feed components to the feed production plant (in Pontivy, Bretagne) were included, but processing at plant (grinding, pelleting) was not included.

Impacts of feed components were assessed at two levels: average national and, for maize only, average regional. Regions included in this study were either the most representative for the production of the crop, or characterised by a contrasting crop management. The period considered begins at the soil preparation for the crop in question and ends at the soil preparation for the next cash crop. This period may include a catch crop.

The functional unit was “1 kg of a mix of feed components corresponding to a feed formula delivered at the feed production plant”. The economic allocation method was applied for feed components resulting from processes yielding several co-products.

The impact categories considered were: eutrophication (kg PO_4--- eq.), climate change (kg CO_2 eq.), acidification (kg SO_2 eq.), terrestrial ecotoxicity (kg 1-4 DB eq.), cumulative energy demand (MJ eq.) and land occupation (m^2a).

2.2. Formulation of poultry feed

Choice of contrasting feed-cost situations. Prices of feed components were taken from the “Dépêche Commerciale” newspaper and reprocessed by ITAVI (French Poultry Technical Institute) to obtain a price at the feed plant. The price of the feed formula is estimated as the sum of price of the feed components without the premix. Three contrasting feed-cost situations (January 2006, December 2007, and March 2009) were identified, based on the price of soybean meal, wheat and maize.

Nutritional and regulatory constraints. This study considered feeds for fast-growing (FG) broilers (growing and finishing), slow-growing (SG) broilers (i.e. quality label, including growing and finishing period) and laying hens. Nutritional characterizations of feed components were based on Sauvant *et al.* (2002). Metabolizable energy and crude protein requirements for different types of poultry production are presented in Table 1. All nutritional requirements and regulatory constraints for different types of poultry production were based on poultry feeding expert advice by ITAVI.

Table 1: Metabolizable energy (ME) and crude protein (CP) requirements for different types of poultry

		FG growing	FG finishing	SG growing	SG finishing	Laying hens
ME (kcal/kg)	Mini	2980	3070	2880	2950	2700
CP (%)	Mini	20	18	18	16	16.5
	Maxi	21	19	25	19	17

Environmental constraints and formulation using LP model. We focused on Eutrophication (E, a regional impact) and Climate Change (CC, a global impact) which were constraints in the feed formulation. The objective of LP model is to minimize the cost of the feed formula, satisfy all nutritional and regulatory constraints, and reduce environmental impacts. Firstly, we searched for least-cost formulas without applying environmental constraints, i.e. “free formula”. Then we integrated environmental constraints in the LP model for each type of poultry production in order to identify the potentially achievable minimum levels for E and CC. Values of E and CC of the free formula were decreased gradually, and to a similar extent, until the LP model could not find any solution. When the same formula was obtained for the three feed-cost situations, it was considered to be the “lowest impact level” for this type of poultry production.

2.3. Studied scenarios

Average national feed ingredients. The feed production plant is located in Pontivy, Bretagne (western France), which is the major poultry production region in France. For “average national feedstuffs” the transport distance between the crop production farm and the feed plant was assumed to be 500 km by rail and 100 km by road. Soybean oil and meal were imported from Brazil and palm oil from Malaysia.

Consideration of production region of feed components: an example with maize. For a feed production plant in Bretagne, "average national" maize in the formulation matrix was replaced by several "regional" maize. The regions of maize production and transporting maize to production plants were considered as Table 2.

Table 2: Average transport distance of regional maize to the feed production plant in Bretagne

Region of maize production	Distance (km)	Road (km)	Rail (km)
Bretagne	110	110	
Pays de la Loire	250	100	150
Centre	450	100	350
Poitou-Charentes	400	100	300
Aquitaine	650	100	550

Modification of the regulatory constraint regarding cereals for slow-growing broiler feed. The regulatory constraint imposing incorporation of "at least 75% of cereals and co-products" for Label broiler production was replaced by "at least 80% of grain legumes, cereals and co-products".

3. Results and discussions

3.1. Average national feed ingredients

Free formulas. CC and E impacts of the least cost formulas without environmental constraints (free formula) for FG broiler (growing-finishing), SG broiler (growing-finishing), laying hen and for three contrasting feed-cost situations studies are presented in Table 3. For a feed production plant in Bretagne, CC and E increased with the energy and protein content of the formula and were affected by the relative costs of feed components. FG broiler formulas had the highest impacts, followed by formulas for SG broilers and laying hens. These differences principally related to soybean meal and cereal contents (Fig. 1). The FG broiler formulas contained 25 to 33% soybean meal and 60 to 65% cereals, while SG broiler formulas contained 18 to 20% soybean meal and 72 to 75% cereals. Laying hens formulas contained less soybean meal (22%) and cereals (65%), but more calcium (9%).

Table 3: Climate change and Eutrophication impacts of least cost formulas without environmental constraints of growing and finishing feed for fast growing (FG) and slow growing (SG) broilers and of laying hens feed in three feed-cost situations

	Climate change (kg CO_2 eq./t)			Eutrophication (kg PO_4 eq./t)		
	Jan 06	Dec 07	Mars 09	Jan 06	Dec 07	Mars 09
FG growing	666	660	738	4.9	5.3	5.0
FG finishing	647	645	714	5.1	5.2	5.1
SG growing	613	610	626	4.6	4.7	4.6
SG finishing	601	595	636	4.5	4.8	4.6
Laying hens	568	570	568	4.3	4.5	4.3

The incorporation rates of wheat and maize, and of soybean oil and palm oil depended on the feed-cost situation. Thus, maize was mainly used in Dec07 formulas and palm oil only in Mar09 formulas. CC of feed formulas was higher for Mar09 than for Jan06 and Dec07 for all least cost formulas except for the laying hens formula, due to the incorporation of palm oil (Table 3, Fig. 1). E of all least cost formulas was higher for Dec07 than for Jan06 and Mar09, due to a higher rate of maize incorporation.

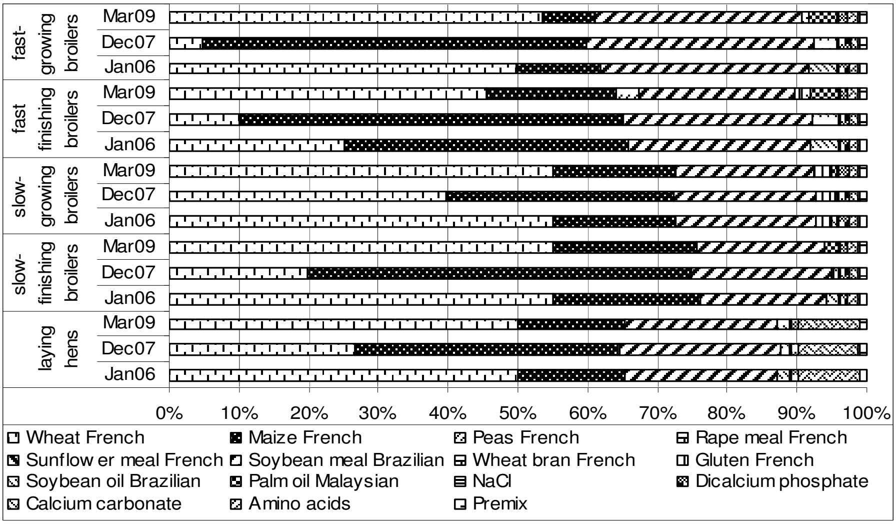

Figure 1: Composition of least cost formulas without environmental constraints (free formula) for different types of poultry feeds using national average raw materials for three feed-cost situations

Least cost formula with environmental constraints. The search for a minimum level of impacts decreased E by 1-8% and CC by 1-12%, and increased cost by 2-8%, depending on the type of feed and the economic situation (Fig. 2). For Dec07, the largest decrease of E was found (4 to 8%) due to reduced maize incorporation, whereas the largest decrease of CC occurred for Mar09 (3 to 12%) due to the replacement of palm oil by soybean oil. The reduction of E and CC for Jan06 was less than for other feed-cost situations as no palm oil was used and less maize was used. So the margins for the improvement of Jan06 are modest, illustrating the major effect of the feed-cost situation on the potential for improvement.

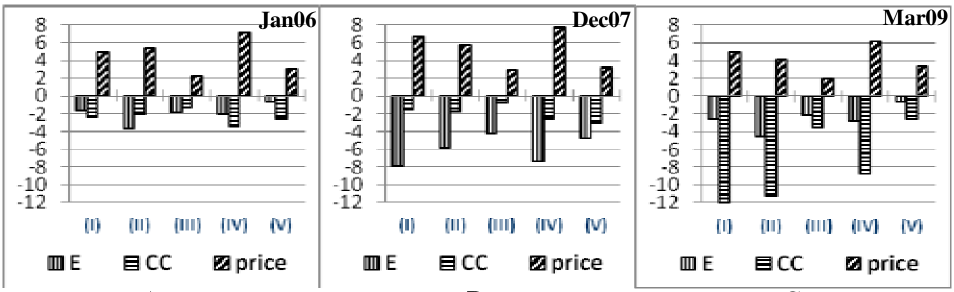

Figure 2 (A, B, C): Potential reduction of the eutrophication and climate change impacts (in %) and increase of the price (in %) of different type of poultry formulas (I: Fast-growing (FG) broiler growing; II: FG broiler finishing; III: slow-growing (SG) broiler growing; IV: SG broiler finishing; V: laying hen) in three feed cost situation (A: Jan06; B: Dec07; C: Mar09)

The reduction of impacts for SG broiler and laying hen formulas was less than that for other types of poultry feed because of their lower nutritional and regulatory constraints.

Impact reduction was obtained by partial substitution of soybean meal and cereals by rapeseed meal, grain legumes and co-products (wheat bran, gluten) (Fig. 3). Other impacts generally decreased when E and CC constraints were applied. Furthermore, almost two thirds of the potential reduction of the E and CC impacts could be obtained at a modest (1-3 %) increase in the cost of the formulas.

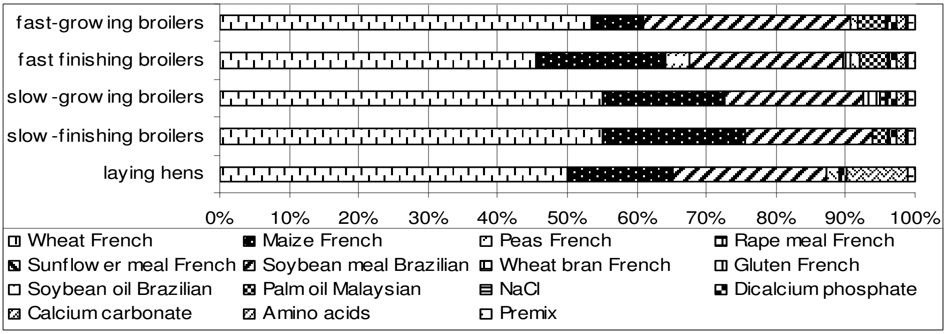

Figure 3: Composition of least cost formulas with Eutrophication (E) and Climate change (CC) constraints for different types of poultry feed using national average raw materials

3.2. Fast-growing broiler feed formula with regional maize

The use of regional data rather than average national data for the production characteristics of feed components revealed additional options for the reduction of the feed's environmental impacts at a lesser cost. For example, E and CC impacts were lower for maize of the Pays de la Loire, Bretagne and Centre regions than for maize representative of average practice in France, because of differences in crop production practices and transport distance. Maize produced according to these scenarios was incorporated at a high rate (55%), due to its smaller impacts relative to average national maize. This allowed a reduction of the feed's E and CC impacts by 2-16 % and 3-17 % respectively at a relatively modest increase in cost (less than 5%), depending on feed-cost situation and source of maize use, as compared to the free formula using average national maize (Fig.4: for Jan06).

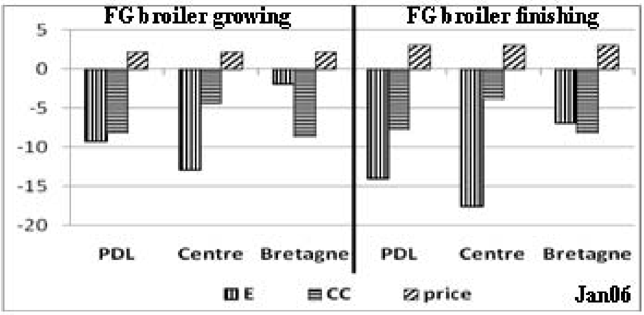

Figure 4: Potential reduction of the eutrophication and climate change impacts and increase of the cost for fast-growing (FG) broiler (growing and finishing) feed formulas in Jan06 with regional maize use (PDL: Pays de la Loire; Centre and Bretagne)

3.3. Modification of the regulatory constraint regarding cereals for slow-growing broiler feed

The replacement of the constraint imposing "at least 75% of cereals and co-products" by a constraint requiring "at least 80% of grain legumes, cereals and co-products" increased the incorporation of grain legumes in the free formula by 15-22%, decreased the use of soybean meal (by 5%) and cereal (mainly maize, by 10-17%). These substitutions of feed components reduced CC by 0-8% but increased E by 12-22%, relative to the free formula with the current constraint (Fig.5A). The increase of E resulted from relatively high nitrate losses for pea.

The effect on formula cost varied from -3.8 to 1.4%. The formula with environmental and new regulatory constraints increased E (7-15%) and decreased CC (10-15%), while the cost increased by 3-5% relative to the free formula with the current regulatory constraint (Fig.5B).

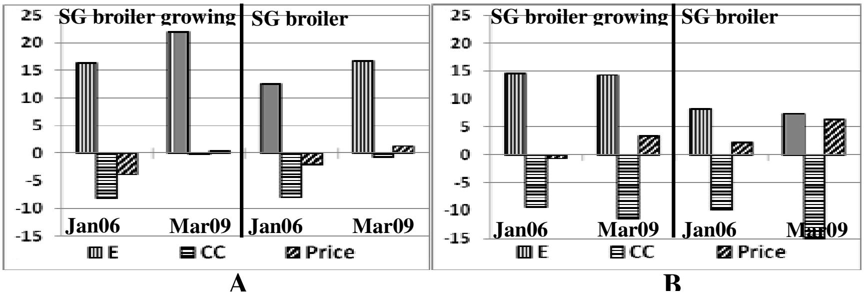

Figure 5 (A, B): Potential reduction of the eutrophication (E) and climate change(CC) impacts (in %) and increase of the cost (in %) for slow-growing (SG) broiler (growing and finishing) formulas (with (B) or without (A) environmental constraints) for the "at least 80% of grain legumes, cereals and co-products" constraint in Jan06 and Mar09, relative to formulas with "at least 75% of cereals and co-products" without environmental constraints

4. Conclusions

The assessment of the potential environmental impacts of established least cost feed formulas demonstrated that the environmental impacts tend to increase with energy and protein content of formulas and, to a larger extent, on the feed-cost situation. Consideration of the impacts of feed components in the formulation model modified raw material incorporation and increase feed price. However, we could find compromise formulas in which environmental performance was improved and cost increase was modest.

We intend to expand the database by including other raw materials based on regional data. The processing of concentrated feed should be included and the evaluation of different feeding systems should be integrated in this approach.

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Life Cycle Assessment of milk production in Argentina: one first approach

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ABSTRACT

This article proposes an evaluation of the environmental behaviour of milk production in the region using LCA. Historically, Argentina has been an exporter of raw materials; recently, non-traditional manufactured products have been incorporated. Concern has arisen lately in buyer countries about the environmental quality of the imported products: eco-labels, certifications, EPDs, food miles and carbon footprint, all of which are closely related to LCA. The aim of this work is to collaborate with milk producers to improve the environmental quality of their products, in order to reach the required certifications and/or standard regulations. The agricultural stage in food production is the key process in most of the impact categories. Also, methane emissions from enteric fermentation have been modelled in a separate scenario to evaluate their possible influence. Since this is one of the first research projects to analize milk production in the region, special attention has been paid to examining the sources of error such as lack of local databases, their dimensions, and how they might affect results.

Key words: LCA, milk production, Argentina, environmental performance, local databases

1. Introduction

This paper proposes the evaluation of the environmental performance of milk production at a regional level using LCA, a methodological approach which has not yet been used frequently in scientific research in the agrifood sector in Argentina. The country has historically been an exporter of raw materials, mainly in the primary sector, with products like grains and meat. Lately, some other products have been included, mainly wine, fine fruits, vegetables and dairy products.

Dairy activity is very important in Argentina, it has expanded greatly and it is highly diversified. The most suitable and profitable regions for the development of intensive dairy activities are in the central belt of the country, the Pampas region and surrounding areas. This being the richest agricultural land of the region, it is occupied by competing activities, livestock and agricultural farming, which are closely linked to profit and their competitor's performance. Dairy production differs among the subregions, resulting in different milk basins which are characterized by their management trends, the raw materials available to them and their productivity. At a regional level, dairy management is mainly extensive and based on pastures, with milk production throughout the year. This is possible due to forage conservation technologies for the winter period.

2. Context

Figure 1 presents an up-to-date general view of Argentine exports of dairy products and their relative positioning. The total numbers of farms have decreased since 2005; there has been a progressive change and now there are fewer dairies in the country, with more animals and a higher productivity, related to the use of concentrate animal feed. During the same

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period, dairy products exports have increased, but the offer in the domestic market has declined due to a fall in its profitability. Being a partially regulated activity, it has been displaced over the last few years by other, more profitable, short-term agricultural activities.

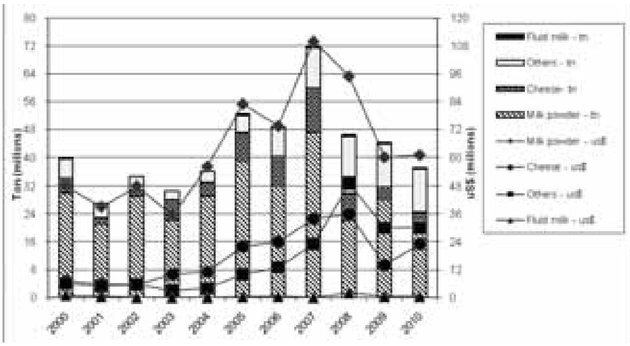

Figure 1: Evolution of Argentine exports of dairy products. January-February 2000-2010. Source: Secretary of Agriculture, Livestock and Fishery, 2010.

Over the past few years, world wide food production production has been affected by unwanted events that have affected consumers' trust in food products. Since then, there has been an increasing interest in quality management systems to certify their origin and production.The White Paper on Food Safety, adopted in January 2000, sets some basics to support food laws in the European Union. These principles are based on a whole product policy, guaranteed by economic operators and verified by competent authorities. The new Regulation on the EU Ecolabel stands for lower environmental impacts throughout a product's life cycle – from its manufacture to its disposal.

Since 2005, ISO has been working on a specific traceability standard (ISO 22000) which gathers, records and certifies information on packaging, transportation, storage and distribution along the supply chain of the product under evaluation. This information is extremely useful when working with LCA, since it considerably simplifies the collection of data.

Concern has recently arisen from buyer countries about the environmental quality of imported products, which has materialized in some ecolabels and certifications. The same happens with other types of required information about the environmental profile of products, like food miles and carbon footprint, which are closely related to LCA. This kind of standards are being asked of argentine producers in order for them to be able to enter or remain in a market they have already achieved; particularly in horticulture, meat, fruits and wine products. Many countries have implemented measures to maintain their positioning in the market, such as regulations that aim to follow the traceability of food products throughout their life cycle.

Nowadays, argentine food exports must comply with specific regulations, demanded by their buyers. Some measures have been applied in different agricultural subsectors: pesticides, toxic contents in food, meat traceability. However, these have not been applied systematically, nor have ecolabels or carbon footprint systems been requested. Nevertheless, organic producers have developed specific certifications for their products, including milk and dairy products, as well as origin certifications. In Argentina, the centralized organizations for national food safety are SENASA[1] and INTI[2]. The former deals mainly with food and health safety, while the latter deals with technology and protocol certifications. In 1991, the

[1] Servicio Nacional de Sanidad y Calidad Agroalimentaria
[2] Instituto Nacional de Tecnología Industrial

REDELAC[3] was created within the CITIL[4] framework. This network groups corporate laboratories, milk producers, independent laboratories and INTI; and it has positioned Argentina´s reproducibility levels among those of the most advanced dairy countries, as recommended by the International Milk Federation.

3. Goal and scope of the study

The main reason for carrying out agrifood LCA studies here and now lies on the possibility to collaborate with milk producers on improving the environmental quality of their products, in order to reach certifications of requested standards to maintain their positioning among buyer countries. The aim is to detect critical points and offer ideas for improvement whenever possible.

Given the differences in management and technology among the different milk basins, one of them has been chosen to begin this study. Abasto Basin is one of the oldest milk basins in Argentina; it is characterized by its animal per land intensity, for having the best productivity index and the highest concentrate feed consumption. The progressive displacement of dairy activity in the region is due to urban expansion and to the advance of other more profitable, short-term agricultural activities.

4. System under study

The data on which this LCA is based refers to the regional analysis performed by INTA in 2003, which deals with average conditions in milk production. The farms that have been studied cover, on average, 230 ha each, of which almost 60% is covered with pastures and other crops for silage or concentrated feed. Each of them has between 160 and 180 dry and milking cows, fed mainly on pastures. They have 1,17 animals/ha on average and daily milk production reaches 2300 liters/day - 16,9 l/day/cow - milking twice a day. Local dairy production is mainly consumed locally, as milk, cheese, yogurt, dulce de leche (milk candy) and powder milk. Milk is commonly refrigerated and delivered to the distribution facilities where it is treated and made fit to be packaged and distributed. Specific data on operations and management was gathered from 3 different farms with 158, 162 and 175 animals each. Regarding the production of calves (one per adult cow per year), 50% are male and are disposed of a few days after they are born (they are either sold or consumed). The females are bred for two years and then incorporated to the productive staff, thus reaching an annual renewal of 25% of milking cows.

The system studied in this work includes the following processes: production of **pastures, of concentrate feed, silage, general dairy operations** and **solid waste disposal,** all of which occur simultaneously. General dairy operation includes milking and other auxiliary tasks performed at the farm. The functional unit considered here was the yearly average milk production, amounting to 850600 L/year. Equipment manufacture and infrastructure have been excluded from this study. Transport to packaging facilities has been excluded as well.

5. Life cycle inventory

5.1 Subsystems

Pastures: Cattle feeds mainly on pastures; therefore this is one of the most important subsystems. There are different management options, with different levels of intensity. The

[3] Red Argentina de Laboratorios Lácteos
[4] Centro de Investigaciones y Laboratorios Lácteos

most common practice, which has been looked into for this study, is biannual crop rotation of different species of pastures, using appropriate agricultural machinery and small amounts of fertilizers.

Concentrated Feed: More than 20% of cattle diet is supplied through concentrate feed, manufactured with wheat, corn, soy and a mixture of forage crops, and using minerals additives. An average of 230 t/year is used to feed 160 productive animals. The agricultural stage considered in this study includes soil preparation, sowing, fertilization and harvest.
The distance to feed manufacturing facilities ranges from 50 to 65 km. Manufacture is included in this study for its contribution of energy, from fuel, gas and electricity. Concentrated feed is distributed in bulk, directly poured in silages from the trucks, which explains the exclusion of packaging at this stage.

Silage: An increasingly common practice is to crop different grains on the field to keep a feedstock backup to be used during the winter or in case of emergency. Milking facilities use up to 200 t/year of HDPE silage infrastructure, mainly for corn. Packaging and fermentation machinery were also included in this study.

General Dairy Operations: This process includes milking and other auxiliary tasks performed at the dairy: milk cooling, use of tractors for multiple tasks (lubricating oil and fuel) and electricity consumption for water pumps and milking machines.

Solid Waste Disposal Solid waste comes mainly from the disposable parts of milking machines, safety and cleaning items, medicine and general waste generated by dairy workers. Since a lot of packaging is involved, it is reused in the establishment whenever possible, or returned to the supplier. But even so, plenty of packaging material is stored and then burnt (open incineration). Yearly, approximately 360 kg of solid waste are generated; mainly different types of plastics, including PVC. Other materials are latex, neoprene, paper and small quantities of tin and steel.

5.2. Material and Energy inputs

The production of the functional unit defined demanded: 230 t of concentrate feed, 200 t of silage, (including 260 t of maize, 46 t of wheat, 55 t of soybean and 69 t of other fodder crops); 139 has of pastures and 82 t of maize, consumed as grain. Energy demand was $1{,}18x10^5$ MJ of diesel, $5{,}26x10^4$ MJ of electricity and $5{,}06x10^3$ MJ of gas. Fertilizers accounted for $1{,}89x10^3$ kg of N, $3{,}67x10^3$ kg of P and $1{,}06x10^3$ kg of K. Plastic consumption is 183 kg of HDPE, 154 kg of LDPE, 12,3 kg of PVC, 75,6 kg PP and 14,4 kg of PET. Lubricant oil consumption was 15 l and other chemical compounds 184 kg (cleaning agents, rubbers, metals, etc), and transport estimations were $2{,}76x10^4$ tkm.

6. Results

Calculations were made using SimaPro 7.0, with BUWAL, ETH and Ecoinvent databases. Some of the data has been adapted in order to represent local conditions, which was the case of electricity. The system was analyzed using EDIP 97 factors.

From the results obtained, excluding methane emissions (fig 2), it is clearly seen that stages related to feeding animals are the most significant process in almost every impact category, contributing up to 95 or 100%. However, for aquatic eco-toxicity, chronic and acute, food related stages decrease up to 40%, being displaced for General Dairy Operations and Waste Treatment Disposition units. As many other authors working with systems of this kind have concluded before (Berlin 2002, Cederberg 1998, Heide, 2002,), this study confirms that agriculture is the main contributing stage regarding environmental impact.

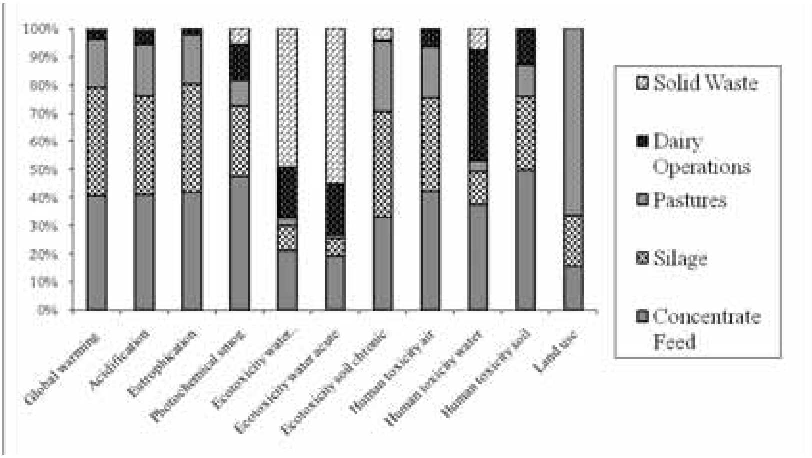

Fig 2: Environmental profile of system under study – Cattle CH4 emissions excluded.

Methane emissions from enteric fermentation have been estimated between 170 g/animal/day (Inventario Nacional UNICEN, 2006)[5] and 215 g/animal/day (78,5 kg/animal/year - INTA, 2003). In order to evaluate the impact, we have focused on the worst results. As expected, the environmental profile including methane emissions resulted in a worse performance for Global Warming Potential and Photochemical Smog.

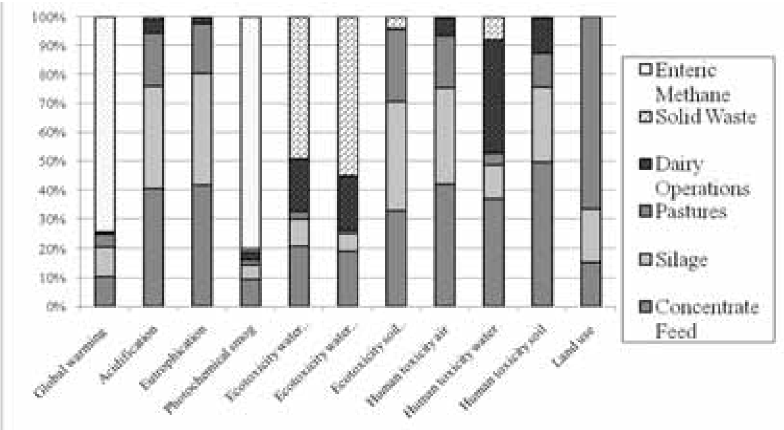

Fig 3: Environmental profile of system under study – CH4 from cattle included

CH4 emissions in Argentina represent 1.4% of worldwide methane emissions. Within Argentina, CH4 constitutes the 29,3% of GHG gases emitted locally. Cattle is responsible for 95% of enteric CH4 emissions; milk cattle only for 11,2%.

These emissions are very difficult to avoid because they occur due to ruminant enteric fermentation as part of the animals' metabolism. Some of the alternatives to reduce CH4 enteric are based on farm management (Gerber et al, 2010), but the most promising is related to the animals´ diet. New mitigating dietary strategies have been developed and applied to reduce CH4 emissions from ruminant, such as the addition of ionophores, fats, the use of high-quality forages, and an increased use of grains. These nutritional changes reduce CH4 emissions by manipulating ruminal fermentation, directly inhibiting methanogens, or by

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diverting hydrogen ions away from them (Boadi et al, 2004).

7. Conclusions and perspectives

This is one of the first research projects to analyze milk production in the region, therefore, special attention was paid to consider sources of error, their dimension and how they might influence the results. Some data included in this study are incomplete or roughly estimated, because no available database accounts for impacts on local conditions. That is particularly the case of detailed outputs from the use of fertilizers. The inputs and outputs due to the production of pesticides and seeds were excluded from the system in study because we could not get the specific data in the time available before this report was finished. Also, the application of biocides we found in available data base were very different from what was used actually in the region. If we have worked with those data, error margins would have been much more important that those we have been working until now.

From all the data gathered for this study, electricity consumption is probably the most uncertain. While making the assessment, nominal consumption and estimated times of use of each machine have been used. Nevertheless, the sensitivity analysis performed on this data results in less than 1% of variation in the environmental profile.

This experience has exposed key issues such as which data are available and which are insufficient and should be further developed. The application of ecolabeling programs would improve the positioning of dairy products in international markets.

In order to proceed from now on with the proposed objective - the environmental assessment of milk production in the region - the following activities are suggested: 1. improving the quality of input data for the data achieved from bibliography, national reports, similar technologies, et; 2. including subsystems that have been omitted here, like pesticide and seed production, in addition to more detailed emissions associated to soil and manure management; 3. extending the study to the rest of the milk producing areas not covered until now.

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Life cycle comparisons of greenhouse gas emissions from pasture-based dairy production of Ireland

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ABSTRACT

The objective of this paper was to estimate the change in greenhouse gas (GHG) emissions from Irish dairy production when mineral fertilizer N is replaced by biologically fixed N using white clover (*Trifolium repens* L.). Based on system trials at the Teagasc Solohead Research Farm from 2003-2006, the GHG (CO_2, CH_4 and N_2O) emissions from clover-based (WC) and mineral-N-fertiliser-based (FG) dairy production were compared using life cycle assessment (LCA) software, Simapro 7.1.8. Compared with the FG system, emissions from fertilizer use in the WC system were reduced by 61.9% and the overall emission from producing 1 kg energy corrected milk (ECM) from WC was reduced by 12.5%. N_2O emissions accounted for the main difference between the systems, which is closely connected with the N cycle on farm and the fertilizer production off farm. In both FG and WC systems, the most significant contributor to climate change was CH_4. Clover had little direct effect (P>0.05) on contributions of CH_4 or CO_2. The result showed that the reduced fertilizer use in the WC system can significantly reduce GHG emissions per kg ECM (if all assumptions are tenable). Detailed emission factors are still lacking and full testing of other impact categories is needed before a definitive conclusion can be drawn.

Key words: LCA, greenhouse gas emissions, Simapro, dairy production, Ireland

1. Introduction

There is growing public concern about the effect of greenhouse gas (GHG) emissions on global climate change. It is of even more concern for Ireland where the per capita GHG emissions are high as a result of the small human population and large cattle population (Waston, 2009). Agriculture is the single largest contributor to the overall GHG emissions in Ireland (EPA, 2009), and beef and dairy production currently account for more than half of agricultural output at producer prices (DAFF, 2008). Thus the GHG emissions of dairy production are of considerable importance to Ireland.

For conventional grazing systems, mineral fertilizer is a major source of nitrogen input. As a result of the increasing price of fertilizers and the more stringent regulation on N losses from intensively managed grassland, white clover (*Trifolium repens* L.) has received attention for its capacity to fix atmospheric N and make it available for pasture production. Research based on two parallel experiments of dairy farms in the Netherlands (Schils *et al*., 2005) found that white clover had a marked effect on the GHG emissions.

Life Cycle Assessment (LCA) is a holistic tool to assess the environmental impact of a system and has been applied to milk production in response to environmental impact concerns (Casey and Holden, 2005; Cederberg and Mattsson, 2000; Haas *et al*., 2001; Thomassen *et al*., 2008; van der Werf *et al*., 2009).

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The objective of this paper was to develop an attributional LCA model of two contrasting dairy systems in Ireland based on grass/clover and grass/fertilizer swards and to assess the potential of white clover for reducing GHG emissions.

2. Materials and Methods

The four parts of LCA methodology were implemented as following:

2.1 Goal and scope

The goal of this study was to assess the potential of white clover in reducing GHG emissions. This paper was based on system trials at the Teagasc Solohead Research Farm from 2003-2006 (Humphreys *et al.*, 2009), in which two dairy systems, one based on grass/fertilizer swards and the other on grass/clover swards, were evaluated (Table 1).

Table 1. System characteristics at Solohead averaged over 2003 to 2006

	Fertilized grass swards (FG)	**Clover based swards (WC)**
Stocking rate1 (LU ha^{-1})	2; 2.2	2; 2.2
Fertilizer N (kg ha^{-1})	218	90
Concentrate feed (kg cow^{-1} yr^{-1})	531	520
Milk delivered at farm gate (litre cow^{-1})	6225	6220
Milk fat percentage (%)	4.20	4.17
Milk protein percentage (%)	3.60	3.54

[1]The stocking rate (LU = livestock unit) was 2 for 2003 and 2.2 for 2004-2006

The functional unit (FU) was 1 kg energy corrected milk (ECM) and was defined as follows (Sjaunja et al., 1990):

$$\text{kg ECM} = \text{kg milk} * (0.25 + 0.122 * \text{Fat\%} + 0.077 * \text{Protein\%}) \tag{1}$$

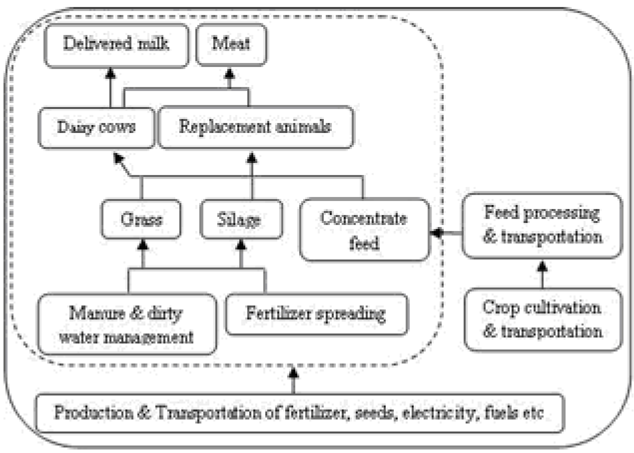

Figure 1. The conceptual model of the dairy unit (dashed line indicates the farm scope and solid line indicates system boundary)

The system boundary was set at the farm gate (Figure 1). Infrastructure and machinery were excluded as they were assumed to be the same for both systems. Soil carbon sequestration and small consumables were also excluded because of lack of data. Economic allocation between milk and meat from surplus calves and culled cows (both 91% for FG and WC) was used based on average market prices during 2000 to 2006.

2.2 Life Cycle inventory

The main Emission Factors (EFs) are summarized in Table 2. Background processes were selected from unit processes in Ecoinvent 2.0 database incorporated in Simapro 7.1.8 (PRé, 2007). Replacement animals (heifers and female calves) were originally excluded from the field system management although they are necessary for the dairy unit to function sustainably. To solve this problem, we assumed that one replacement equalled 0.95 livestock unit (LU), and the overall livestock were thus scaled up to 26.74 LU for 2003 and 29.18 LU for 2004-2006, respectively.

Table 2. Emission factors for grass-based dairy production in Ireland

	Carbon dioxide	Methane	Nitrous oxide
Enteric fermentation		GEI * 0.065/55.65 kg/cow [a]	0
Excreta deposited in field		$2.04 g/m^2$ dung [b]	dung 0.19%, urea 0.56% [c]
Slurry storage		$0.0082 kg/(m^3,d)$ [d]	$0.01 g/ m^3$ [e]
Slurry spreading		$0.00286 kg/m^3$ [f]	$0.0083 kg N/m^3$ [g]
FYM storage		$0.0059 kg/(m^3,d)$ [d]	$0.0011 kg/ (m^3,d)$ [g]
FYM spreading		2.7mg/kg [h]	0.0159 kg/t [g]
Fertilizer production [i]	8.2 kg kg CO2 eq/kg CAN-N, 3.07 kg CO2 eq/kg urea-N		
Fertilizer spreading			0.83% kg/kg N for CAN [j]
Concentrate feed production [i]		0.434 kg CO_2 eq/kg concentrate	
Electricity production [j]		0.636 kg CO_2 eq/kWh	
Diesel production and use [k]	3.56kg/L	0.00064kg/L	0.0007kg/L
Road transportation [l]	$207.8 kg/10^3tkm$	$0.32 kg/10^3tkm$	$0.045 kg/10^3tkm$
Water transportation [l]	$9 kg/10^5tkm$	$0.014 kg/10^5tkm$	$0.002 kg/10^5tkm$

[a] O'Mara *et al.*, 2006; [b] Jarvis *et al.*, 1995; [c] Yamulki *et al.*, 1998; [d] Husted, 1994; [e] Sneath *et al.*, 2004; [f] Sneath *et al.*, 1997; [g] Chadwick *et al.*, 1999; [h] Chadwick *et al*. 2000; [i] Ecoinvent 2.0; [j] Howley et al., 2008; [k] Kaltschmitt and Reinhardt, 1997; [l] Casey and Holden, 2005.

CH_4 from enteric fermentation was estimated from the annual gross energy intake (GEI) of feed that followed the average Irish composition (O'Mara *et al.*, 2006). Ingredients percentage in concentrate feed was obtained from feed suppliers and is commercially sensitive. Manure from the two groups of cattle was stored in one open tank and was applied back to each system based on calculated volumes of slurry produced by the animals (Humphreys *et al.*, 2009). Indirect N_2O emissions were estimated from IPCC (2006).

2.3 Life cycle Impact assessment

"IPCC 2007 GWP 100a" in the Simapro method library was used to assess the GHG per kg ECM, which defined that the Global Warming Potential (GWP) of CO_2 as 1, of CH_4 as 25, and of N_2O as 298 (100 years time span). The total emissions of GHG were determined as follows:

$$GHG = \sum GWP_i \times m_i \tag{2}$$

Where m_i is the mass (kg) of the emitted gas (Heijungs et al., 1992). The total impact was expressed as kg CO_2 eq (equivalents) per kg ECM. The “exclude infrastructure processes” was selected when running the LCIA.

2.4 Interpretation

Comparison between the two systems was based on emissions per kg ECM.

3. Results and Discussions

The emissions per FU and the contributions of the three GHGs are shown in Figure 2 (left). The WC system had 12.5% overall lower GHG emissions per FU than the FG system. Methane was the main contributor to the GHG emissions per kg ECM and clover in WC has the same impact on this value. However, the most significant reduction in GHG/kg ECM was resulted from the reduced nitrous oxide in the WC system (40.8% lower).

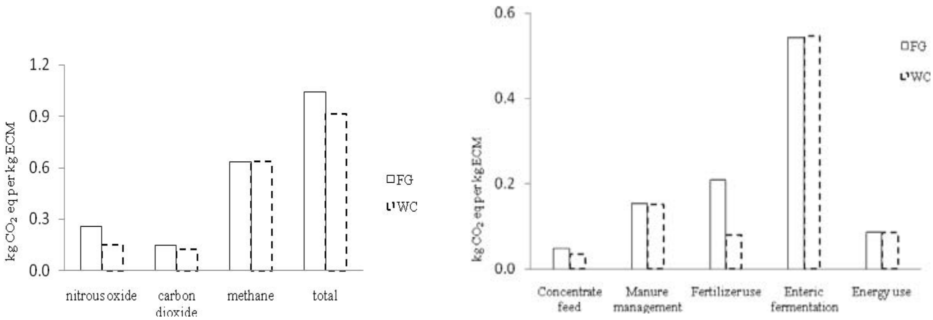

Figure 2. Left, overall GHG emissions per kg ECM and contributions of the three GHGs to global warming; Right, contributions of the main stages to global warming.

The main contribution of processes are shown in Figure 2 (right). Enteric fermentation dominated the life cycle of milk production up to the farm gate, which contributed 52.1% and 59.9% in FG and WC systems. It’s slightly higher in WC system as a result of higher dry matter intake ($P>0.05$). The second largest contributor in WC system was the manure management. Fertilizer use (including the production, transportation and spreading of fertlizer on farm) was the largest contributor to the difference between the two systems, which was 61.9% lower in GHG per kg ECM due to 58.7% lower in application rate (kg N/ha) for WC.

Casey and Holden (2005) studied the GHG emissions from an average dairy unit in Ireland and found producing 1 kg ECM would generate 1.3 kg CO_2 eq. While this is higher than that was estimated for the FG system in this paper, it should be noticed that there are several differences between the two papers: (1) they used a slightly lower economic allocation factor of 0.85; (2) the GWP they adopted for CH_4 was 21 and for N_2O was 310; (3) the dairy herd in their paper consisted of 47 dairy cows and 66 other animals; (5) they selected different EFs. A sensitivity analysis of those choices may be informative in the future.

Without detailed information about the production system and calculations used, direct comparison with other literature is even more difficult. In this paper the two systems have 12.5% difference in total emissions per kg ECM (1 kg ECM is about 1.036 kg milk), which is much lower than the 22% difference per kg milk as indicated by Schils et al (2005).

However, if the soil carbon sequestration reported in Schils' paper is deducted, which introduced emissions of -0.47 and -0.41 kg CO_2 eq per FU in grass/fertilizer and grass/clover system respectively, the difference between grass/fertilizer-N and grass/clover swards was only 11.2% and is close to what was found in this paper.

4. Conclusion

Andrews *et al*. (2007) suggested that the on-farm environmental impact (nutrient leaching and GHG emissions) from a mixed pasture where white clover contributes around 20% of total dry matter production can be similar with that from a perennial ryegrass pasture receiving 200 kg N $ha^{-1}yr^{-1}$. At this stage our results largely support this contention on GHG emissions because most of the differences predicted by the LCA are off-farm. However, detailed EFs are still lacking and full testing of other impact categories is needed before a definitive conclusion can be drawn.

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Using LCA in a forecasting method for reducing environmental impact of dairy farms

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ABSTRACT

Optimization of farm activities can be a key strategy to mitigate impacts on the environment. LCA was applied at the farm level to assess environmental impacts and identify environmental hot spots to propose improvement options. An experimental dairy farm with both dairy and cash-crop subsystems was analysed. Per 1000 kg of protein produced, the dairy subsystem had higher impacts than the crop subsystem. Compared to conventional intensive dairy farms in other European countries, the dairy subsystem had higher energy use per 1000 kg of milk, due mostly to feed production. The first actions to mitigate farm energy use should focus on the dairy subsystem in agreement with the farmer wishes. Study results will help shape operational and theoretical frameworks for improving the environmental performance of dairy farms.

Keywords: LCA, dairy farm, system improvement, experiments

1. Introduction

According to the recent law "Grenelle Environnement", France has committed to reducing its GHG emissions and energy consumption by 20% by 2020. By 2013, it aims to have 30% of farms independent of external energy sources. This aim requires a decrease in direct and indirect energy use (e.g., for tractors and machinery, buildings and greenhouses, other inputs) and production of renewable energies. Dairy farms, like other production systems, must deal with these new environmental challenges by moving towards autonomy and more efficient use of inputs. This is particularly the case for the consumption of non-renewable energy, which should be minimised along with greenhouse-gas emissions.

Life Cycle Assessment (LCA) is one of the tools developed for the evaluation of environmental impacts of production systems. Van der Werf and Petit (2002) showed that LCA was a valuable tool for analysing environmental impacts of agricultural systems. LCA at the farm level often has been used to determine the environmental impacts of contrasting farming systems (Haas et al., 2001; de Boer, 2003; Thomassen *et al.*, 2008) and to identify environmental hot spots of these systems. Thus, LCA can be used at the farm level in an improvement strategy based on four steps: i) analyse the environmental impacts of a system, ii) identify its environmental hot spots, iii) modify the system, and iv) compare the new system to the previous one and repeat this cycle. LCA can be associated with experiments or simulation modelling at the farm scale to assess the effect of changing specific farming practices and so avoid any transfer of pollution. On a dairy farm, it is possible to test different options to reduce environmental impacts associated with feeding practices or the use of biomass to produce energy.

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This paper presents preliminary results from a project aiming at the analysis of an experimental intensive dairy farm. The objectives of this project are to transform this farm into a model farm with respect to its energy dependence (direct and indirect energy use). The first part of the project was to conduct a LCA to identify hot spots and propose changes to the system that were acceptable to the farm manager.

2. Methods/Approach

2.1. Scope of the study and data collection

The dairy farm of UCEA Bressonvilliers (an experimental dairy farm of INRA, the French National Institute of Agronomic Research), located on the southern edge of the Parisian Basin, was studied during a one-year production cycle. This system is composed of 2 subsystems: a cash-crop system (249 ha of Usable Agriculture Area, UAA; principal crop rotation: rapeseed-wheat-maize/other cereals) and a dairy system including animals (Holstein dairy cows, 287 French Livestock Units, defined to compare numbers of animals of different species based on their feed requirements, OJFR 2000), fodder crops, and grass (216 ha of UAA). Characteristics of the farm are given in Table 1. All crop and animal operations were recorded from August 2007 to July 2008 (after the harvest of the cash crops). Construction and maintenance of the farm's building were not included in the system.

Table 1: Characteristics of the farm

Characteristic	**Units**	**UCEA Bressonvilliers**
Farm structure		
Usable Agricultural Area (UAA)	ha	465.0
Fodder crops and Grass	% in UAA	46.4
Commercial crops	% in UAA	53.6
Inputs		
Concentrate feed use	kg cow^{-1} yr^{-1}	2483.0
N input mineral fertiliser	kg ha^{-1}UAA yr^{-1}	116.8
N input in concentrate feed	kg ha^{-1}UAA yr^{-1}	136.5
Diesel use	kg ha^{-1}UAA yr^{-1}	234.1
Electricity use	kWh ha^{-1}UAA yr^{-1}	486.1
Output		
Milk production	kg cow^{-1} yr^{-1}	9500.0
Milk fat content	%	3.8
Milk protein content	%	3.3
Milk sales portion of total sales	%	55.5
Grain production	kg ha^{-1} yr^{-1}	8467.0
Grain sales portion of total sales	%	44.5

2.2. Inventory analysis

Diesel consumption for agricultural machinery was estimated using a model based on the operation and the machine used (Institut de l'Elevage, 2009).

Moreover some inventories were from the Ecoinvent database (i.e. DDGS, Rape oil). In these cases the inventories were adapted to our methodology. Data on the environmental impacts associated to the production and supply of the inputs stem from the Ecoinvent (2007) database.

Emissions of nitrous oxide (N_2O) and nitric oxide (NO_x) at field level were estimated according to the IPCC guidelines (2006). Emission of ammonia was estimated using emission factor depending of the type of fertilizer or manure (Nemecek, 2007). Nitrate leaching at the farm scale was estimated as proposed by Basset-Mens (2007).

Phosphate emissions were estimated according to Nemecek (2007). For heavy metal emissions a farm-gate balance was established, considering input by mineral and organic fertilizer and output via plant-based products. The surplus of this balance was considered to be an emission to the soil. Heavy metals content values for both inputs and outputs result from Nemecek (2007). Impacts from pesticides use (toxic effects) were not taken into account due to lack of data. Only pesticide production and its field application (machinery use and diesel consumption) were considered.

2.3. Functional units

As an important goal of agriculture is to feed people, we first chose to compare the two subsystems using one kilogram of proteins for human consumption as the functional unit. This allowed us to determine their contribution systems to the global impacts of the farm relative to their nutritional function (Fig. 1). We then focused on the dairy system, choosing as functional units 1000 l of milk at the farm gate and 1 ha of UAA.

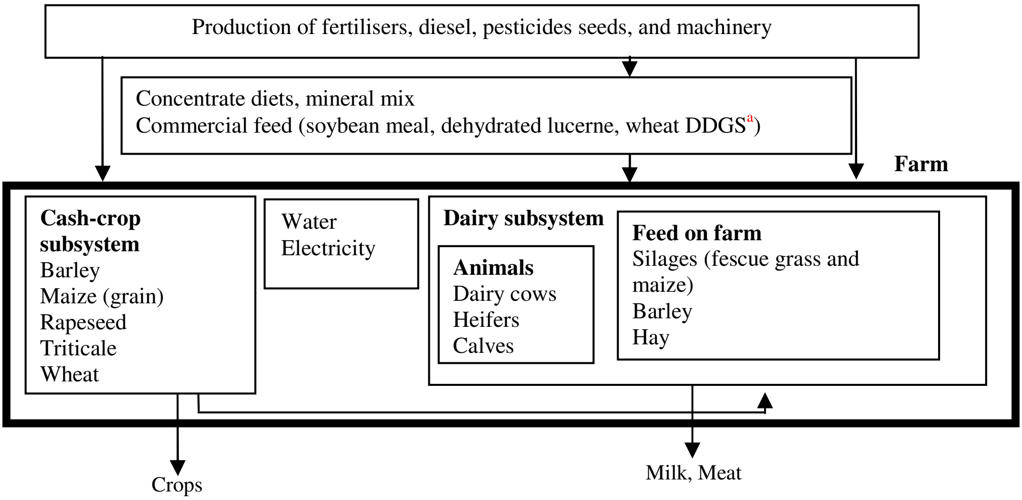

Figure 1: Simplified flowchart of the Bressonvilliers system
[a] DDGS: dried distillers grains with solubles

2.4. Impact assessment method

Life cycle assessment was conducted according to the methods CML 2001 (version 2.04), Total Cumulative Energy Demand (version 1.05), and GWP_{100} (with updated characterisation factors from (IPCC, 2007). Results are presented as traditional midpoint indicators (e.g., GWP, total energy demand, eutrophication, acidification, etc.).

3. Results and discussion

As reduction of farm energy dependence is the main objective for the transformation of this farm, the first step was to determine which part of the system contributed most to energy use. The contributions of milk and grain production to the principal midpoint impact categories are given in Figure 2.

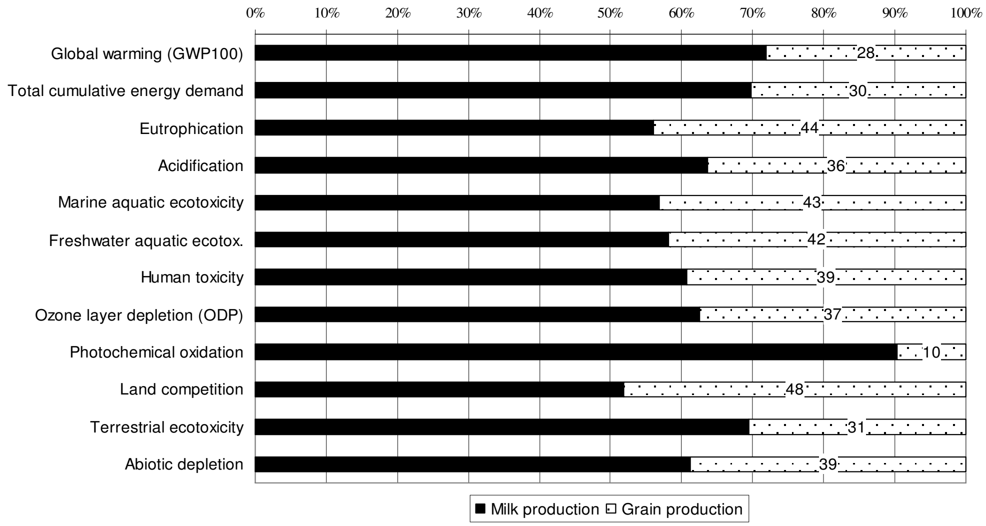

Figure 2: Percentage contribution from grain and milk to the environmental impacts of the Bressonvilliers system when expressed per kg of protein

Milk production contributed more than grain production to the environmental impacts. The use of primary energy was 155 MJ kg^{-1} of edible protein in the dairy subsystem and 67 MJ kg^{-1} of edible protein in the crop subsystem. The potential contribution of the dairy subsystem to global warming was 35.5 kg CO_2 eq. kg^{-1} of edible protein, whereas it was 25.5 kg CO_2 eq. kg^{-1} of edible protein in the crop subsystem.

The higher contribution of the dairy subsystem to environmental impacts can be explained, amongst others, by the lower N-efficiency ratio (N output in products divided by N intake) of animal production than crop production. This observation is especially interesting since the crop and dairy subsystems have similar on-farm surface occupation (54 vs. 46% of UAA, respectively, Table 1) and N inputs (145 and 137 kg N per ha UAA, respectively). In this study, the N-efficiency ratio for milk production was about 31%, which is consistent with the literature for Holstein dairy cows (Yan *et al.*, 2006). It is agreed that dairy production has a low efficiency to produce proteins for human food. However, animal products supply complete proteins containing all essential amino acids and are richer and more absorbable sources of specific micronutrients than plant products (FAO, 2010). Due to the energy demand for the production of mineral fertiliser and concentrated feed, the poor N-efficiency ratio of dairy subsystem influences the energy requirements of the farm system. To summarise, the milk subsystem produced 15% of the farm's edible protein but was responsible for more than 65% of its environmental impacts. The estimated environmental impacts are consistent with published results for conventional dairy systems, except for a higher energy use (Table 2).

Table 2: Global warming potential, eutrophication, acidification and energy use expressed per 1000 l of milk and per hectare for the Bressonvilliers dairy system (BDS), compared to conventional intensive dairy farms in France (F (van der Werf *et al.*, 2009)), Germany (D, (Haas *et al.*, 2001)) and the Netherlands (NL, (Thomassen *et al.*, 2008))

Impact category	**Per 1000 l of milk**				**Per ha**			
	BDS	**F**	**D**	**NL**	**BDS**	**F**	**D**	**NL**
GWP (kg CO_2-eq.)	1300	1037	1300	1300	7400	6271	9400	-
Eutrophication (kg PO_4-eq.)	7.0	7.1	7.5	10.8	40.7	39.8	54.2	140
Acidification (kg SO_2-eq.)	17.6	7.6	19.0	10.0	100.0	48.1	136.0	160
Energy use (GJ)	7.9	2.8	2.7	5.0	44.9	18.9	19.1	-

As indicated, because it is used for experimental research on dairy cow reproduction, the farm is not optimised for energy use (experimental heifers, staff facilities, offices, experimental equipment). Nonetheless, because 62% of direct and indirect energy use by the dairy subsystem is due to animal feed (Table 3), the first actions to mitigate farm energy-use should focus on the feed system.

Table 3: Contribution of system components to energy use in the dairy subsystem

Item	**% of energy use**
Electricity	31.8
Commercial feed	25.1
Maize silage	11.7
Hay	10.4
Concentrate diets	6.4
Straw	6.2
Fescue silage	6.0
Barley	2.0
Mineral mix	0.5

Reducing direct energy consumption usually occurs by replacing existing equipment with more efficient equipment; however, reducing indirect energy consumption via inputs requires changes in the production system and/or changes in agricultural practices. Changes in an agricultural system can be effective if they are consistent with the wishes of the farmer. In light of these results, the first actions to reduce environmental impacts of the farm should focus on the dairy subsystem. The farmer could implement some system modifications without modifying animal performance, such as reducing the environmental impact of the herd feeding system by rethinking the production of forage (reducing maize silage production, increasing the area of temporary pasture for grass-silage production, increasing legume part in the grass mix, etc.), and reducing off-farm inputs to cow rations (fodder and concentrates) and/or using commercial foods with local origins.

The results of this first LCA will help define on-farm experiments and guide the investigation of improvement options through simulation modelling of the farm system. The environmental impacts of these options then will be assessed via experimentation, and the results will be compared to the previous LCA and followed by a cost-benefit analysis. This study aims to propose operational and theoretical frameworks for the environmental improvement of dairy farms.

4. Conclusion

This paper presents the first results of the "UCEA low input-system" project, which aims to analyse the environmental impacts of an intensive dairy system to identify and test improvement options for mitigating the environmental impacts of livestock activities. In coming years, more and more farms will be encouraged to produce "green energy" (e.g., installing photovoltaic panels or wind turbines, producing biogas). Therefore, it would be interesting to reconsider the energy-use indicator by taking into account these new sources of renewable energy. For this purpose, a combined use of LCA methodology and Emergy (Odum, 1996) seems promising.

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Life cycle assessment of two Australian pork supply chains

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ABSTRACT

Australia's primary industries are under increasing environmental, social and economic pressure to measure and reduce resource use and environmental impacts. For the pork industry, major resource and environmental issues are related to water use, energy use (primary energy – PE) and greenhouse gas emissions (measured as global warming potential – GWP). To address this, a project was conducted to assess of water use, PE, and GWP of two Australian pork supply chains using life cycle assessment. One supply chain was located in southern Australia with pigs grown-out in deep-litter sheds. The second supply chain was located in northern Australia, where all pigs were housed in slatted and flushed sheds. The study investigated pork production through to the point of wholesale distribution of carcasses using the functional unit, '1 kilogram of hot standard carcass weight – HSCW'. Primary energy use in the two supply chains varied from 20.3 – 24.5 MJ/kg HSCW and GWP for the two supply chains measured 3.1 and 5.5 kg CO_2-eq./kg HSCW. Waste stream emissions were found to be the major contributor to GWP.

Keywords: pigs, pork, energy, GHG, Australia.

1. Introduction

Australia's primary industries are under increasing environmental, social and economic pressure to measure and reduce resource use and environmental impacts. For the pork industry, major resource and environmental issues are related to water use, energy use and greenhouse gas (GHG) emissions, however, to date there has been no assessment of resource use or GHG emissions from the whole Australian pork supply chain. This paper presents results for global warming potential (GWP) and primary energy (PE) use from two Australian pork supply chains (water results are presented in Wiedemann *et al.* (2010) and Wiedemann and McGahan. (2010)).

A great many resources are used in the production of pork at many different points in the supply chain, however the greatest intensity of resource use is generally required for on-farm production of the pigs. GHG emissions occur from a range of sources including the burning of fossil fuels (coal for electricity generation, liquid fuels, gas) and from livestock related emissions (i.e. methane and nitrous oxide from piggery waste streams). Several LCA studies have been done for various types of management systems of pork production, primarily in Europe (Basset-Mens and van der Werf, 2005, Cederberg and Darelius, 2001 cited in Cederberg and Flysjo (2004), Cederberg and Flysjo, 2004, Dalgaard *et al.*, 2007, Weidema *et al.*, 2008, Williams *et al.*, 2006). The most common impact categories assessed were global warming potential (GWP) and primary energy (PE).

A study was conducted was conducted to primarily provide information to industry on the environmental impacts of producing pork in Australia. Other goals included identifying and validating environmental research priorities in the pork production supply chain and to

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inform industry and government research investment; identifying the environmental impacts of different production systems (i.e. deep litter compared to conventional production systems); and identifying the likely environmental impacts associated with changing waste stream management (particularly the environmental benefit associated with capturing methane from the liquid effluent treatment ponds).

2. Materials and Methods

The system boundary was established to include the primary production system (pig farms), extending to the meat processing plant docking gate (point of distribution). The functional unit of the study was 1 kg of hot standard carcass weight (HSCW) pork at the meat processing docking gate, represented as whole carcasses, not retail-ready products. The modelling considered the impacts of a 'static' production system for a determined timeframe (2007/08).

2.1 Supply Chain Description

The assessment compared alternate management systems and geographical regions to provide an indication of variability of environmental performance within the Australian pig industry. Two pork supply chains were investigated as part of the study. They are referred to as the northern (Queensland) and southern (Victorian) supply chains.

The northern pork supply chain consisted of a conventional farrow-to-finish operation, with feed supplied by two off-site feed mills and sale pigs marketed to several meat processing plants. The piggery is a closed production system, with all pigs bred on-farm. This piggery had three distinct production units on the one farm; a multiplier facility, a breeding facility and a finishing facility.

The southern supply chain piggery consisted of a conventional farrowing unit producing weaners (3 weeks of age), followed by deep litter grow out units (where pigs are housed on litter rather than slatted floors) that house pigs through to sale. Feed for each enterprise was supplied from an off-site feed mill owned by the pig breeding company. Sale pigs were marketed through a single meat processing plant. Pigs were reared to weaning age (3 weeks) in conventional concrete slatted floor housing where effluent is flushed into a liquid effluent treatment system. From the breeder system, the weaned piglets are transported to a deep litter weaner facility where they are housed until 8 weeks of age. From this facility they are transported 240 km to a deep litter grow-out facility, where they are housed until finishing weight (95 kg). From there they are transported 175 km to the meat processing plant.

Both case study supply chains are large, progressive piggeries that operate using the best management practices for Australian pork production with peak performance.

2.2 Data Collection

Foreground data were collected from all farms in the supply chain for a period of one year (2007/08). This included farm infrastructure and machinery associated with the piggery operations, but not the meat processing plant. Foreground data were also collected for feed milling and diet formulation as an input to the modelling of production and upstream impacts from feed supply. Data for feed grains were modelled using a desktop assessment based on literature and local expert knowledge of Australian grain production. Foreground data were collected from four meat processing plants where pigs were slaughtered. The processing plant data were aggregated to highlight differences in the pig farms rather than the processing plants.

2.3 Modelling the Supply Chain

Greenhouse gases from agricultural systems arise from complex waste stream and soil processes and are emitted from several points on a pig farm (the piggery shed, effluent treatment pond and soils). Emissions were calculated by conducting a mass balance of the piggery system using the program PIGBAL (Casey *et al.*, 2000), which recommended as the Australian tier 2 approach (DCC, 2007). The mass balance was focused on carbon and nitrogen, and considered production inputs to the piggery (primarily feed) and production outputs (sale pigs, mortalities). These production inputs and output were based on foreground data collected from the piggery, and were cross checked against waste stream parameters. The mass balance program estimated excreted carbon (in the form of undigested feed and volatile solids in manure) and nitrogen. Emission estimates used methods and factors from the Australian tier 2 methodology for GHG assessment (DCC, 2007), which is based on the IPCC (2006). For methane estimation from lagoons, the DCC (2007) recommends a Bo factor of 0.45 m^3 CH_4/kg VS (as recommended by the IPCC for Oceania) and an MCF of 90% (which is 10% higher than the highest values recommended by the IPCC for lagoon systems). Nitrous oxide factors for Australian systems are considerably lower for direct soil emissions under dryland crops than are observed in European countries (EF = 0.03%), while indirect emissions from ammonia volatilisation are similar (EF = 1%). At the piggery, nitrous oxide from deep litter systems were higher (EF = 2%) than recommended by the IPCC (2006). Emissions from effluent and manure application used an EF of 2%. Simapro™ was as used for the impact assessment.

Allocation of co-products was done using a mass allocation process without differentiation between prime pigs, cull pigs or edible offal.

3. Results

Primary energy use in the two supply chains varied from 20.3 to 24.5 MJ/kg HSCW (southern and northern supply chains respectively). Primary energy use was lower for the southern supply chain (deep litter housing for weaner/finisher pigs) which was partly in response to lower energy demand for pig housing.

Global warming potential for the two supply chains were 3.1 – 5.5 kg CO_2-e / kg HSCW for the southern and northern supply chains respectively. The contribution analysis showed that waste stream emissions of methane (CH_4) was the single largest contributor to supply chain GWP, particularly for the northern piggery which utilised a liquid effluent treatment pond system.

To improve the comparability of the results with studies presented in the literature, allocation at the point of slaughter between primary products and co-products was also done using the three most common methods (Table 1). System expansion using an alternative product as the marginal substitute for edible by-products (offal) and low grade pork from cull sows was also done for comparison. This used grass-fed Australian beef. Beef is used in many Australian processed meats as a blend with pork, which was seen as a justification for considering this product a valid substitution. Emissions for grass-fed beef were estimated following the Australian tier 2 methodology and resulted in similar values to those reported in previous Australian beef studies (i.e. Peters et al. 2010).

Table 1: GWP for pork production with three methods for allocating emissions to co-products

Supply Chain	Units	Mass allocation	Economic allocation	System Expansion (grass-fed beef)
Northern Supply Chain	kg CO_2-e / kg HSCW	5.5	5.6	5.0
Southern Supply Chain	kg CO_2-e / kg HSCW	3.1	3.6	2.3

A series of sensitivity tests and scenarios were conducted to test these data and compare with a modified system (pond covering and methane flaring). These are reported in the discussion section. A sensitivity analysis of emission factors for methane production per unit of volatile solids produced in manure and nitrous oxide per unit of nitrogen produced in manure or utilised in land application of waste showed a cumulative range from -28% to + 59% for GWP in the southern supply chain, and -29% to + 11% for the northern supply chain depending on the emission factors applied.

4. Discussion and Interpretation

Primary energy in pork production in the literature ranged between 15-18 MJ/kg carcass weight (CW), though one study (Weidema *et al.*, 2008) was an order of magnitude higher than this at 193 MJ/kg CW. Primary energy use for the Australian production systems (20.3 to 24.5 MJ/kg HSCW) was 10-54% higher than most studies presented in the literature. This is likely to be in response to a greater GHG footprint of electricity supply and greater transport distances in the Australian pork supply chains.

On the basis of GWP, results from the two Australian supply chains were comparable to other studies presented in the literature (see Table 2). For the southern system, where pigs are raised on deep litter from 3-23 weeks, the GWP was comparable to the lowest emissions reported in the literature (Table 2).

Table 2: GWP from Australian and international pork production studies reported in the literature

Reference	Country	GWP kg CO_2-e/kg CW[1]	Main contribution to burden
Basset-Mens & van der Werf (2005)	France	3.0	73% crop / feed
Southern Supply Chain	**Australia**	**3.1**	27% crop / feed 25 % waste stream
Dalgaard *et al.* (2007)	Denmark	3.3	61% crop / feed
Cederberg & Flysjo (2004)	Sweden	4.4	NR
Cederberg & Darelius (2001), in Cederberg & Flysjo (2004)	Sweden	5.5	NR
Northern Supply Chain	**Australia**	**5.5**	66% Methane from pond
Williams *et al.* (2006)	UK	6.4	NR
Weidema *et al.* (2008)	EU average	11.2	NR

[1] CW is carcass weight, measured as Hot Standard Carcass Weight in this study. Allocation methods may restrict the comparability of these studies.

GWP from the northern Australian supply chain was dominated by methane emissions from the effluent treatment ponds (66% of GWP) highlighting the importance of the waste management system. This is not surprising, as primary treatment ponds in Australia are designed to treat volatile solids with an anaerobic treatment process which produces a large volume of methane as a by-product (APL, 2004). Higher ambient temperatures and longer retention times for Australian industry conditions will correspond to higher methane emissions, as reflected by the high MCF recommended in the Australian tier 2 GHG methodology. A similar trend was apparent for the southern supply chain, though to a lesser extent. In this system, nitrous oxide from the deep litter housing systems contributed more than 10% of GWP, while methane from the breeder system effluent treatment ponds contributed 14% of GWP.

In comparison to European studies (i.e. Basset-Mens and van der Werf 2005; Dalgaard *et al.* (2007), crop emissions contributed a lower proportion of GWP. This is in response to the lower nitrous oxide emission factors applied by the tier 2 GHG estimation methodology for Australia.

A simple scenario was run for each supply chain where primary ponds at the piggeries were covered and a simple flaring device fitted. The additional capital inputs for this management system were included in the scenario. It was assumed that no on-going inputs are required for the flaring system. This scenario reduced GWP at the northern supply chain to 2.3 kg CO_2-e/kg HSCW and to 2.7 kg CO_2-e/kg HSCW for the southern supply chain. The larger reduction in the northern supply chain is because all effluent in this system is treated using a liquid pond system and could be mitigated using this approach. In contrast the emissions from the southern supply chain showed a lesser reduction, because waste stream emissions were only mitigated at the breeder piggery.

5. Conclusions

The results suggest that GWP from pork production in two Australian supply chains is similar to other studies presented in the literature; however, comparison to other studies is difficult due to issues such as the handling of co-products. It should be noted that the functional unit 'HSCW' for this study is significantly different to 'retail' pork, having the head, feet and skin on the carcass. For this reason direct comparison with other species will not be valid without adjustment for differences in carcass processing.

The contribution analysis showed higher contributions from effluent lagoon emissions and lower contributions from feed inputs compared to the European studies reviewed. This is in response to the higher MCF for effluent lagoon methane emissions and lower nitrous oxide levels from grain production. When waste stream emissions were mitigated, emissions were lower than other literature values.

The comparison of deep litter and conventional housing showed that, for the current management systems, deep litter housing required lower energy inputs and resulted in lower GWP than pork produced from conventional housing. These GWP results were reversed when pond covering was used in both the supply chains.

It is important to note that the study is highly sensitive to the emission factors used in the piggery waste stream calculations. These emission factors have not been derived from Australian research and represent a major uncertainty in the project, corresponding to variation of -28% to +59% in GWP.

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