PARALLEL SESSIONS 2

2A / LCA of milk and diary systems

Eco-efficiency of cheese making process: DEA vs restricted weightings DEA

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ABSTRACT

Establishing the best environmental practices in production processes requires not only the integration of environmental aspects, but also of economic ones. The concept of eco-efficiency embraces these two aspects. The aggregation of the environmental pressures into a single environmental damage index is an important challenge to quantify eco-efficiency. Data Envelopment Analysis (DEA) can be used as a tool with which to integrate the environmental results obtained by means of Life Cycle Assessment (LCA) with the economic results in order to measure eco-efficiency. DEA allows objective weightings to be obtained, regardless of individual thought and preference. Nevertheless, DEA solutions can lead to some environmental impact weightings of zero, which is not easy to understand. For this reason, a model that measures eco-efficiency incorporating value judgments through weight restrictions has been built. These value judgments are obtained by means of the Analytic Hierarchy Process (AHP). The model has been applied to a case study on cheese production.

Keywords: AHP, DEA, eco-efficiency, LCA, restricted weightings

1. Introduction

The eco-efficiency of production is concerned with the capacity to produce goods and services while causing minimal environmental degradation. According to WBCSD (2000), eco-efficiency is represented by the ratio "Product or service value/Environmental influence". Van Passel *et al.* (2007) think that eco-efficiency is a very popular measure to express contributions to sustainability. Farrell and Hart (1998) state that a single aggregated number can be very useful in communicating information on general sustainability to the public and to decision-makers. Indeed, without a multivariate model, one is often constrained to compare individual ratios, which can lead to ambiguous results.

Although the eco-efficiency concept is well defined, it is not easy to quantify and different models have been proposed to measure the eco-efficiency of processes. In fact, the aggregation of the results of the impact categories into a single environmental damage index is a challenge of eco-efficiency measurement (Tyteca, 1996). The aggregation can be carried out in two generic ways, either on the basis of a specific weighting method, such as DEA, or by the "expert judgment" of the decision-makers (Rüdenauer *et al.*, 2005).

The first proposal of aggregation using DEA to quantify eco-efficiency according to its definition (Economic value added/Environmental damage) comes from Kuosmanen and Kortelainen (2005). In our work, by modifying the Kuosmanen and Kortelainen model, we propose to incorporate expert judgment by means of the Analytic Hierarchy Process. The former model and the new one are applied to a case study. Specifically, 16 scenarios of Mahón-Menorca cheese production in Spain have been evaluated in order to obtain the net

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income and the environmental impacts caused by the production process. Environmental impacts have been quantified through Life Cycle Assessment.

2. Methodology

2.1. DEA model for eco-efficiency measurement

DEA is usually used to estimate technical efficiency measures. The definition of efficiency in DEA is based on the engineering concept of total factor productivity and is specified as the ratio of the weighted sum of outputs to the weighted sum of inputs of a production unit or a scenario. The adaptation to measure eco-efficiency requires some modifications. For the numerator of the ratio of eco-efficiency, Kuosmanen and Kortelainen (2005) suggest a global measure of the production process value as the economic value added. For the denominator, the authors define a linear function of the environmental damage $D(z) = w_1 \cdot z_1 + w_2 \cdot z_2 + \ldots + w_n \cdot z_n$, called "virtual impact", which involves the problem of determining the weightings of the different environmental impact categories (z). The model measures the relative eco-efficiency of each production scenario by means of an eco-efficiency (EE) ratio that always lies between 0 and 1. An EE ratio equal to 1 means that the scenario is relative eco-efficient. The model implies solving an optimization program for every scenario so actually there will be as many programs as scenarios. For a given scenario, the program calculates a set of weightings of the environmental impact categories that maximizes the EE ratio subject to the fact that the same set of weightings applied to the rest of the scenarios will not allow an EE ratio greater than 1 in any of them. The weightings represent a relative value system for each assessed scenario that provides the highest possible EE ratio for the scenario concerned. That is to say, a scenario is eco-efficient because no other scenario with any combination of weights can beat it. On the contrary, and more transcendental, an eco-inefficient scenario, even using the most favorable weight allocation, is not able to achieve an EE ratio equal to one. The fractional problem (1)-(4) for i scenario, considering m scenarios and n environmental impact categories is shown below. This program is easy to linearize by taking the inverse of the eco-efficiency ratio.

$$\max_{w} EE_i = \frac{V_i}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}} \qquad (1)$$

subject to

$$\frac{V_1}{w_1 \cdot z_{11} + w_2 \cdot z_{12} + \ldots + w_n \cdot z_{1n}} \leq 1 \qquad (2)$$

$$\ldots$$

$$\frac{V_m}{w_1 \cdot z_{m1} + w_2 \cdot z_{m2} + \ldots + w_n \cdot z_{mn}} \leq 1 \qquad (3)$$

$$w_1, w_2, \ldots, w_n \geq 0 \qquad (4)$$

Where:

V_i: economic value added per functional unit for scenario $i=1..m$

w_j: weight of the environmental impact category $j=1..n$

z_{ij}: value of the environmental impact category $j=1..n$ per functional unit for scenario $i=1..m$

2.2. Restricted weightings DEA model

While humans are good at finding important variables, they are not as good at integrating such diverse information sources optimally. DEA techniques can help the integration process. Nevertheless, the weightings estimated by DEA can prove to be inconsistent with prior knowledge or the accepted views on the relative values of the impact categories. In this way, large weightings may be assigned to environmental impacts of secondary importance, leaving a zero weight for impact categories that are generally regarded as the important ones. To avoid this issue an obvious option is to restrict the weightings of the environmental impacts. However, we are dealing with very different units of measurement and a decision-maker, even a very specialized one, would find it difficult to fix absolute weight restrictions. Wong and Beasley (1990) suggested restricting the weight flexibility by fixing the minimum share of each component of denominator over the whole denominator. Restricting the "virtual impact" in this way could be the most suitable and intuitive option for decision-makers.

To set the restrictions of the virtual impact, we propose the Analytic Hierarchy Process (AHP), (Saaty, 1980). AHP is a popular tool in the field of Multiple Criteria Decision Making (MCDM). In our model, the opinion of a decision-maker is elicited by comparing environmental impact categories. Impact categories are compared pair-wise and judgments on the comparative importance of the impact categories are captured using a 1-9 rating scale. Each a_{ij} element of the matrix holds that $a_{ij} > 0$; $a_{ij} = 1/a_{ji}$; $a_{ii} = 1$ for all the i. The weightings of the impact categories are calculated from the judgment matrix using the eigenvector method. The normalized eigenvector corresponding to the principal eigenvalue provides the weightings of the impact categories.

Our proposal is that part of the information obtained from AHP be added as new restrictions in the DEA program. Specifically, the minimum and the maximum weight of each impact category from the AHP weightings of a group of decision-makers will be set into the DEA program as the lower and upper bounds of each virtual impact. In this way, the assignation of weightings, and hence the estimation of the eco-efficiency, will be carried out using DEA, but the relative importance of each category will be in the range of the decision-makers. Zhu (1996) already used the combination of DEA and AHP in a slightly different way. Twice as many restrictions as impact categories will be added to the fractional problem, following the equations (5) and (6) for scenario i and impact category j.

$$\phi_j \leq \frac{w_j \cdot z_{ij}}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}} \quad (5)$$

$$\frac{w_j \cdot z_{ij}}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}} \leq \psi_j \quad (6)$$

Where

ϕ_j: Minimum weighting obtained through AHP for the j^{th} impact category

ψ_j: Maximum weighting obtained through AHP for the j^{th} impact category

3. Case study

In order to try and compare both models, they have been applied to a case study of Mahón-Menorca cheese making. Mahón-Menorca cheese is a traditional cheese manufactured on the Island of Menorca (Spain). The analysis is performed on a small scale of production, with an average processing capacity of between 3 and 4 million L of milk/year, representative of most of the dairy companies on the island. Sixteen scenarios have been built which take both technical (automation degree) and cleaner production criteria into account, Figure 1 shows the tree of scenarios. The goal is to decide which scenario is the most eco-efficient and also to check the possible differences between the results given by each model.

As the main function of the studied systems is to produce cheese, the functional unit is 1 kg of semi-mature cheese ripened for 105 days, packaged and ready for shipment. A period of 105 days has been considered because it is the average ripening time of a semi-mature cheese, the most widely sold. With respect to the system boundaries, the following operations have been included: milk reception, milk pasteurization and the cheese making process, cheese drying and ripening, cheese packaging, cleaning of the facilities and electricity production. Upstream (i.e. cow farming) and downstream stages (i.e. transport, retailing, consumption and waste management) are the same, regardless of the scenario, and, therefore, have been omitted from the comparison. Mould manufacturing has not been included because they are goods with a long life. The manufacturing of cleaning agents has not been included due to lack of data. Capital goods production (machinery and buildings) and manpower have not been included either, as is usual in these studies.

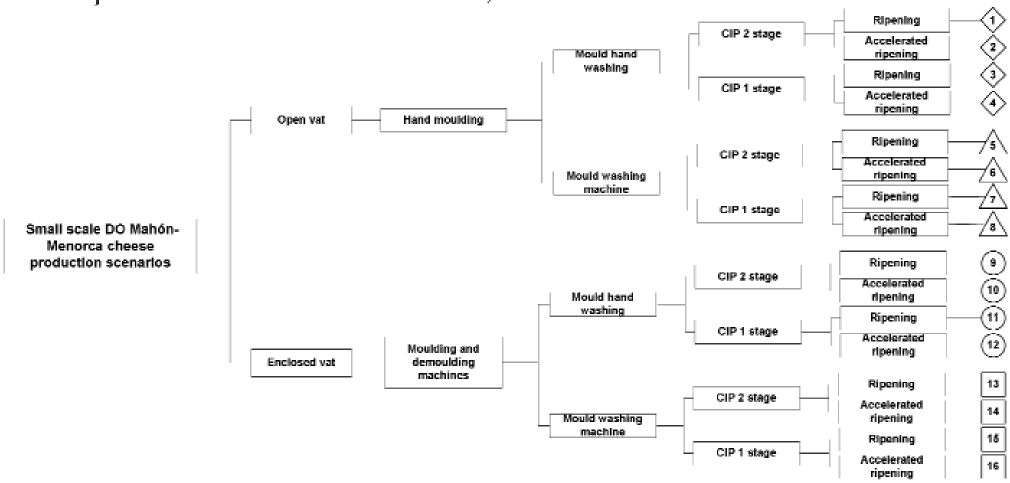

Figure 1: Cheese making scenarios

The data sources used to characterize the scenarios have been cheese firms, machinery manufacturers and the direct measuring of energy consumption in production plants. From the aforementioned data sources and the inventory database of the software, the life cycle inventory and the impact assessment have been carried out.

The following impact categories have been chosen: global warming, eutrophication and water consumption. Other impact categories such as ozone layer depletion, acidification, photochemical ozone formation and abiotic resource depletion have not been considered because, in this study, all of them depend directly on energy consumption, like global warming. A preliminary LCA showed that these impact categories presented the same trend that energy consumption for every scenario. Toxicity related impact categories, caused by the cleaning agents, have not been considered due to a lack of data. In order to assess the impacts of global warming and eutrophication, the EDIP 2003 methodology was used and the results have been expressed as kg CO_2 eq. and kg NO_3^- eq., respectively. Water consumption has been expressed as litres of water.

In the economic assessment, the variables related to revenues and costs have been obtained in order to estimate net income. Revenues come from cheese selling. The estimated production costs are capital, labour, energy, material inputs and purchased services.

In order to set the minimum and maximum share of the virtual impact for every impact category, ten LCA specialized academic decision-makers filled in the pair-wise comparison matrix. They were asked to compare the environmental impact categories as to their importance. The obtained range is shown in table 1.

Table 1: Range of shares of the virtual impact

Environmental Impact Category	Min.	Max.
Eutrophication	8.97%	14.29%
Global warming	40.55%	63.33%
Water consumption	26.05%	47.96%

4. Comparison of results

Figure 2 shows the eco-efficiency score obtained for each scenario by applying the two proposed DEA models. The eco-efficient scenarios 10, 12 and 16, are the same in both models (figure 2). It could be expected that, as a restricted model, the DEA-AHP eco-efficiency model, might show a higher power of discrimination than the DEA eco-efficiency model, which is to say, fewer scenarios could be found as eco-efficient, but in this case that did not happen. The eco-efficient scenarios present a high degree of automation (enclosed vat plus moulding and demoulding machines) and apply accelerated ripening to cheese. Nevertheless, scenario 10 does not incorporate a washing machine for moulds. The use of a washing machine reduces both water consumption and the costs of labour and water, but it increases the eutrophication and global warming impact categories. In this trade-off, the washing machine is not a decisive feature. In the rest of the scenarios, the non-eco-efficient ones, the EE ratio is lower in the DEA-AHP model than in the DEA model. The additional restrictions of the composition of the virtual impact move these scenarios away from the eco-efficient frontier made by scenarios 10, 12 and 16.

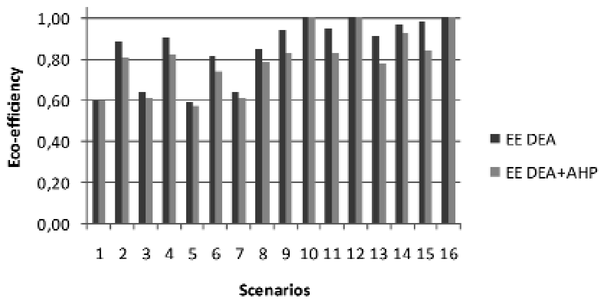

Figure 2: Eco-efficiency ratio per model and scenario

Looking over the virtual impact in the DEA EE model, it is easy to notice a dominant component in each scenario. As can be observed in Figure 3, the shares of the components of the virtual impact are very unbalanced. The DEA-AHP EE model succeeds in obtaining a more balanced virtual impact in which every impact category is in the range fixed by the decision-makers. Figure 3 clearly shows the change caused by the inclusion of the additional restrictions in the DEA program.

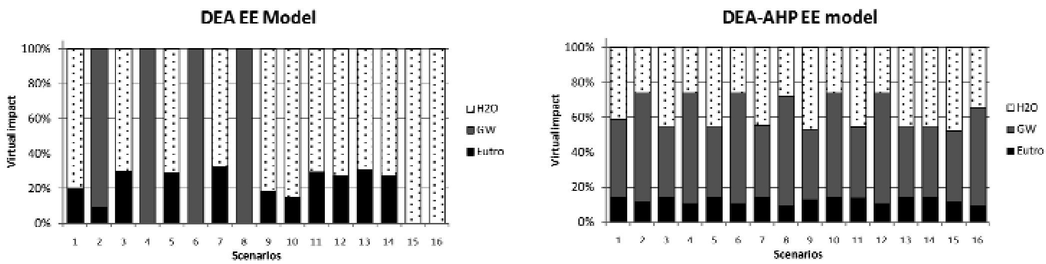

Figure 3: Virtual impact

5. Discussion

The use of DEA techniques to measure eco-efficiency provides an objective method of weighing the environmental impacts, irrespective of individual thoughts and preference. Despite this positive feature, the fact of obtaining unbalanced weightings may cast doubts on this technique. The combination with AHP allows the decision-makers opinions to be integrated and, thus, weightings to be obtained within the expected limits.

The weightings assigned by means of the linear program are specific for every solution, thus the weightings of the environmental impacts that we have used to estimate the eco-efficiency ratio of a given scenario are specific for this scenario. The fact that the EE DEA model does not estimate a common set of weightings (CSW) of the environmental impacts is a controversial point since people usually employ a fixed framework. In this way, a large weighting may be assigned to an environmental impact category where a scenario performs good, favouring a high EE score although that same scenario performs badly in the rest of categories. In this sense, the DEA-AHP model ensures that the weightings will be within a fixed range and this could be useful to discard extreme scenarios that are favored by showing a good performance in just one impact category. Moreover the fact of considering human views could give decision-makers more confidence in the obtained solutions.

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Effect of farming system changes on life cycle assessment indicators for dairy farms in the Italian Alps

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ABSTRACT

In some Alpine areas dairy farming is going through a process of intensification with significant changes in farming systems. The aim of this study was to investigate environmental performance of a sample of 31 dairy farms in an Alpine area of Lombardy with different levels of intensification. A cradle to farm gate life cycle assessment was performed including the following impact categories: land use, non-renewable energy use, climate change, acidification and eutrophication. From a cluster analysis it resulted that the group of farms with lowest environmental impacts were characterized by low stocking density and production intensity; farms that combined good environmental performances with medium gross margins were characterized also by high feed self-sufficiency and lowland availability. Environmental impacts of dairy farms in the mountain areas could be mitigated by the improvement of forage production and quality and by the practice of summer highland grazing, that significantly reduced eutrophication per kg of milk of the less self-sufficient farms.

Keywords: dairy farming systems, LCA, Italian Alps

1. Introduction

European agriculture in mountain areas is suffering from the increasing competitive economic pressure of plain agriculture, from the consumption of agricultural land in the valley floors caused by industrial and infrastructural uses, and from some peculiar social problems, like depopulation. During the last decades, Italian Alps were characterized by a very high rate of agricultural area abandonment, that mainly affected small farms with a maximum size of 5 ha (Streifeneder *et al.*, 2007). The remaining farms, especially in the dairy sector, showed an evolution trend towards increasing size and intensifying production, in order to increase competitiveness and sustain profitability. In the mountain areas of Lombardy annual milk yield per cow increased from 5871 kg in 2000 to 6798 kg in 2007 (AIA, 2008). This development was associated with marked changes in dairy farming systems: the switch from local to specialized dairy breeds (Holstein Friesian), the increase in purchased feeds (especially concentrates) to sustain higher milk yield, the sowing of maize for silage in substitution of permanent meadows in the valley fields, the growth of stocking density. The increasing nutrient burden resulting from the intensification process can affect the environmental sustainability of milk production in Alpine areas. Moreover farm intensification contributed to the decline of the traditional practice of summer pasturing of livestock in the highland, due to the problems of transferring large herds and to the high nutrient requirements of specialized breeds that overcome the supply from pastures.This is a further risk factor for the Alpine environment considering the central role of grazing livestock systems in preserving natural resources in mountain areas (Casasùs *et al.*, 2007).

The objective of this study was to assess the effects of farming system on the environ-

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mental impact potential of a group of dairy cattle farms located in the Italian Alps using the life cycle assessment (LCA) approach.

2. Materials and methods

The study involved a sample of 31 dairy cattle farms situated on the floor of two Alpine valleys in the Central Italian Alps, selling their milk to a local cheese factory. All farmers were interviewed individually and part of the data came from the statistical database of agriculture in Lombardy (SIARL, 2006). A "cradle-to-farm-gate" life cycle assessment was performed for the reference year 2006. The functional unit (FU) was defined as 1 kg of fat-and-protein corrected milk (FPCM, 4.0% of fat content and 3.2% of protein content) leaving the farm gate or 1 hectare of farm valley land. The impact categories considered were: land use (m^2), non-renewable energy use (MJ), climate change (kg CO_2 eq.), acidification (kg SO_2 eq.) and eutrophication (kg NO_3 eq.). The characterisation factors for substances causing climate change, acidification and eutrophication were derived from IPCC (2007) and Guinée *et al.* (2002). We distinguished direct impacts (on-farm) that originate on the farm site from indirect impacts (off-farm) associated with the production and transport of inputs to the farm. Transports of materials and animals were included also in this study. Water use, farm buildings, machinery, seeds, medicines, mineral salts and washing detergents were not taken into account. For pesticides impacts associated with production and supply were considered only, while toxic effects associated with their use were not considered. Many farms bought heifers from Switzerland; as a consequence an LCA was performed on heifer production in Swiss farms. Allocation was based on the economic value of the products. An economic allocation was applied also for meat obtained as co-product of milk production (bull calves, old cows). The life cycle inventories (LCI) of diesel, fertilizers and pesticides production and use were derived from, respectively, Michaelis (1998), Davis and Haglund (1999) and Brand and Melman (1993). The main references used are summarized in Table 1.

Table 1: Main literature references for Life Cycle impacts

	Italy	**Switzerland**
Livestock rations	interviews	Agridea (2008)
Origin of feeds	Eurostat (2006)	Eidgenössisches Finanzdepartement EFD (2006)
Methane emissions	ERICA (Provolo, 2005) for cows and ISPRA (2008) for heifers. Estermann *et al.* (2001) during highland grazing	Switzerland GHG Inventory 1990-2005 (2007)
Nitrogen excretion	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers. Cornell-Penn-Miner (2004) during highland grazing	EMEP/EEA (2009)
Ammonia emissions	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers and during highland grazing	EMEP/EEA (2009)
Nitrous oxide emissions	ERICA (Provolo, 2005) for cows, EMEP/EEA (2009) for heifers. IPCC (2006) during highland grazing	EMEP/EEA (2009)
	On-farm	**Off-farm**
Ammonia emissions	Manure spreading: ERICA (Provolo, 2005). Artificial fertilizers: EMEP/CORINAIR (2002)	Manure spreading: Thomassen et al. (2008). Artificial fertilizers: EMEP/CORINAIR (2002)
Nitrous oxide emissions	Manure spreading: ERICA (Provolo, 2005). Artificial fertilizers: IPCC (2006)	Manure and artificial fertilizers spreading: IPCC (2006)
Leaching	Nitrates: Grignani and Zavattaro (2000) for grassland; Audsley (2000) for maize Phosphates: Nemececk and Kagi (2007)	Nitrates: IPCC (2006) or Italian literature. Phosphates: Nemececk and Kagi (2007)

A cluster analysis was performed to group the farms, based on the usual agglomerative hierarchical clustering and using centroid method (SAS, 2000).

Fixed effects were tested in a GLM analysis on dependent variables, using the model:

$$Y_{ijklm} = \mu + PI_i + MP_j + HG_k + Z_l + e_{ijklm}$$

Where Y_{ijklm}= dependent variables (impact categories); μ = overall mean; PI_i = effect of production intensity per ha (i=1 to 3; <8700, 8700-11500, >11500 kg FPCM/ha); MP_j = effect of milk production per cow (j=1 to 3; <4600, 4600-6200, >6200 kg of milk/cow); HG_k = effect of highland grazing of cows (k = 1 to 2; no or yes); Z_l = effect of feed self-sufficiency (l=1 to 3; <53, 53-72, >72% on DM basis) or percentage of lowland hectares used for maize silage production (l=1 to 3; 0, 0-22, >22%); e_{ijklm} = residual error.

3. Results and discussion

The main average farm characteristics are in table 2. The 13 farms that transferred their milking cows to highland during the summer produced on average 9.9 ± 2.0 kg FPCM/cow d^{-1} in the grazing period (92.1 ± 22.1 d/year), whereas in the lowland period milk yield in all farms averaged 16.5 ± 3.9 kg FPCM/cow d^{-1}.

Table 2: Main characteristics of the sample farms (n=31)

Parameter	unit	mean ± SD
Cows	n	51.9 ± 54.9
Livestock Units (LU)	n	76.0 ± 92.4
Valley land	ha	22.5 ± 24.0
Stocking density	LU/ha valley land	2.9 ± 1.4
Milk yield	kg FPCM/cow $year^{-1}$	5798 ± 1482
Milk/ha	kg FPCM/ha	13556 ± 8164

[a] FPCM = fat-and-protein corrected milk

On average, 62.9 ± 16.8% of the total dry matter (DM) of cow rations consisted of feed ingredients produced on the farm. All the concentrate feed was purchased, but also part of the forages were bought. No farms sold forages or exported manure.

The average results of the 31 sample farms for the five LCA categories per kg of FPCM were: 3.18 (± 1.87) m^2 for land use, 5.14 (± 2.02) MJ for energy use, 1.13 (± 0.27) kg CO_2-eq for climate change, 0.021 (± 0.006) kg SO_2-eq for Acidification and 0.075 (± 0.019) kg NO_3-eq for Eutrophication. The LCA categories per hectare of lowland were 326 (± 227) kg SO_2-eq and 1150 (± 894) kg NO_3-eq.

The high land use and acidification results per kg of milk were similar to the results from organic farms (Corson and van der Werf, 2008; Haas *et al.*, 2001). The high energy use per kg of milk was probably due to the marked land fragmentation in the valley floors.

The cluster analysis identified five main groups of farms (table 3) and one marginal farm not reported in the table. Characteristics of clusters 1 and 3 are: small herd size, low animal density and production intensity in the valley land, high farm pasturing rate (percentage of farms practicing summer highland grazing) and, respectively, high and low feed self-sufficiency. Farms in clusters 2 and 4 are medium sized and have medium gross margins. They differed in terms of production intensity (low and medium respectively), self-sufficiency (high and medium) and pasturing rate (medium and low). Cluster 5 collected the farms with large herd size, high milk yield per cow and production intensity, low self-sufficiency. Their average gross margin was about twice the ones of Clusters 2 and 4. Farms from Cluster 2 resulted in better environmental performances than farms from Clusters 4 and 5 for all the impact categories considered. In conclusion farms in Cluster 2 seem to show the best synthesis between environmental impact and gross margin, even if their gross margin per hectare and milk production per cow were low. In these farms the improvement of production and quality of self-produced forages, that was generally poor, can lead to better performances in terms of milk production and profitability, considering that in the Alpine environment successful forage conservation is crucial for milk production (Charmley, 2001).

Table 3. Mean values of farms from the different cluster groups (on-f= on farm, off-f= off farm)

	Cluster1	Cluster2	Cluster3	Cluster4	Cluster5
Farms (n)	5	8	5	6	6
Farms pasturing rate	0.60	0.37	0.60	0.16	0.33
Cows (n)	26.0	55.3	27.4	56.7	90.8
Valley land (ha)	16.1	32.7	12.8	24.5	23.2
Stocking density (LU/ha)	1.9	2.2	2.2	3.2	5.0
Milk yield (kg FPCM/cow)	5612	5446	5302	5848	6876
Production intensity (kg FPCM/ha)	8593	8901	9413	14124	24798
Feed self-sufficiency (%)	70.2	72.2	58.6	58.8	44.7
Gross margin (€)	60,038	123,059	47,938	133,345	211,150
Gross margin (€/ha)	3719	3769	3684	4918	8565
Land use off-f (ha/kg FPCM)	1.17	1.04	1.16	1.23	1.58
Energy use (MJ/kg FPCM)	4.31	4.85	4.59	4.95	5.36
Climate change (kgCO_2/kg FPCM)	1.05	1.09	1.08	1.11	1.15
Acidification (kg SO_2/kg FPCM)	0.018	0.021	0.018	0.023	0.026
Eutrophication (kg NO_3/kg FPCM)	0.063	0.073	0.065	0.078	0.095
Climate change on-f (kg CO_2/ha)	5213	6023	7171	8382	13157
Acidification on-f (kg SO_2/ha)	78.8	133	111	201	331
Eutrophication on-f (kg NO_3/ha)	194	380	267	555	949

From GLM analysis, it appeared that acidification was higher in farms with low feed self-supply in comparison with the other farms (0.025 *vs* 0.019 kg SO_2-eq/kg FPCM for feed self-sufficiency of <53 and ≥53% on DM, respectively; $P<0.05$) especially due to the higher off-farm acidification ($P<0.05$). Low self-sufficient farms had also higher off-farm land use and off-farm eutrophication compared to the high self-sufficient farms. These impacts are mainly related to the production and transport of feeds from the outside. Feed self-supply significantly affected gross margin per kg of milk (0.357 *vs* 0.451 €/kg FPCM, for low and high percentage of feed self-sufficiency, respectively; $P<0.05$): farms buying less external feed were more profitable. Feed self-supply was related to the percentage of maize land on the valley land that was 7.0, 14.6 and 29.2%, for farms with low, medium and high feed self-sufficiency ($P<0.05$). All off-farm impacts per kg of milk decreased with increasing maize land ($P<0.05$), but on-farm eutrophication significantly grew with increasing maize land (from 0.020 and 0.030 kg NO_3/kg FPCM with no maize and <22% maize land to 0.035 kg NO_3/kg FPCM with >22% maize land; $P<0.05$).

Acidification and eutrophication grew with production intensity of farms in terms of kg FPCM/ha: acidification was 0.019, 0.020 and 0.024 kg SO_2/kg FPCM per farms with <8700, 8700-11500 and >11500 kg FPCM/ha, respectively ($P<0.05$); eutrophication was 0.065, 0.067 and 0.084 kg NO_3/kg FPCM for the same classes of intensity ($P<0.05$). Farms with medium level of intensity (8700-11500 kg FPCM/ha) had the lowest values in all the impact categories and an acceptable gross margin. The intensification process of farming systems in the mountain areas has its worst consequences on a local scale. Acidification was 108, 129 and 255 kg SO_2/ha per farms with <8700, 8700-11500 and >11500 kg FPCM/ha, respectively ($P<0.05$); eutrophication was 280, 326 and 730 kg NO_3/ha for the same classes of intensity ($P<0.05$).

Production intensity was mainly related to stocking density (LU/ha; $P<0.05$) whereas milk production per cow was not statistically different among groups. Both feed self-sufficiency and production intensity are related to valley land availability. Since agricultural land on the valley floors is becoming a lacking resource, farmers could partly bridge the gap by using the forage resources of the highland during the summer period. Farms with low feed self-sufficiency (<53% DM) could improve their environmental sustainability by practicing summer grazing. Highland grazing decreased total eutrophication per kg of milk of farms with low self-sufficiency (from 0.092 to 0.070 kg NO_3/kg FPCM; $P=0.07$), thus offering a possibility to improve farm environmental performances without increasing maize land.

4. Conclusions

From the cluster analysis it resulted that the group of farms with lowest environmental impacts were characterized by low stocking density and production intensity; farms that combined good environmental performances with medium gross margins were characterized also by high feed self-sufficiency and lowland availability. In particular from GLM it resulted that farms with low feed self supply had significantly higher acidification, off-farm land use and off-farm eutrophication per kg of FPCM than the other ones, mainly due to the production and transport of feeds from the outside. At the same time farms with high level of production intensity, in terms of kg of milk per ha, had significantly higher acidification and eutrophication per kg of FPCM but also per ha, with the worst effects on a local scale.

There might be two scenarios of environmentally sustainable evolution for these farms: a process of extensification, by a decrease in the number of reared animals, or an increase of feed self-sufficiency by the improvement of the production and quality of self-produced forages. Finally, summer grazing in the highland could play an important role in both decreasing stocking density in the lowland and increasing self-sufficiency.

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The challenge to harmonise carbon footprint (CF) calculations for milk from different regions – a case study from Sweden and New Zealand

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ABSTRACT
This paper provides examples on how carbon footprint (CF) results can change depending on methodological decisions, with two contrasting milk production systems (Sweden and New Zealand) as a case study. Co-product handling was identified as a major factor, which can have significant impact on the final CF result. Moreover, as the CF result of milk to a large degree is based upon the extent of animal derived methane and nitrous oxide emission, it becomes crucial how these emissions are calculated and not at least which emission factors (EF) are used. Finally, the present paper also discusses and gives recommendations within which frames it would be advantageous to harmonise CF calculations for milk and dairy products.

Keywords: carbon footprint, lifecycle assessment, milk, uncertainties, allocation

1. Background

The environmental burdens from milk have featured frequently in research on food production. Various studies have been carried out using lifecycle assessment (LCA) to analyse the contribution to global warming (among other environmental impact categories) from milk production (e.g. Cederberg *et al.,* 2009; Ledgard *et al.,* 2009; Thomassen *et al.,* 2008a; van der Werf *et al.,* 2009). However, it can be difficult to compare the results from various studies, due to methodological challenges and differences between studies. Many industries and organisations are aiming of harmonising the methodology for carbon footprint (CF) calculations of products, and there are several initiatives, e.g. PAS 2050 (BSI, 2008), ISO 14067 (International Standard Organisation) and the Greenhouse Gas Protocol Initiative (World Business Council for Sustainable Development and World Resource Institute). Moreover, a specific initiative within the global dairy sector is progressing, where the International Dairy Federation and the Sustainable Agricultural Initiative, in cooperation with the Global Dairy Platform, are trying to look to which extent it is possible to harmonise the calculations on GHG emissions of dairy products.

Furthermore, the recent focus on harmonisation of CF methodology also needs to face the balance of the aim of harmonisation with other essential objectives, e.g. scientific validity. Harmonisation should not provide a laundry list of default assumptions and data, at the expense of scientific arguments – but should pave the way for better consistency, scientifically sound choices and use of the most appropriate data. It is also central to understanding the consequences of a decision (e.g. choosing allocation instead of system expansion or omitting emissions from land use change).

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This paper aims to analyse how the final CF result of milk ex farm-gate can vary, depending on different methodological choices. Additionally, it investigates to what extent it is advantageous to harmonise methodology for calculating the CF of milk. For this, two contrasting milk production systems in Sweden (SE) and New Zealand (NZ) serve as case study.

2. Materials and methods

There are several reasons why it might be very difficult to compare CF results obtained on milk from different studies.

1) Overall modelling approach, such as attributional LCA or consequential LCA modelling, as analysed by Thomassen *et al.* (2008b).
2) Handling of co-products (allocation or system expansion), which are one of the more important methodological issues, as described by Cederberg and Stadig (2003).
3) Calculation of biogenic emissions, such as methane from enteric fermentation and nitrous oxide from managing soils, arising from complex biological systems are often based on simplified equations and therefore give rise to uncertainties in the final GHG emission estimate (Rypdal and Winiwarter, 2001; Basset-Mens *et al.,* 2009).
4) Level of detail on data input (system boundary setting and cut off criteria), such as including or excluding capital goods (Frischknecht *et al.,* 2007) or including or excluding land use and land use change (e.g. the CF for soy bean meal can differ significantly depending on how deforestation is accounted for).

However, it is also noticeable that the above stated 'issues' to some extent are related, e.g. the type of modelling approach is closely connected to how co-products are handled. In Thomassen *et al.* (2008b) the CF result for milk is 44% lower applying consequential LCA compared to attributional LCA and one reason for this difference is explained by using system expansion instead of economic allocation. In Cederberg and Stadig (2003) the difference in co-product handling using system expansion gave a 31% lower CF compared to using economic allocation.

Here, we have compared two different co-product handling methods[1] for milk production in Sweden and New Zealand: physical causality allocation and system expansion. The allocation factors (i.e. share of emissions attributed to milk) applied here for physical causality allocation are 85% for Sweden (Cederberg and Stadig, 2003) and 86% for New Zealand (Ledgard *et al.,* 2009). For system expansion, the milk production system, including rearing of calves not used for replacement, give rise to milk and meat (shaded area to left in Figure 1). The meat produced in the milk system is assumed to displace (same amount of) other meat produced in a beef production system (shaded area to right in Figure 1). Thus the environmental impact is the total emissions from the milk production system, including rearing of a calf, minus emissions from the beef production system. No consideration has been given for the quality of the meat.

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[1] Only co-product handling between milk and meat has been analysed; for feed ingredients economic allocation has been applied in both cases.

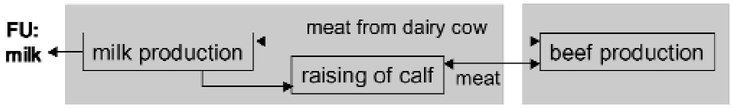

Figure 1: Illustration of system expansion applied for the milk production system.

The CF of milk consists largely of methane (45-65%) and nitrous oxide (20-35%), while fossil-derived carbon dioxide represents a smaller fraction (10-25%). It is extremely difficult to model the biogenic emissions of methane and nitrous oxide as they arise from complex biological processes, which can depend on many factors (e.g. nitrous oxide emissions are influenced by temperature, water and oxygen in the soil) and also vary over time and space. These emissions are typically calculated using IPCC guidelines (IPCC 2006a,b) where different emission factors (EFs) are used in the calculations, e.g. how much nitrous oxide is emitted per kg nitrogen applied to soil. There is however uncertainties in these EFs and in the IPCC guidelines there are uncertainty ranges provided for the EFs. Individual countries may use their own (country specific) EF, if it is documented that these are more representative for the specific conditions in the country. NZ has for example a country specific EF for nitrous oxide from nitrogen excreted during grazing.

Here we analysed sensitivity of the EFs for 1) direct nitrous oxide emissions from application of nitrogen, 2) direct nitrous oxide emissions from excreta deposited on pasture and 3) methane from enteric fermentation, which is the largest single emission for milk's CF. For the EFs for direct nitrous oxide emissions, the min and max values from the uncertainty ranges in IPCC (IPCC 2006b) were used. The sensitivity analysis for methane from enteric fermentation was based on IPCC suggestion that EFs "estimates using the Tier 2 method are likely to be in the order of ±20%" (IPCC 2006a). A summary of the EFs used in the sensitivity analysis is found in Table 1.

Table 1: Variation of EFs used in the sensitivity analysis.

emission factor (EF)	unit	value in this study	values for sensitivity analysis
EF for N_2O from applied nitrogen	kg N_2O-N per kg N	0.01	0.003-0.03 (min and max value for IPCC uncertainty range)
EF for N_2O from excreta during grazing	kg N_2O-N per kg N	0.01*	0.007-0.06 (min and max value for IPCC uncertainty range)
EF for CH_4 from enteric fermentation	kg CH_4 per tonne DMI	21.6	17.3-25.9 (±20% based on IPCC recommendations)

*NZ specific EF, IPCC default value is 0.02

The impact of level of detail on data input (system boundary setting and cut off criteria) was not included in the present study. Since biogenic emissions (methane and nitrous oxide) are the major contributors to milk's CF, capital goods only have a minor impact on the final CF result. In contrast, biogenic carbon emissions from land use and land use change may have significant impact on the CF result, however, addressing these emissions are extremely complex and currently no shared consensus or methodology on how to deal with these exist, which is why this was excluded.

The functional unit (FU) studied in the present study is the delivery of one kg of energy corrected milk (ECM) at farm gate in SE and NZ, respectively. Data on both milk production systems are taken from Flysjö *et al.* (2010). Data on GHG emissions for beef production is assumed to be 25 kg CO2e per kg slaughter weight based on comparison of several studies (Nguyen *et al.*, 2010).

3. Results

The calculated CF per kg ECM (including all by-products) in SE and NZ is 1.2 kg CO2e and 1.0 CO2e, respectively (Flysjö *et al.*, 2010). If physical causality allocation is used (where 85% and 86% is allocated to milk for SE and NZ respectively) the CF for milk is 0.99 kg CO2e for SE and 0.86 kg CO2e for NZ and if system expansion is applied, as described earlier, the CF per kg ECM is 0.62 kg CO2e for SE and 0.54 kg CO2e for NZ (see Figure 2).

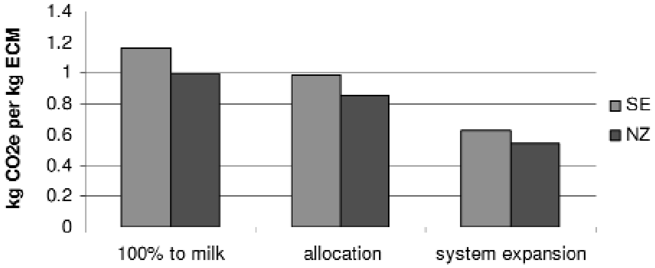

Figure 2: CF results for milk in SE and NZ when i) by-products are not accounted for, ii) allocation is made based on physical causality and iii) system expansion is applied.

The results from the sensitivity analysis of EFs are shown in Figure 3, analysing uncertainty ranges of the 1) EF for nitrous oxide from applied nitrogen (e.g. fertiliser, manure and crop residues), 2) EF for nitrous oxide from excreta during grazing and 3) EF for methane from enteric fermentation. The EF for nitrous oxide from applied nitrogen had the greatest impact on the CF of milk in SE while the EF for nitrous oxide from excreta during grazing was the most significant for NZ. Since NZ has a country specific EF for nitrous oxide from excreta during grazing, it is likely to be an overestimate to use the max value in the IPCC uncertainty range.

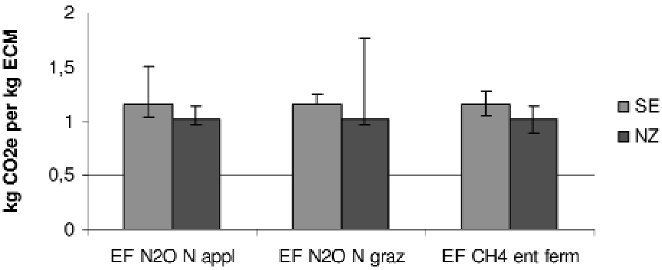

Figure 3: CF results for milk (not accounting for by-products) in SE and NZ when analysing uncertainty range of EFs for biogenic emissions of nitrous oxide and methane.

4. Discussion

At present, it is very difficult to make reliable comparisons of results from independent CF studies of milk. The choice of method for co-product handling has a significant impact on the final CF result, as has the choice of EFs. If the aim is to compare CF numbers, for example in carbon footprinting of dairy products, it is important to reach further consensus on how to perform calculations and what methods to use. Co-product handling is one methodological issue where harmonisation could be achieved quite easily. However, even though standards exist on the preferred order of co-product handling, there is still no common procedure for when it is possible to apply system expansion and when allocation needs to be used.

Since a large part of milk's CF consists of biogenic emissions, it is crucial to have a transparent description of how the emissions are estimated. To some extent, similar calculation models/equations can be used, but when emissions are highly site dependent, the reality is too complex for these models to produce reasonably accurate results. Also, the natural variations within biological systems are difficult to fully account for, and therefore it is important with sensitivity analysis to investigate the variation and/or uncertainty in the input data.

In Table 2 total GHG emissions for milk production (ex farm gate) is summarised, sorted by emissions (i.e. CH_4, N_2O and CO_2) and divided depending on their origin. This is an attempt to understand where it is possible to further harmonise data used for calculating the CF of milk.

Table 2: Summary of the potential for using harmonisation of databases and/or calculation models in calculating the CF of milk.

emission (% of total CF)	origin	on/off farm emission	complexity using a common database or calculation model/EF
CH_4 (45-65%)	enteric fermentation	on farm	Difficult, possible to some extent
	manure management	on farm	Difficult, highly site dependent
N_2O (20-35%)	field (feed production)	on farm	Difficult, highly site dependent
	field (global purchased feed)	off farm	Possible
	manure management	on farm	Difficult, highly site dependent
	fertiliser production	off farm	Possible
CO_2 (10-25%)	diesel/tractor	on/off farm	Possible
	electricity	on/off farm	Possible
	other energy	on/off farm	Possible
	fertiliser production	off farm	Possible

Harmonisation can be reach in various degrees for different "activities"; one way is to have a common database where data (for activities off farm) are derived in the same way. As seen in Table 2, all fossil carbon dioxide emissions (and emissions of nitrous oxide from production of nitrogen fertiliser) can relatively easy be harmonised by using a common database. Also for emissions from globally purchased feed, a common feed database would be possible. This could of course lead to an oversimplification and exclude diversity that exists in reality. Obviously, data from a common database should only be used when no better data is available. For emissions of methane and nitrous oxide, harmonisation is more challenging. Methane emissions from enteric fermentation can be calculated by using the same method. Today several methods exist providing different results (Kristensen, 2009). Methane emissions from manure management are site specific and therefore also more difficult to calculate using the same method. Harmonisation of nitrous oxide emissions from soil is probably most difficult, since these emissions to a large extent are dependent on local soil quality and climate conditions. IPCC provides a good basis for calculating emissions, using different tier methods (tier 3 being the most detailed level). However, comparing a CF result obtained using tier 1 with another CF result obtained using tier 2 is problematic, since the level of detail differ significantly. Thus, it is important to be aware of which level of detail is used for data to make fair comparisons. There is a need for further research to obtain more precise EFs or models to calculate biogenic emissions. More research is also needed within the area of harmonisation; to better understand how simplifications can be made and what implications it can have on the final CF result.

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Environmental assessment of two dairy systems in Brazil South

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ABSTRACT

We identified two groups of dairy farms representing the West and South of Santa Catarina, in Brazil South, with medium level of technology. The main difference between the two systems is the grazing system: unlike the properties of the West, the farms in the South use rotational grazing, making better use of the productive potential of pastures. We performed an LCA of the two groups of farms, using the SimaPro® software and data from Ecoinvent® database. The functional unit adopted was 1 kg of colled milk in farm, without energy correction. The results for the systems of continuous (West) and rotational (South) grazing show that the demand of non-renewable energy is greater in the West's system. Although the data in this study are still preliminary, we find that rotational grazing systems present less environmental impact per kg of milk produced.

Keywords: Environmental impact, dairy system, Life Cycle Assessment, LCA.

1. Introduction

The growing awareness by demand for "clean products" or "environmentally friendly products" is being driven largely by the need to ensure the sustainability of productive processes, but especially by the need toensure the health of the planet as a whole. The agricultural production models more widespreaded in the world in the last four decades gave priority to technical and economic efficiency aspects. The physical productivity was increased in a significant way in order to meet market demand and maximizing profits, but without a proper concern for its sustainability aspect over time (Spies, 2009).

The cattle may be a risk factor when the necessary measures to prevent pollution are not been taken (GTAA, 2001). In a large measure the production of cattle is characterized by its extensive practices or by integrated into the farm practices, supplemented with crop or forestry production - which are not objects of great environmental concern. Conversely, productions with high concentration of animals have a high risk of pollution and consequent environmental degradation (GTAA, 2001).

The characterization of dairy cattle production systems is important for the identification of hotspots in the productive sector and for the implementation of regional development projects. In Brazil there is great diversity of milk production systems. The genetic variability and consequently the feeding management are important variables of the current production models characterization (Assis *et al.*, 2005). The authors point out that in Brazil the dairy farming has two distinct characteristics: a national coverage and large production systems practices variability. This heterogeneity of the system characteristic contributes to the environmental, social and economic impacts.

The milk production in Brazil grew by 4.1% per year from 2003 to 2007 by the average growth rate of the largest producers on a non-uniform way, varying more than 8.8% in Santa Ca-

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tarina (SC) - state located in Brazil South. In the period from 2000 to 2007, the west and south areas of Santa Catarina were highlighted with a production growth of 124% and 71% respectively (Heiden, 2009).

In Santa Catarina State, production is characterized of small farmers spread over the territory, making use of many different production systems with different levels of technology – from producers who primarily marked for subsistence, to those highly specialized (Duarte, 2009). The rural settlements of Santa Catarina have on average an area of no more than 50 ha and constitutes an important activity for the economic income of a significant contingent of producers, especially small ones (Santos *et al.*, 2006).

The milk subject of Santa Catarina have different environmental impacts due to its heterogeneous production systems with strong genetic, food, equipment, facilities, and also animal handling pattern variations. Despite this heterogeneity, we can say that the livestock system in Santa Catarina is based on rotational and continuous grazing.

The continuous grazing is characterized by keeping the animals continuously in a same area without interruption. The staying on them there may be from a few weeks or months as temporary and annual, or even several years (Costa, 2007).

The rotational grazing is characterized by the grazing subdivision in a variable number of paddocks, which are used one after another. This way providing periodic rest to forage plants, whose duration depends on the number of paddocks and on the extension of each paddock occupation period (Smetham, 1995).

1.1. Environmental Assessment Approach

The LCA is a methodology that provides qualitative and quantitative factors of environmental impacts caused by products, not only during production processes, but also throughout the other stages of product life, as in obtaining raw materials and basic production of energy needed to supply the product system (Carlsson-Kanyama, 1998). The principles and structures are patterned by standard ISO 14040 and its requirements and guidelines are given by the standard ISO 14044. The four phases that make up the LCA are: goal definition and scope, life cycle inventory analysis, life cycle impact assessment and interpretation.

Although LCA was developed initially for environmental studies of industrialized products, more recently it has been applied in agriculture. Environmental assessment of dairy farming with this approach has been the focus of studies in some European countries as: Sweden (Cederberg & Mattson, 2000), Germany (Haas *et al.*, 2001), Norway (Hogaas, 2002), Spain (Hospido *et al.*, 2003) and Portugal (Castanheira, 2008).

The aim of this study is to compare the environmental impact of milk production in West and South of Santa Catarina State.

2. Methodology

2.1. Region study

Santa Catarina State is located between parallels 25°57'41"and 29°23'55" latitude South and between the meridians 48°19'37" and 53°50'00" West longitude. According to Köppen classification, the climate prevailing in this state is the type Cfb, "humid mesothermal with hot summer" (Medeiros *et al.,* 2004) and Cfa "mesothermal humid with cool summer." The Cfa variation is found in almost all state in the areas below 800 meters of altitude. Cfb already is in the highland areas above 800 meters. Rainfall is evenly distributed in the territory of the state because of the actions of the relief, so there is no rainy season or dry season.

The feed system of studied dairy farms is based on perennial pastures and winter pasture, with the use of additional fodder, commercial feed and silage. The main difference between the two systems is in the grazing system: unlike the properties of the West, the farms in the South use rotational grazing, making better use of the productive potential of pastures.

2.2. Goal and scope

The objective of the study was to compare the environmental impacts associated with the milk production in properties of two regions of Santa Catarina, in the period from July 2004 to June 2005. The supply chain under study is described as for milk production and not dairy. The functional unit (FU) was set to produce 1 kg of milk cooled in the property. For this study, the system limits considered were: production of agricultural machinery, production and combustion of diesel, transport of agricultural harvest, at an average distance of 250 km, production and use of chemical inputs, pesticides and organic fertilizers, energy and materials for cleaning and disinfection consumption, production of pasture, fodder and grain in the property (and part of the food from outside the property) with its emissions to air, water and soil and emissions from enteric fermentation in animals. It was not considered the production of goods related to rural facilities stage due to unavailability of data.

2.3. Inventory analysis

Data were provided by the *Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri)*, through the Rural Administration and Socioeconomics program, which uses a farms accounting monitoring network for planning purposes. The data collected from the properties are entered in software named Contagri (Agricultural Accounting) developed for management of rural properties. However, some additional technical information that was not available in the Contagri database were collected directly visiting properties.

We studied 22 proprieties of dairy farms representing the West (eight farms) and South (14 farms) of Santa Catarina, with medium level of technology. We used the program SimaPro ® and the database used was Ecoinvent®. Although this database is specific to Europe, it was considered that most of the production processes are similar. However, for food production, grain drying, burning diesel and electric power, the processes have been adapted for the Brazilian situation.

2.4. Environmental Impact Assessment

In this study the impact assessment covered all the steps recommended in ISO 14040, except the normalization and weighting. The impact assessment method was the CML in 2001 (baseline) and added the Land Occupation category (originally "land competition) from CML in 2001 (all categories) 2:04 version and Total Cumulative Energy Demand version 1.05. For Climate Change (originally "Global Warming Potential 100 - GWP100) we updated values of characterization factors (Forster et al., 2007) is bio-genic methane (new value 25) and nitrous oxide (new value 298).

We present results for the following impact categories: acidification, eutrophication, climate change, terrestrial ecotoxicity, land occupation and total cumulative energy demand. This modified method was chosen since it contains the impact categories usually related to the impacts of the agricultural products' supply chain.

3. Results and discussion

In this study we present partial results, since the research project is still running. The data colected by now were used in the LCA and presented results shown in Table 01 for each impact category analyzed.

Table 1: Environmental impacts of dairy farms in the West and South of Santa Catarina, Brazil, per kg of fresh milk.

Impact category	Unit	West	South
Acidification	kg SO_2 eq (*100)	1.635	2.101
Eutrophication	kg PO_4 eq (*100)	1.904	1.918
Global warming (GWP100)	kg CO_2 eq	1.692	1.420
Land occupation	m^2 a*	2.025	1.760
Total cumulative energy demand	MJ eq	6.278	2.470

* *Annum or per year*

The results for the systems of continuous (West) and rotational (South) grazing show that the demand of non-renewable energy is greater in the West's system, reaching more than two-fold difference in terms of MJ eq. (Figure 1).

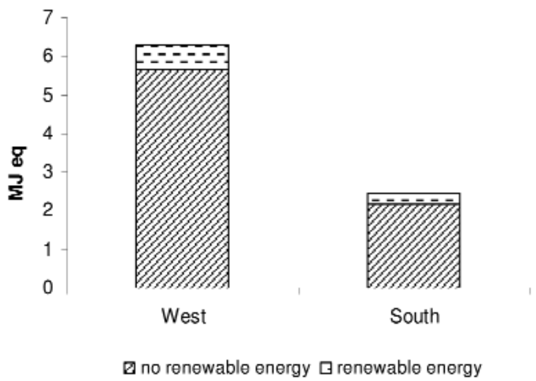

Figure 1: Energy demand of dairy farms in West and South of Santa Catarina, per kg of cooled milk.

The use of fossil fuels in food production represents the higher contribution of non-renewable energy demand in this impact category.

The difference for now-renewable energy demand is connected to the lower system productivity and consequently the larger use of food per kg of milk. This also explains the higher land occupation (Table 1) and the larger amount of CO_2 equivalent emission in the category of climate change.

Cederberg and Flysjö (2004) found the range of 2.1 to 2.7 MJ per kg of milk of energy demand in dairy systems with higher level of technology in Sweden. In dairy farms of South of Santa Catarina, that are more technology, we found values of energy demand that are in this range.

Overall results for climate change found in Santa Catarina farms are higher than the ones found by Cederberg and Flysjö (2004) and by Cederberg *et al.*, (2009). Thes authors presented the values of 1000 kg CO_2 eq. and the range of 1200 to 1400 kg of CO_2 eq, respectively. This difference is probably due to the lower productivity level of brazilian systems evaluated, that means a higher level of food consumption per each kg of milk produced.

In climate change, the major contribution comes from the carbon dioxide (Figure 2). The two main sources of CO_2 emissions are the use of fossil fuels in the stages of input production and the emissions from the field.

However, to estimate the emissions of nitrogen monoxide and methane, we use temporarily a single source of information in both systems, because the research is still in the preliminary phase.

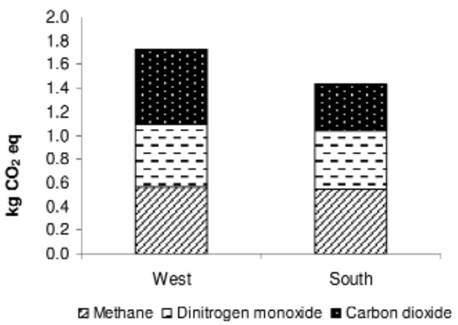

Figure 2: Greenhouse gases contribution (in kg of CO_2 eq) of dairy farms in West and South of Santa Catarina per kg of cooled milk.

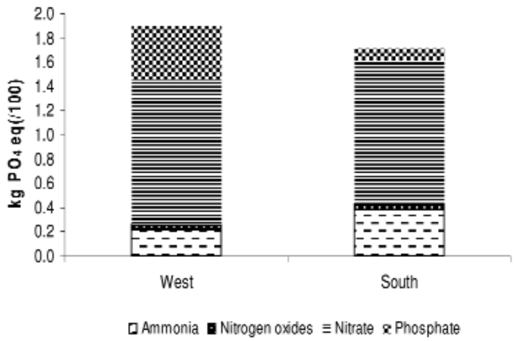

Figure 3: Eutrophication contribution (in kg of P_2O_4 eq) of dairy farms in West and South of Santa Catarina per kg of cooled milk.

For the eutrophication category (Figure 3), although the total value of PO_4 equivalent emitted was similar, there was a greater contribution by the emitted phosphate in the continuous grazing system (West), due to higher use of chemical fertilizers per kg of milk (Figure 3).

The eutrophication impact category presented values higher than ones reported by Cederberg and Flysjö (2004) for both systems evaluated. The low productivity is the main cause for the higher impact observed in Santa Catarina. These authors also found higher levels of nitrate in the nitrifying substances.

4. Conclusions

The system of rotational grazing (South) showed lower impacts in terms of climate change, energy demand, acidification and land use. However there are different levels of emissions in e-ach production system, the impacts are most associated with their productivity. The most striking factor is the production of feed for cows, so the system that consumes more food per kg of milk produced ends up impacting more.

To improve the use of energy in the system of milk production, one should optimize the use of concentrated feed, looking for dosing according to the curve of milk production. The higher input of feed and fertilisers leads to large emissions of CO_2 eq., due to the use of fossil fuels. Therefore improvements in these factors may represent a better environmental performance for both systems studied.

Because the data used in this study are still preliminary, the results should be carefully analysed, and should not be considered as a final conclusion of this research.

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Life Cycle Assessment of Italian high quality milk production

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ABSTRACT

This study applied Life Cycle Assessment in order to analyse the environmental impacts coming from the whole life cycle of an Italian brand of high quality milk, bottled in one litre Tetra Top package. The study was carried out in compliance with the "PCR for milk" prepared according to the International EPD® System. The environmental impact assessment results show that raw milk production at farms is the most critical life cycle phase, mainly because of: CH_4 airborne emissions caused by enteric fermentation, CO_2 airborne emissions caused by diesel consumption and finally NH_3 airborne and NO_3 airborne emissions coming from organic fertilizers use. A comparison among farms was also carried out, as well as a comparison between these LCA results and the registered EPD of milk.

***Keywords**:* LCA, Food, Agriculture, Dairy, Environmental Product Declaration

1 Introduction

According to the EU report "Environmental Impact of Products - analysis of the life cycle environmental impact related to the final consumption of the EU-25" (available on http://ec.europa.eu/environment/ipp/pdf/eipro_report.pdf), milk and dairy products are responsible for around 5% of global warming potential, 10% of eutrophication potential and 4% of photochemical ozone creation potential in the EU. Because of these remarkable environmental impacts, tools that allow dairy sector's companies to communicate their products environmental performance could enhance their competitiveness and encourage a more sustainable consumption. An example is the ISO type III Environmental Product Declaration (EPD), developed by the Swedish international system according to ISO 14025 and based on Life Cycle Assessment (LCA).

LCA studies have recently been carried out in order to compare conventional and organic milk production in some European countries (Cederberg & Mattson, 2000; Thomassen *et al*, 2008). In New Zealand, an LCA study has been performed on dairy farming to compare the eco-efficiency of an average national dairy farm with that of three contrasting intensification dairy systems (Basset-Mens *et al*, 2008). LCA has also been used to assess greenhouse gas emissions (GHG) from milk production system in Ireland (Casey & Holden., 2005). All these studies focus on the farming system, i.e. raw milk production at farm, including also crops cultivation and feed production. The whole life cycle of milk has been analyzed in Spain (Hospido *et al.*, 2003), although in a simplified LCA, in Norway (Hogaas Heide, 2002) and in France (Kanyarushoki *et al.*, 2008). An U.S. study (Heller *et al.*, 2008) has evaluated both GHG emissions and energy consumption of a large scale organic dairy.

The study here presented was performed in collaboration with and the financial support of a large Italian retailing company. LCA was applied in order to evaluate the environmental impacts related to the whole life cycle of an Italian brand of high quality milk. The study was

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carried out in compliance with the PCR (Product Category Rules) for milk and milk based liquid products (www.environdec.com).

High quality milk must comply with rigorous requirements fixed by Italian regulation (law n°169/1989, D.M. 185/1991), which regard cattle health and their feeding, stables hygiene, milking conditions, storage, dairy structure, heat treatments and packaging. Fat and proteins content of raw milk has not to be lower than 3,6%, and 32g/l respectively.

2 Methods

2.1 Goals

The purposes of this study were the following:

- To assess the environmental impacts coming from the entire life cycle of an Italian brand of high quality milk and to identify the most critical hotspots;
- To compare these LCA results with the registered EPD of milk.
- To compare the environmental impacts of different types of farms producing raw milk for the specific brand.

2.2 Functional unit and system boundaries

The cited PCR defines the functional unit as 1 litre of packaged milk. In our case, the reference flow is 1 litre of high quality milk bottled in a Tetra Top package. System boundaries included milk production at farm, i.e. cows breeding (including crops cultivation for fodder production), milk transport to dairy, pasteurization, bottles production, filling, packaging and delivery to distribution centres. Transport of purchased products, eg. fertilizers, chemical products, animal complementary fodder, as well as waste disposal were included for each stage. Production and use of primary packaging as well as secondary packaging (cardboard, polyethylene films and wooden pallets) were considered. Buildings, infrastructures, production of equipment, medicines, consumer and post-use phases were not included.

2.3 Inventory and data quality

Specific primary data, referred to 2008, were collected at the two dairies producing high quality milk for the Italian retailing company. Each dairy collects raw milk from a large number of farms. Farms delivering their milk to dairy B, which are located in a mountain region, are smaller than those delivering milk to dairy A. In order to obtain a representative sample, three farms (small, medium, large) for each dairy were selected as representative of the whole production and were involved in the primary data collection (referred to 2007). All primary data were collected according to the PCR for milk. Data of Tetra Top bottle production came from a previous LCA study developed by Tetra Pak (Università degli Studi di Padova, 2005). Databases (Ecoinvent, LCA Food, ETH) and literature were used for all the other data.

An attributional approach was applied according to the stated goal of the study (ILCD Handbook, 2010).

N_2O and NH_3 airborne emissions as well as NO_3 waterborne emissions, which occur during fertilizers use and manure and slurry spreading, have been estimated by using dispersion models published in Audsley *et al.* (2006) and IPCC (2006) and documents produced by Emilia Romagna region (www.ermesagricoltura.it). Pesticides emissions were not calculated as ecotoxicity is not included in EPD's impact categories.

During modelling phase, we divided milk life cycle into four main stages: 1) farm operation (i.e. agricultural phase and cows breeding and milking); 2) milk delivery to dairy (i.e. transport from farm to dairy); 3) milk processing at dairies; 4) transport to distribution centres.

3 Results and discussion

3.1 Impact assessment results on high quality milk production

The impact categories were chosen according to the PCR for milk (Table 1). The document "Requirements for an international EPD Scheme" (available on www.environdec.com) gives the list of the characterization factors to be used. The 'farm operation' stage dominates the milk production chain in all impact categories. The normalization based on the method CML2001, World 1990, shows that the contribution to ozone depletion and photochemical oxidation is negligible.

Table 1: Impact assessment results per 1 litre of high quality milk and percentage contribution of each life cycle stage

Impact categories	Units	Total	Farm operation	Milk delivery	Milk processing at dairies	Transport to distribution centres
Global warming	kg CO_2 eq.	1,54	84%	1%	12%	3%
Ozone layer depletion	kg CFC-11 eq.	7E-08	61%	3%	26%	10%
Photochemical oxidation	kg C_2H_4 eq.	2,8E-04	83%	1%	12%	4%
Acidification	kg SO_2 eq.	1E-02	90%	1%	7%	2%
Eutrophication	kg PO_4^{3-} eq.	7,8E-03	97%	<1%	2%	<1%

The main elements contributing to total results of global warming (GW) are methane, which accounts for 37%, carbon dioxide (36%) and nitrous oxide (27%). CH_4 airborne emissions are almost completely due to enteric fermentation from cows and heifers; CO_2 airborne emissions mainly arise from diesel consumption during agricultural processing; finally, N_2O airborne emissions are due to chemical and organic fertilizers use as well as cultivation of soy contained in complementary fodder. The main elements contributing to total results of acidification (Ac) are ammonia, which accounts for 71%, and NO_x (17%). These airborne emissions mainly arise from organic fertilizers use and from diesel consumption respectively. The main elements contributing to total eutrophication (Eu) are NO^-_3 waterborne emissions, which account for 65%, and ammonia airborne emissions (21%). These emissions are mainly caused by chemical and organic fertilizers use as well as soy and maize cultivation for the production of complementary fodder. The results of the category 'resources with energy content' are mainly due to the contribution of biomass, i.e. crops (maize, barley, hay) of fodder given to dairy cattle. In the category 'resources without energy content', most remarkable flows are clay, iron and gravel (included in building materials), calcium carbonate and sodium chloride (contained in complementary fodder).

3.2 Comparison with literature studies

We compared the results of GW, Ac and Eu obtained from our LCA study - both raw milk production at farm gate (Table 2) and the entire life cycle (Table 3) - with the results of other studies on milk production already published in literature. As a first step, we needed to convert our results per litre of milk into results per kg Energy Corrected Milk (ECM) or Fat and Protein Corrected Milk (FPCM) (both ECM and FPCM consider the fat and protein content of raw milk), using the following equation (Thomassen *et al.*, 2005):

$$\text{FPCM (kg)} = 0{,}337 + 0{,}116 * \text{\% fat} + 0{,}06 * \text{\% protein} * \text{kg milk sold}$$

As regards GW, raw milk production at farms accounts for 80% in Hospido *et al.* (2003), 88% in Kanyarushoki *et al.* (2008) and 68% in Heller *et al.* (2008). The results are affected by the values of CH_4 emission during enteric fermentation, which are different in the studies we compared. The choice of different dispersion models for calculation of fertilizers field emissions affects Eu and Ac and leads to a significant dispersion of the results.
The results of our study fall within the range of literature studies values, but a more detailed comparison is not possible because of the different methodologies and assumptions used in each of these LCA studies.

Table 2: Comparison with LCA studies at farm gate published in literature

At farm gate (per kg FPCM)				
GWP (kg CO_2eq)	**Acidification (kg SO_2 eq)**	**Eutrophication (kg PO_4^{3-} eq)**	**Country[b]**	**Reference**
1,08	1,8E-2	6,1E-3	Sweden/C	Cederberg (2000)
0,95	1,6E-2	6,8E-3	Sweden/O	Cederberg (2000)
1,4	9,5E-3	1,1E-2	Netherlands/C	Thomassen (2008)
1,5	1E-2	7E-3	Netherlands/O	Thomassen (2008)
0,84[a]	5E-3 [a]	3,9E-3 [a]	Spain/C	Hospido (2003)
1,3-1,5	-	-	Ireland/C	Casey (2005)
0,86	7,4E-3	2,7E-3	New Zealand/C	Basset Mens (2009)
1,0	-	-	U.S./O	Heller (2008)
1,03	9,3E-3	8,2E-3	France/C	Kanyarushoki (2008)
1,32	9,2E-3	7,7E-3	Italy/O	This study

[a] These results are given per 1 litre of milk; [b] C stands for Conventional; O stands for Organic

Table 3: Comparison with LCA studies (whole life cycle) published in literature

Whole milk life cycle (per kg FPCM)				
GWP (kg CO_2 eq)	**Acidification (kg SO_2 eq)**	**Eutrophication (kg PO_4^{3-} eq)**	**Country[b]**	**Reference**
1,05 [a]	8,5E-3 [a]	5,3E-3 [a]	Spain/C	Hospido (2003)
1,7 [a]	-	-	U.S./O	Heller (2008)
1,17	8,9E-3	9,8E-3	France/C	Kanyarushoki (2008)
1,57	1,02E-2	7,9E-3	Italy/C	This study

[a] These results are given per 1 litre of milk; [b] C stands for Conventional; O stands for Organic

3.3 Comparison of farms

The analysis of the characterized results of the 6 farms selected as samples (Figure 1) shows that smallest farms, i.e. B1 and B2, which have also the lowest milk yields per cow, have the worst results of GW, OD and PO. The other two impacts categories are dominated by the use of fertilizers: B1, which has the lowest consumption of manure and slurry, presents the best results; B2, which has the highest use of chemical fertilizers, presents high results.

3.4 Comparison between the results of this study and the registered EPD of milk

This LCA study (here called M1) has been compared with the EPD of milk published in 2007 (here called M2). Both M1 and M2 studies were carried out in compliance with the PCR for milk. System boundaries were the same, i.e. from cradle to final distribution, and milk was produced in the same geographical area and processed following similar technologies. Nevertheless, the results obtained show significant differences in some impact categories (Table 4).

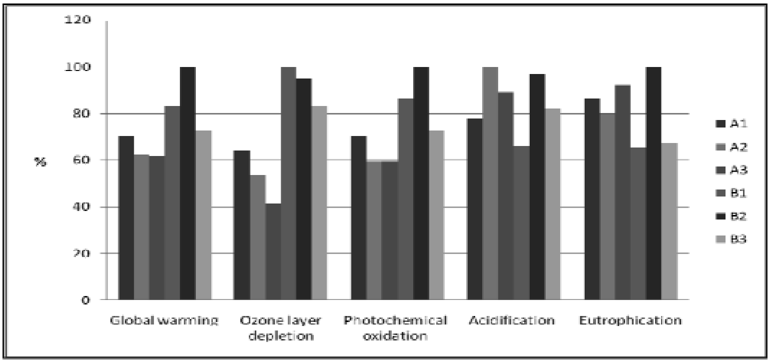

Figure 1: Characterization chart concerning the comparison of 6 farms

Table 4: Comparison between the results of M1 and M2 and interpretation

Impact category	[(M1-M2/M2)*100]	Interpretation
Global warming	+18%	Inclusion of N_2O airborne emissions in study M1
Acidification	+82%	Inclusion of NH_3 airborne emissions from fertilizers use in study M1
Eutrophication	+76%	Models used for NO_3 waterborne emissions calculation and inclusion of NH_3 airborne emissions from fertilizers use in study M1
Resources with energy content	>100%	Inclusion of the biomass (soy, corn, barley) energy content in study M1
Resources without energy content	>>100%	Inclusion of sodium chloride and calcium carbonate flows (contained in complementary fodder) and of gravel flow in study M1
Waste production	-88%	Inclusion of waste disposal in study M1

As the PCR document does not give specific rules for the calculation of fertilizers field emissions, it's up to the LCA practitioner to decide whether to calculate them or not, and to choose the dispersion models to be adopted. The inclusion of NH_3 airborne emission as well as the dispersion models to calculate NO^-_3 waterborne emissions strongly affect the results of both impact categories Ac and Eu: these values in study M1 are 82% and 76% higher than in study M2, respectively. The category 'resource without energy content' has a value two order of magnitude higher in study M1 than in study M2, mainly due to sodium chloride and calcium carbonate flows contained in complementary fodder. This production, indeed, was included only in study M1, because the PCR are not sufficiently detailed as regards this topic. Finally, the inclusion of both waste final destination and waste treatments only in study M1 leads to different results in the category 'waste production', where the value in study M1 is 88% lower than in study M2.

4 Conclusions

This LCA study concerning the entire life cycle of an Italian brand of high quality milk has confirmed that raw milk production at farms dominates the whole life cycle for all impact categories (its percentage contribution is always higher than 60%). Main flows affecting the results are: CH_4 from enteric fermentation, CO_2 from diesel consumption and NH_3 airborne emissions as well as NO^-_3 waterborne emissions coming from chemical and organic fertilizers use. The comparison with other studies on milk production, already published in literature, has highlighted that the adoption of different modelling and assumptions does not allow an accurate comparison among studies, and that harmonisation efforts are necessary. Finally, the comparison with the existing EPD of milk has demonstrated that LCA studies reproducibility as well as EPD comparability cannot be assured when PCR documents lack detailed rules. The revision of the PCR for milk, which will be carried out during 2010, will have to handle this issue and to better detail rules and prescriptions.

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Eco-design of cascade membrane processes for the preparation of milk protein fractions: approach and LCA results

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ABSTRACT

Milk protein fractions with target properties are commonly prepared using chromatographic processes, but membrane processes are considered with interest, since they are supposed to be more environment-friendly than chromatographic processes. The ECOPROM[1] project aims to propose a cascade of membrane operations to prepare α-lactalbumin and β-lactoglobulin enriched fractions with target properties, which will be optimized both in terms of environmental performance and preservation of protein properties. This article describes the Life Cycle Assessment (LCA) of the membrane process designed to obtain protein fractions, based on initial technical choices before environmental improvements. According to the results, it could be useful to study ways to reduce consumption of resources. Indeed, the energy-consuming processes appear to be the hotspot of the system. Moreover large freshwater consumption must be considered with interest. Finally product loss reduction should be also studied.

Keywords: LCA, eco-design, membrane processes

1. Introduction

Food and beverages contribute significantly to the environmental impact generated by European consumption (JRC 2006a). The environmental load of food products is mainly linked to agricultural production. However, as underlined by Roy *et al.* (2009), there are opportunities to improve each stage in the life cycle of a food product, including the transformation phase. Moreover, as suggested by Berlin (2002), it is interesting to exclude milk production from the impact assessment in order to focus on the dairy activities considered easier to improve. Finally, as Jungbluth explains (2000), the food-processing industry can directly act at three levels of environmental decision-making: "pre-product and additives", "processing" and "one product (types of packaging…)". In this context, the objective of the ECOPROM project is to eco-design a cascade of membrane processes allowing the extraction of two milk proteins with target properties: α-lactalbumin and β-lactoglobulin.

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The process studied is currently being developed, and its environmental performance optimization is carried out in 4 stages: 1) Description of the technological choices made for the initial process; 2) An LCA of this initial process to identify its weaknesses and define eco-design recommendations; 3) Eco-design for the initial process; 4) Validation and/or improvement of the design choices via an LCA comparing the eco-designed process to the initial process and to the reference chromatographic process generally used at the industrial scale for this type of application (Bonnaillie and Tomasula, 2008), but whose wastewater production remains problematic. This article describes the LCA of the initial process. Eco-design and environmental comparisons will be carried out afterwards.

2. Methodology

2.1 Definition of the objectives and scope of the study:

Objectives: This LCA aims to allow the definition of eco-design recommendations in order to improve the environmental performance of the studied process. This process is assessed with respect to the initial technological choices defined by the project partners.

Scope of the study: The system studied is the entire process implemented, from the entry of the milk into the plant to the production of dehydrated fractions of purified proteins (see Figure 1). It includes the unit operations, with the transformation and cleaning phases and the associated equipment. It excludes the facilities (buildings, lighting, etc.). Its geographic scope is France. The lifetime of the system is set at 20 years, in conformity with the lifetime scale of many transformation processes. The process studied is carried out on two distinct industrial sites 100 km from each other (one "conventional" dairy and one unit to separate protein fractions), which requires product transport, taken into account in the study.

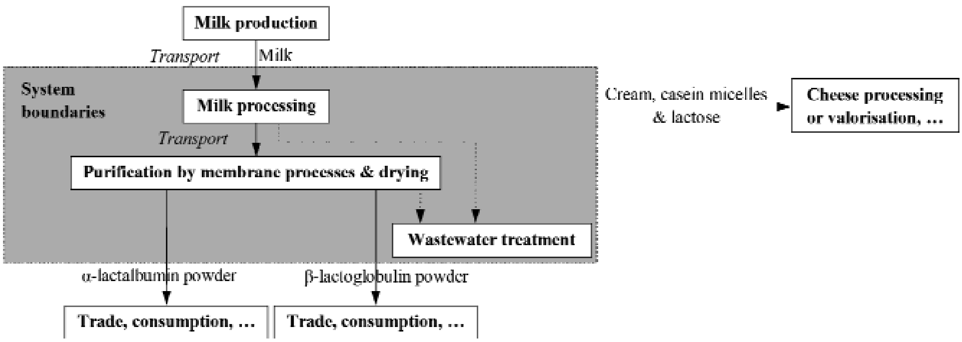

Figure 1: System studied

Functional Unit (FU): In this first study it was decided to use a functional unit that corresponded to the processing of a volume of milk equivalent to that processed every day in a dairy in France (583,000 L) and enabling the production of the following co-products: cooled-down cream, the cooled-down retentate of casein micelles and lactose, which are valorized outside of the process studied, and the two fractions of purified dehydrated proteins, which are the valorization products. In a second phase, the processes (initial, eco-designed and chromatographic) will be compared on the basis of the protein properties defined (purity, usage properties such as foaming capability).

Allocation rules: Since the objective was to study a process rather than to assess the environmental load generated by the manufacture of a product, we voluntarily did not establish a rule for allocation between the different co-products formed.

2.2. Inventory

The inventory was carried out on the basis of data specific to the project and generic data from the EcoInvent data base. The specific data correspond to controlled flows (e.g. the electricity consumption of the cream separator motor: 1035 kWh/day). They were either collected for each unit operation in the process based on the industrial knowledge of the operations, or estimated using calculations, since the process is in the development phase. Given the FU chosen, the controlled flows were quantified on the basis of one production day. The generic data correspond to the production of the controlled flows (e.g. electricity production). To make it easier to identify the sources of impacts and then ways to reduce them, it was decided to identify and quantify the controlled flows of the process for each unit operation and to break the system down into the following 4 sub-systems: processing, cleaning, equipment used and transport between the two industrial sites.

"Processing" sub-system: It is composed of a chain of some 30 unit operations that can be grouped together in the following functions:

Table 1: "Processing" sub-system

Function	Unit operations
1- Control of product microbiological safety	Cooling the whole raw milk at 4°C; Pasteurization of the skimmed raw milk at 72°C; Cooling of the pasteurized skimmed milk at 4°C°; Cooling of the serum concentrate at 4°C; Cooling of the raw cream at 6°C; Cooling of the casein micelles retentate at 4°C
2- Transformation of the milk to manufacture the co-products	Skimming the whole raw milk; Separation proteins / casein micelles (heating and microfiltration (MF) at 50°C); Cooling and separation serum-proteins / lactose (ultrafiltration (UF) at 15°C); Lactose concentration (reverse osmosis RO)
3- Purification and concentration of the two protein fractions	Separation α-lactalbumin and β lactoglobulin (heating to 50°C, acidification, dilution, MF); Concentration of the α-lactalbumin (cooling, re-solubilization and UF); Concentration of the β lactoglobulin (cooling and UF).
4- Powder formation	Drying of the α-lactalbumin; drying of the β lactoglobulin

Note: stocks that are not refrigerated are not indicated here but are included.

"Cleaning" sub-system: Each cleaning operation represents the cleaning of one or several machines on the line. It requires water and cleaning solutions (generally reutilized, with the exception of the operations using membranes, normally used only once according to industry practice) and generates wastewater that is then treated by a wastewater treatment plant (WWTP). These operations consume electricity and in some cases require the use of a gas boiler to heat the water and the cleaning solutions. A treatment plant was sized on each site to treat the quantity of Chemical Oxygen Demand (COD) generated daily by the cleaning wastewater. The impact of the treatment of each wastewater by one of the two plants is calculated on the basis of its COD. The pollutant load of the water exiting the plant was assessed on the basis of regulatory waste thresholds (JORF 1998, JRC 2006b). Since the precise outcome for the tensio-active and other molecules included in the detergent formulation, two extreme hypotheses can be expressed, depending on whether one considers them to be completely degraded or not at all degraded prior to discharge. We thus tested their potential impact in the framework of a sensitivity analysis between these two extreme situations.

"Equipment" sub-system: The equipment mainly includes: tanks, plate heat exchangers, a separator, a pasteurizer, pumps, a spray dryer and different types of membrane filtration installations: MF with ceramic membranes, UF and RO with polymer membranes.

The pipes are also included. The various elements of equipment were sized for the process studied. Given the data available, only the type and the mass of the materials were taken into account. With the exception of the membrane installations, for which we know the required masses of materials, the material masses for the equipment were estimated. For each piece of equipment, the mass of materials consumed during the system's lifetime (20 years) was quantified and then determined for 1 day of operation. The pieces of equipment were not assessed individually but by equipment group involved in the same unit operation (for example, cooling requires: 1 plate heat exchanger, a pump and pipes).

"Transport" sub-system: Transport between the two industrial plants distant of 100 km from each other, requires a tank truck.

3. Results and discussion

The results were achieved using the IMPACT 2002+ method and are represented as normalized damage. IMPACT 2002+ assesses the environmental load of our system using 14 midpoint categories. It then proposes to aggregate these impacts into 4 damage categories. It should be noted that in the absence of scientifically recognized information, no damage characterization factor was determined to take into account aquatic acidification and aquatic eutrophication in the assessment of the damage category "Ecosystem quality", which nevertheless includes aquatic ecotoxicity (Jolliet *et al.*, 2003). Since the discharge from the WWTPs in our system complies with the regulatory standards, we believe that excluding these two midpoint categories from the damage assessment does not challenge the relevance of this representation. Normalization then makes it possible to compare the different damage categories in our system with a certain homogeneity and with respect to the same reference: the environmental load of an average European per year for these same damage categories.

3.1 System:

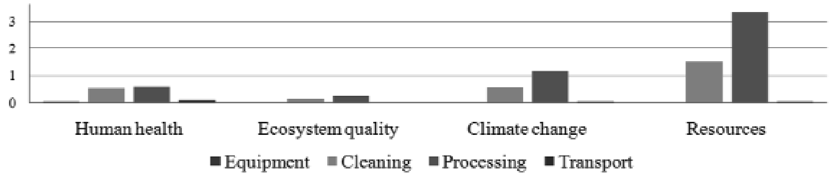

Figure 2: Normalized damages: comparison of the 4 components of the system according to the IMPACT 2002+ method, SIMAPRO software

Figure 2 shows that the main damage caused by the system is the depletion of resources which includes the extraction of minerals and the consumption of non-renewable energies. The "Processing" sub-system contributes the most to all of the damage categories tested.

3.2 "Processing" sub-system:

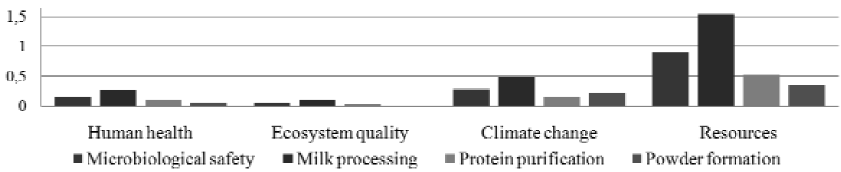

Figure 3: Normalized damages: comparison of the 4 components of the "Processing" sub-system according to the IMPACT 2002+ method, SIMAPRO software

Figure 3 shows that the main damage of the "Processing" sub-system is the depletion of resources, which in fact reveals the strong impact of energy consumption in the process. In this sub-system, the "Control of microbiological quality" function is guaranteed by operations which consume gas (pasteurization operation) and electricity (various cooling operations). The main source of impact of the "milk processing" function is the proteins/ casein micelles separation performed by MF at 50°C. It would require heating the milk, which would consume gas and in itself consumes electricity (pump operation and maintaining the filter fluid at temperature). The major source of the impact of the "protein purification" is linked to the protein separation: the precipitation and the MF at 50°C, consuming gas and electricity, have the strongest impact. Citric acid involved in the precipitation by acidification of the α-lactalbumin appears to a lesser extent. It should be noted that this last result still needs to be confirmed, since in a first phase, in the absence of data set on citric acid in life cycle inventory databases we proceeded to an approximation. Finally, the environmental load of the "Powder formation" is linked to its gas consumption.

3.3 "Cleaning" sub-system:

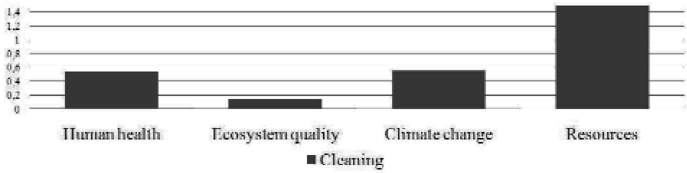

Figure 4: Normalized damages of the "Cleaning" sub-system according to the IMPACT 2002+ method, SIMAPRO software

The main impact of the cleaning operations (Figure 4) is linked to the electricity consumption of the WWTPs, to a lesser extent to the production of sodium hydroxide used for the single use cleaning solutions, and finally to the heating of certain cleaning solutions. In this respect, the cleaning of the first MF has the strongest impact. It should be noted that the cleaning operations consume large quantities of water, discharged into the aquatic environment after wastewater treatment. As Pfister *et al.* observes (2009), if the water used undergoes a loss of quality and/or if it is transferred to another watershed, this corresponds to a reduction of fresh water resources. Moreover as Koehler (2008) observes, while the methodological framework of the LCA is suited to this type of assessment, the impact assessment methods neglect this aspect. In our case, no assessment was made to this end by the IMPACT 2002+ method, with the risk of underestimating the real environmental load of the cleaning operations. Likewise, the cleaning substances tested in the framework of the sensitivity analysis, EDTA and sodium hypochlorite, are not taken into account by the method. We therefore do not assess the potential of their possible emission into the water.

3.4 "Equipment" sub-system:

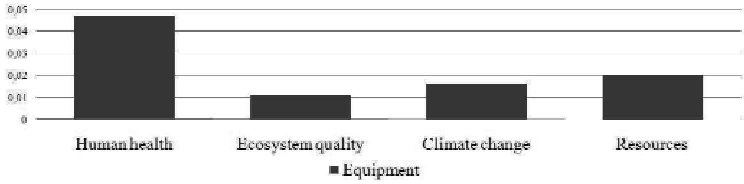

Figure 5: Normalized damages of the "Equipment" sub-system according to the IMPACT 2002+ method, SIMAPRO software

(Figure 5) The mass of stainless steel masks the impact of the consumables required for the filtration installations. The latter will be studied in more detail in the future, including their manufacturing and end-of-life phases in a comparison of several membrane processes.

4. Outlook and conclusion

The results reached will be used in the future to eco-design the initial process. In addition to reducing the environmental load and preserving the properties of the two protein fractions, the technological alternatives will have to meet two constraints: controlling product hygiene, and economic feasibility. Firstly, we will make recommendations aimed to reduce energy consumption, notably electricity. As emphasized by Notarnicola *et al.* (2008) in a study on reverse osmosis, membrane filtration steps are high electricity consumers. Another way of improvement could be the reduction of gas consumption, for example in replacing the MF at 50°C with a cold MF requiring certain adaptations of the process. Given that for milk the agricultural production phase has the largest impact, it could be useful to study ways to reduce product loss. This could also help reduce the quantity of organic matter to be treated by the WWTPs. Finally, we plan to create a simple flow indicator that would allow quantification of water use and also make it possible to monitor the improvement contributed by water recycling.

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