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International Dairy Journal 13 (2003) 783–796
INTERNATIONAL DAIRY JOURNAL
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Simplified life cycle assessment of galician milk production

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Received 16 September 2002; accepted 12 April 2003

Abstract

Milk, an example of staple food, has an outstanding demand by consumers as it is considered a prescription for good health. Life cycle assessment (LCA) is an excellent tool of environmental management and it provides a widespread knowledge on the environmental burdens associated to a product or to a human activity. In this study, a simplified methodology of LCA has been applied to analyse a representative scheme of milk production in Galicia (Spain), where a reliable inventory is still lacking. High quality data for the inventory was obtained in different representative fodder factories, farms and dairies for time periods over two years. The analysis of these data by LCA has permitted to quantify the potential impact associated to milk production and also to determine the reductions attained by the application of different improvement actions, such as the most adequate formulation of cattle feed and the implementation of treatment systems for water and air emissions. The consideration of these actions can lead to a maximum reduction of almost 22% of the global normalised impact.

Keywords: Life cycle assessment (LCA); Dairies; Farm; Milk

1. Introduction

In recent years, the idea that methods and techniques must be designed on the concept of sustainability has gained acceptance. This perspective considers a comprehensive evaluation of all upstream and downstream effects of human activity or product manufacture to evaluate the cumulative and synergistic effects on the environment over space and time. In this sense, one of the most internationally accepted methods for examining the global impact associated to activities or products is life cycle assessment (LCA).

LCA has been defined as "a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released into the environment; to assess the impact of the energy and materials used and released into the environment; and to identify and evaluate opportunities to affect environmental improvements" (Consoli, 1993). Although this guiding principle has been used in some industrial sectors in terms of "eco-balancing", "resource and environmental profile analysis" or "cradle-to-grave assessment", LCA has experienced a wider methodological development since the early 1990s when its relevance as an environmental management tool in both corporate and public decision making became more evident. An important review of different applications of LCA was made by Azapagic (1999), who pointed out its main uses as:

- Identification of environmental improvement opportunities,
- Strategic planning or environmental strategy development,
- Product and process optimisation, design and innovation,
- Environmental reporting and marketing,

Based on the work carried out by the Society for Environmental Toxicology and Chemistry (SETAC), the International Organization for Standardization (ISO) has developed a series of standards: the ISO 14040 series, based on life cycle assessment. These documents try to establish a framework to carry out the LCA studies in a technically credible practice (ISO, 2000).

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0958-6946/03/$ - see front matter
doi:10.1016/S0958-6946(03)00100-6

1.1. Life cycle assessment methodology

The LCA methodology includes the following stages: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results.

The goal definition points out the reason to perform the study and the intended use of the results. The scope clearly states the basic parameters of LCA such as functional unit, system boundaries, allocation rules, data quality and simplifications.

According to ISO 14040:1997, the functional unit (FU) is defined as the quantified performance of a product system for use as a reference unit in a LCA study. The ISO 14041:1998 standard accomplished the definition by indicating that one of the primary purposes of the FU is to provide a reference to which the input and output data can be normalised in a mathematical sense, therefore, FU has to be clearly defined and measurable.

The LCI consists of the collection of data concerning the resource use, energy consumption, emissions and products resulting from each activity in the production system. As was mentioned above, all these in- and outflows are calculated on the basis of the FU.

The purpose of the LCIA, the third phase, is to consider the LCI results to better understand their environmental significance. LCIA classifies the inputs and outputs of the inventory into specific categories and models the inputs and outputs for each category into an aggregate indicator. This stage is composed of several mandatory elements and there are also optional elements for normalisation, grouping or weighting of the indicator results and data quality analysis techniques (Fig. 1).

Finally, the life cycle interpretation is a procedure to identify, qualify, check and evaluate the information from the results of the LCI and/or LCIA of a product system.

1.2. Milk production

The dairy industry is one example of a factory characterised by the association of different production systems: agriculture, livestock, dairy farming, dairy packaging and product distribution. These systems are closely related, since the final product quality is highly dependent on the appropriate combination between the systems mentioned. The industrial activity of this sector is focused on the production of milk, cheese, butter or yoghurt. Regarding this multi-product system, there are two major factors: first, there is a tendency towards production in a few large specialised dairies and secondly, it is difficult to adjust the amount of incoming milk to rapidly changing market requirements, therefore companies tend to produce new consumable articles to control the demand for their outputs (Berlin, 2002b).

In April 2000, the European Commission published an extensive report concerning the environmental impact of the dairy production in the European Union (E.C., 2000). Taking into account this report, a classification of countries according to herd size can be established:

(1) The first group comprises The United Kingdom, Denmark, The Netherlands and Luxemburg, where herds with more than 50 heads prevail.
(2) The second one includes Germany, France, Belgium, Ireland and Sweden. Populations between

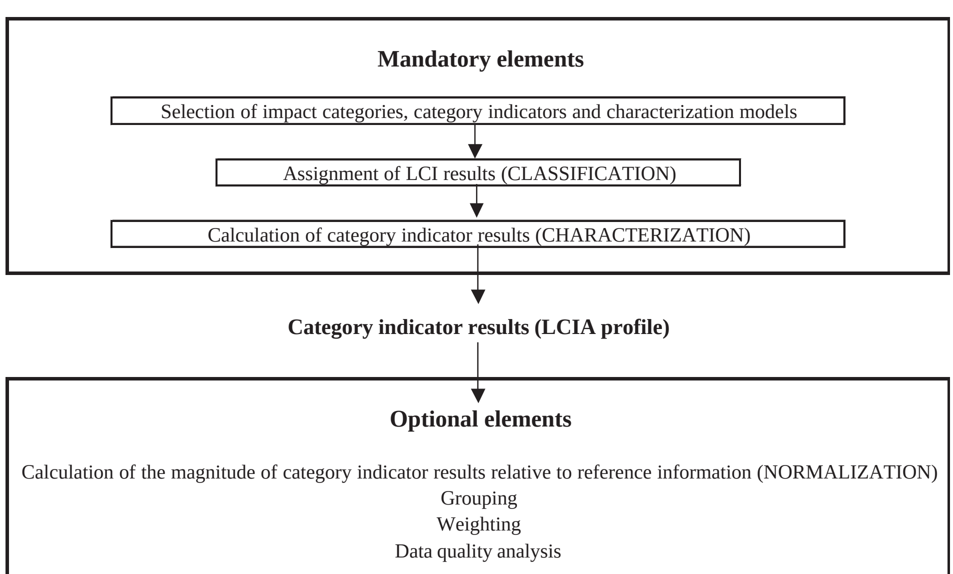

Fig. 1. Elements of the LCIA phase. Source: ISO/FDIS 14042:1999.

20–25 cows represent more than 35% of all farms with more than 45% of total cows.

(3) The third one considers the four Mediterranean countries (Spain, Portugal, Italy and Greece) as well as the two new members (Finland and Austria), in which herds with less than 10 cows represent an average percentage of 60% of total. In particular, Galicia, a Spanish region with an important milk production, presents an atomised distribution. Statistical data indicate that 75% of its farms have less than 10 cows, while the remaining 25% have encountered an industrialisation and modernisation process with a superior surface and herd size, which correspond to a renovated livestock concept.

Although statistical data from our region show that the majority of the farms have less than 10 cows, since mid-80's milk production in Galicia is suffering a devastating recession. Consequently, a high number of farms have been obliged to close: 1159 on year 2001 and 1435 on year 2002, with an increasing tendency observed since last years. In fact, the number of farms in Galicia has decreased from 109,284 farms operative on 1982 to 24,910 at the end of 2002. The first farms to undergo these consequences are the smaller ones because they cannot be competitive so the farms that have a significant contribution in the productive framework are the bigger ones (two of them were selected for this study).

The dairy sector has been extensively studied from the perspective of LCA in Norway: milk production (Høgaas, 2002a); Sweden: milk production focused on the farm level (Cederberg & Mattson, 2000) and semi-hard cheese (Berlin, 2002a); and Germany: milk production, with a special interest on impacts associated to agriculture (Cederberg & Mattson, 2000; Haas, Wetterich, & Köpke, 2001). As can be deduced, most of the LCA studies on milk production were carried out for countries belonging to the second group. In the case of the third group, a reliable inventory for Life Cycle Analysis was still lacking.

Although all dairy products are essential for the everyday nutritional regime, milk production has been chosen in this work as the most representative due to its outstanding position as an important staple food. In fact, most citizens consider consumption of milk in infancy, childhood and throughout adult life, as a prescription for good health. Regarding the different types of milk, three different ones, differing in the amount of fat, are the most significant: skimmed milk (0.5% fat), semi-skimmed milk (1.5–1.8% fat) and whole milk (3.5% fat). The most common one in the Spanish market is whole milk, with sales greater than 2700 millions of annual litres (data of year 2001), followed by semi-skimmed milk with 857 millions of litres per year and skimmed milk with a consumption of around 759 millions of litres per year (Vilbo, 2002). Even though whole milk still maintains its supremacy, semi-skimmed and skimmed milk are getting an increasing share of consumers preferences and nowadays they represent 40% of total sales. In the future, consumption of vitamin-added or enriched milk must be considered since although its market share is now only 1%, this product has an important expansive dynamic which responds to a changing urban way of life (Vilbo, 2002).

According to the European Commission report (E.C., 2000), Spain occupies the 6th position in annual milk production, behind Germany, France, The United Kingdom, The Netherlands and Italy. Relating to the percentage distribution by regional areas of national global production (6828 thousand tonnes in the year 1997), Galician dairies play a fundamental role with a contribution of 26.38% (MAPA, 2002).

2. Goal and scope definition

2.1. Objectives

The objective of this study is to examine the total life cycle of production and processing of milk in order to quantify the potential environmental impact. Two dairies and two farms have been selected as representative of Galician milk production to define both production and processing scenarios. Additionally, other relevant sub-systems have been identified and studied separately: fodder production and packaging, the former by considering two important fodder factories and the latter by public report data.

The identification of the activities with a major environmental impact will permit to establish the improvement actions on the process and to quantify the impact reduction associated to the proposed actions.

2.2. Functional unit

The functional unit (FU) selected is 1 L of packaged liquid milk, ready to be delivered.

2.3. System boundaries

The determination of the system boundaries is a complex difficulty in most LCA studies, because the food sector is a multipart and large production system (Andersson, Ohlsson, & Olsson, 1994). The life cycle of milk production included in this analysis is shown in Fig. 2, where the following hierarchy has been established:

- First level: main stages of global process.

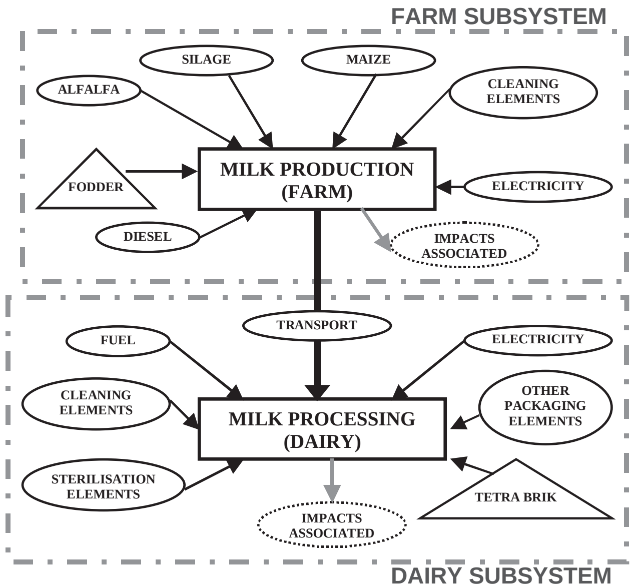

Fig. 2. Schematic flow chart of the life cycle of milk. The main stages of the process are represented in blocks; Inputs associated with industrial processes in triangles; Inputs from LCA databases in continuous circles; impacts associated in discontinuous circles.

- Second level: inputs that have an industrial process associated and have been analysed in detail.
- Third level: inputs taken from LCA databases.

Apart from the main product, other outputs of the system such as co-products, waste and emissions to water, air or soil, are also included in the inventory. The most often omitted sub-system is the consumer phase and it has not been considered in the present study.

2.4. Allocation rules

During the performance of LCA, allocation problems arise when the life cycle of different products are connected.

In other works (Høgaas, 2002a), a cow is defined as a multifunctional production system, supplying several products: milk, meat, skin and manure. The allocation rule for the two main products (milk and meat) was based on the biological demand of fodder while the other two products were not considered: the manure was used as a fertiliser at the farm and it was not looked upon as a product (Cederberg & Mattson, 2000), and the skin of the cows was omitted due to its much lower importance (economic and mass). Although the farms evaluated were specialised in milk production, the study of economic revenue per cow based on historical Galician market prices from years 2000 to 2002 for milk and meat has entailed the following distribution of the associated economical benefits: 87% for milk and 13% for meat. This figure is not negligible so economic allocation was considered for raw milk production.

At the milk processing stage, the dairies chosen are basically mono-functional and the cream obtained as a co-product represents less than 2.5% of the total annual production, consequently, allocation rules considering cream were not applied.

During fodder production and tetra brik manufacture process, mass criteria have been chosen depending on the distribution of final products.

2.5. Data quality

To assess the most accurate environmental impacts associated to Galician milk production, we mainly considered data from Galician industries. Real data from the two farms and the two fodder factories were collected in several periods during three years: 2000, 2001 and 2002.

There are other types of data whose production systems are not present in Galicia and they have been obtained from companies from other regions. For instance, Tetra brik containers are only manufactured in a factory located in Arganda del Rey (Madrid) and its inventory is obtained from Environmental Statements of 1998 and 1999 (TetraPak-España, 2000) and the Sustainability Report of 2000 (TetraPak-España, 2001). In relation to the electricity production profile, an electrical percentage distribution according to data from the Institute for Diversification and Energy Saving (Spain) has been used: 35.8% of the electricity is produced from coal, 27.6% is nuclear, 13.9% is hydro-electric, 9.9% is obtained from oil power plants, 9.7% from gas power plants, 2.2% from wind power plants, 0.6% from waste use and 0.3% from biomass use (IDAE, 2002). However, due to the non-availability of data quantifying the environmental burdens associated to the different ways to produce electricity in Spain, we chose data from the database BUWAL250 (1996). In Table 1, we present a list of the data taken from databases, their main sources, their period and their geographical origin.

2.6. Simplifications

According to Høgaas and Ohlsson (1998), two methods can be used to carry out the LCI: the simplified method or the detailed method. On one hand, the former considers all the production systems (farms and dairies, in this particular case) as a black box, quantifying the flows corresponding to the inputs and outputs of the systems, that is to say global consumptions that include additional activities. On the other hand, the detailed method allows to specify emissions, energy and water consumption for the different process steps (pasteurisation unit, sterilization system, pumps, etc.), which requires a great effort (time and means) because it is necessary to obtain a very detailed

Table 1
Sources, period and geographical origin of data

	Element	Source[a]	Period	Geographic area
Farm	Paper	Franklin Assoc.	1995–1999	North America
	Acid solution	IDEMAT	1990–1994	Europe, Western
	Alkaline detergent	BUWAL	1990–1994	Europe, Western
	Diesel	IVAM	—	—
	Electricity	IDAE + BUWAL	2000	Spain
	Maize/Silage/Alfalfa	Gov. Catalonia	1990–1998	Catalonia, Spain
	Fodder	2 Factories	2000–2002	Galicia, Spain
Dairy	Raw milk	2 Farms	2000–2002	Galicia, Spain
	Tetra brik	Tetra Pak	1998–2000	Madrid, Spain
	Cardboard	Franklin Assoc.	1995–1999	North America
	Film	Pre 4	1985–1989	Europe, Western
	Hydrogen peroxide	IVAM	—	—
	Sodium hydroxide	Pre 4	1985–1989	Europe, Western
	Fuel	IVAM	—	—
	Electricity	IDAE + BUWAL	2000	Spain
	Transport	BUWAL	1990–1994	Europe, Western

[a] DATABASE REFERENCES: Franklin Associates USA LCI Database Documentation, Franklin Associates, Prairie Village, Kansas, USA, 1998. IDEMAT database, Faculty of Industrial Design Engineering of Delft University of Technology, The Netherlands, 1998. BUWAL 250, Ökoinventare für Verpackungen, Schriftenreihe Umwelt 250, Bern, 1996. IVAM LCA Data 2.0 Database and User's Guide, IVAM Environmental Research, Amsterdam, The Netherlands, 1998. Pre 4 database, PRé Consultants, Amersfoort, The Netherlands, 1998. Government of Catalonia (Spain), Department for the Environment. Anàlisi del Cicle de Vida de la Pell. Aplicació a la definició de criteris per a la concessió de l'ecoetiqueta, 1998.

collection of data. If there is not enough data from all the equipments and auxiliary devices, significant mistakes can be derived.

In this way, the philosophy of the simplified one has been followed in this study on the basis of the established objectives and the data available.

3. Life cycle inventory

The main stages of the process of milk production correspond to milking process at farms, animal food preparation and milk processing in dairies.

3.1. Farm subsystem

Two well-managed farms were inventoried (Table 2). Their renewed facilities, consisting of an automatic milking system with recollection pipes and a storage tank, are a good example of the modernisation philosophy that is in practice nowadays.

The first one is operative since 1997 and its inventory data were calculated on the basis of its annual production of 2000 (228,286 L), with 50 heads (23 dairy cows and 27 suckler cows), that means an average yield of 9925 L per cow and year.

The second one was opened in 1996 and its inventory data were calculated taking into account its annual production corresponding to 2001 (353,725 L), with 60 heads (38 dairy cows and 22 suckler cows) that means an average yield of 9309 L per cow and year.

The milking process takes place twice a day and the raw milk is stored in a refrigeration tank awaiting transportation to a dairy. After being emptied, both the tank and the milking system are daily cleaned with an alkaline detergent and weekly cleaned with an acid solution.

Data of global consumption of electricity were compared with the historical data of energy consumption before the implementation of the automatic milking system and we quantified that almost one third was due to the milking system. The other two thirds correspond to pumping, lighting, maintenance and refrigeration devices.

Regarding other inputs, it is important to indicate that the most frequent infectious illness in dairy cows is mastitis, a general term which includes different kinds of specific mammary gland infections. One portion of the antibiotics used in mastitis treatment can be found in milk, therefore it is necessary to throw it away within 72 h after treatment or during the time specified in the antibiotic prospectus (Amiot, 1991). In this study, the most common antibiotics were qualitatively identified: Synulox LC (Pfizer Italiana S.p.A.), Cepravin VS (Shering-Plough), Receptal (Intervet International B.V.), and Prosolvin (Intervet International B.V.).

Ruminants, due to their special digestive systems, produces methane, which much be considered in the LCI tables because it is a potent greenhouse gas that can

Table 2
Inventory data of the farm (FU = 1 L of raw milk)

Inputs			
From the Technosphere		From the Nature	
Materials and fuels		Raw materials	
1. Food		1. Water	2.66 ± 1.15 L
a. Maize	370.3 ± 141.7 g		
b. Fodder	386.0 ± 17.7 g		
c. Silage	440.9 ± 168.1 g		
d. Alfalfa	96.2 ± 57.2 g		
e. Corrector	10.23 g		
2. Alkaline detergent	0.61 ± 0.26 mL		
3. Acid solution	0.06 ± 0.01 mL		
4. Disinfectant	0.92 ± 0.40 mL		
5. Paper	0.355 g		
6. Linchpin	7.38×10^{-5} units		
7. Diesel	3.68 ± 0.09 mL		
Electricity			
1. Electricity	47.4 ± 9.31 Wh		
Outputs			
To the Technosphere		To the Nature	
Products and co-products		Emissions to air	
1. Raw milk	1 L	1. Methane	10.86 g
Waste for treatment		Emissions to water	
1. Urban solid waste	0.24 g	1. Wastewater	1.08 L
		COD[a]	8.22 g L^{-1}
		TSS[b]	2.70 g L^{-1}

[a] COD = Chemical organic demand.
[b] TSS = Total suspended solids.

contribute to the global climate change. Globally, ruminant livestock produce about 80 million tons of methane annually, accounting for about 22% of global methane emissions from human-related activities. According to available data from EPA (2002), an adult cow emits 120 kg of methane per year and this average data has been included in the inventory (output section).

3.2. Animal food preparation

Fodder plays an important role in animal food. Maize, fodder, silage, alfalfa and corrector are the main components in the formulation of fodder to attain acceptable levels of protein and energy supplement in the final mixture (between 15.5 and 18.5% protein and 1.70–1.72 Mcal kg^{-1} of dry material).

This subsystem associated to milk production has been studied in detail and a life cycle inventory of this manufacture process has been carried out. The inventory data proceeded from two factories sited in Galicia (Table 3). The first one has an annual production of over 100,000 tonnes and an animal distribution of 60% for cattle, 35% for pig and 5% for other animals. The second one has an annual production of 90,000 tonnes, which is distributed in the following percentages: 90% for cattle destined to milk production and 10% for cattle belonging to rural families destined to their own milk consumption. The distribution of the production in terms of areas of influence is the following: 98% of total production is delivered within 30–40 km and 2% goes to longer distances (100 km). Blending capacity is a design parameter to define the load of its batch-production: 2000 kg of the mixture is the value for the former and 4000 kg for the latter.

3.3. Dairy factories

The dairy inventory data were calculated on the basis of its annual production for the year 2001, around 200 millions litres. The products produced are packaged liquid milk: 71%, whole; 18%, semi-skimmed and 11%, skimmed milk. Cream is obtained as a co-product (4,617,000 kg in 2001) and it is sold for further processing in France (Table 4).

Each dairy has designated several routes to collect the milk. At the dairy gate, quality controls have to be done as well as the measurement of the quantity of milk before storage (Fig. 3). Trucks, after being emptied, as

Table 3
Inventory data of the fodder factory (FU = 1 kg of fodder)

Inputs			
From the Technosphere		From the Nature	
Materials and fuels		Raw materials	
1. Raw materials		1. Water	66.62 mL
a. Maize	165.8 ± 34.2 g		
b. Barley	189.2 ± 15.9 g		
c. Wheat	47.7 ± 7.7 g		
d. Rye	82.22 g		
e. Soy bean	143.7 ± 10.4 g		
f. Soy shell	19.4 ± 0.6 g		
g. Gluten	104.8 ± 15.2 g		
h. Cotton seed	34.7 ± 5.3 g		
i. Molasses	22.1 ± 1.3 g		
j. Calcium carbonate	13.2 ± 3.9 g		
k. Phosphate carbonate	4.6 ± 2.1 g		
l. Alfalfa	3.6 ± 1.7 g		
2. Paper bags	1.39 ± 0.03 g		
Electricity			
1. Electricity	49.1 ± 3.3 Wh		
Outputs			
To the Technosphere		To the Nature	
Products and co-products			
1. Fodder	1 kg		
Waste for treatment			
1. Urban solid waste	0.11 kg		
2. Oil	0.08 g		

well as the storage silos have to be cleaned by means of Clean In Place system (CIP), equivalent to the cleaning system in milking facilities. Before specific thermal treatment, a filter and a clarifier are necessary to exclude particles and impurities, and an aeration tank to remove the occluded oxygen and volatile compounds that could bring ulterior problems.

There are two thermal milk treatments: Pasteurisation and Ultra High Temperature (UHT). The pasteurisation proceeded with the preheating of the milk to 65°C before skimming. Secondly, milk is heated to 78°C for 15 s and cooled down to 4–6°C and finally, it is stored. This facility has the CIP system for hygienic conditions. UHT treatment consists of rapid heating to 132°C minimum, followed by rapid cooling to room temperature and aseptic packaging. UHT facilities also have CIP system and additionally, sterilisation for an hour and a half.

Then, Tetra-brik filling takes place automatically in filling machines, where hydrogen peroxide is used as sterilising agent (later removed by evaporation). These machines also have to be cleaned with the same CIP system as UHT facilities.

Finally, six or 12 bricks are packed in a cardboard box, and later on pallets.

4. Life cycle impact assessment

4.1. Characterisation

In the first steps of classification and characterisation, emissions and resources coming from the inventory are sorted into different groups or impact categories according to their potential impact on the environment. In accordance with the default list of impact categories elaborated by Guinèe et al. (2001), some of them have been chosen among the called baseline impact categories: climate change (also called global warming, GWP), stratospheric ozone depletion (ODP), acidification (AP), eutrophication (EP), photo-oxidant formation (POCP) and depletion of abiotic resources (ADP) (Table 5).

In addition, a flow indicator, energy consumption (EC), has been considered as well. The quantities of energy consumed in each process can be added together in a fairly straightforward way. For fossil fuels characterisation factors are their lower heating value (MJ LHV) whereas factors used for uranium, hydropower, ... as well as for biomass are stated at 1 (Pré-Consultants, 1997)

On the basis of the defined functional unit, Table 6 displays the total value of characterisation phase for each category as well as the flow indicator for both farm and dairy subsystems.

Raw milk production at farm is responsible for more than 80% of the GWP impact (80.32%). Note that the item "impacts associated to milk production" includes emissions to air as well as to water, and in particular methane emissions into the air from cows digestive process are directly responsible for one third of this effect.

The analysis of ODP indicates that the transport of raw milk from farms to dairies is accountable for one third of the total effect (34.93%). This transport takes place in isothermal diesel trucks that keep raw milk at an appropriate temperature along the collection routes (around 200 km each one).

In relation to AP and EP, raw milk can be identified as the greatest contributor at each total potential impact, with a contribution of 58% and 73%, respectively. In the case of the farm, fodder production is the item accountable for the higher EP contribution. The origin of that contribution comes from the agricultural phase (that is to say, maize and fodder production), which was found to be of significance for all the environmental impacts. However, another factor must be taken into account at EP: wastewater generation at farms. There, several streams can be identified and different parameters can be evaluated. Specifically, the quantification of COD in the wastewater generated in the milking room showed an average value of $12.47\,g\,L^{-1}$, which is much lower than the COD of raw milk (Selmer-Olsen, 1992): $224\,g\,L^{-1}$. The milk

Table 4
Inventory data of the dairy (FU = 1 L of packaged milk)

Inputs			
From the Technosphere		From the Nature	
Materials and fuels		Raw materials	
1. Raw milk		1. Water	4.41 L
2. Tetra-brik	1.15 ± 0.05 L		
3. Cardboard	1.009 ± 0.006 u		
4. Film	16.8 g		
5. Hydrogen peroxide	0.183 g		
6. Nitric acid	0.69 ± 0.34 g		
7. Sodium hydroxide	0.53 ± 0.13 g		
8. Fuel	1.69 ± 0.07 g		
	7.07 ± 1.55 g		
Transport			
1. Truck 40 ton	222 ± 11 kg km		
Electricity			
1. Electricity	46.3 ± 10.9 Wh		
Outputs			
To the Technosphere		To the Nature	
Products and co-products		Solid emissions	
1. Packaged milk	1 L	1. Combustion waste	2.16 g
2. Cream	22.26 g		
		Emissions to air	
Waste for treatment		1 SO_2	0.19 ± 0.04 g
1. Cardboard	0.305 g	2. NO_2	3.47 ± 0.55 g
2. Used oil	0.04 g	3. CO	3.82 ± 1.01 g
3. Used oil filters	10^{-7} units		
4. Used Tetra-brik	0.003 units	Emissions to water	
		1. Wastewater	0.182 L
		COD	0.020 g L^{-1}
		TSS	0.022 g L^{-1}
		Emissions to soil	
		1. Sludge	0.053 L
		Fe	12.98 mg L^{-1}
		Cr	0.377 mg L^{-1}
		Hg	0.008 mg L^{-1}
		Zn	2.914 mg L^{-1}

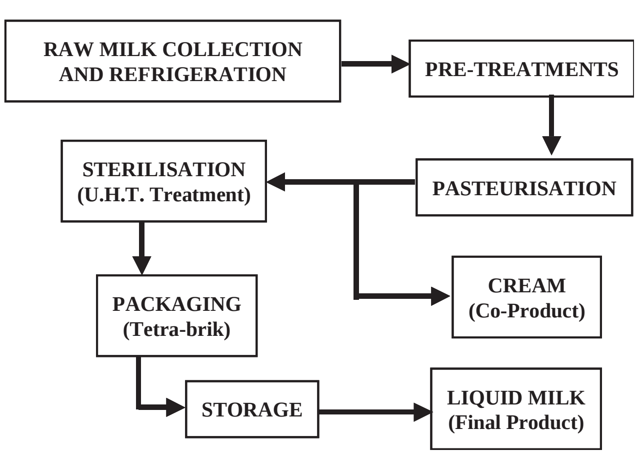

Fig. 3. Block diagram of milk processing at the dairy.

losses corresponded to a diluted milk stream (5.6%). This figure is, however, negative to the economy of the farmer and responsible for the eutrophication of fields and watercourses.

As far as PCOP is concerned, two are the most important damage sources: emissions into the air from the fuel combustion in dairy boilers (just about 60%) and methane emissions coming from cows at farms (more than 20%).

With regard to ADP, tetra-brik manufacture is responsible for almost the total potential impact (84%) mainly due to the production of paper and the consumption of natural gas along the manufacture process.

Mainly due to the same reason, tetra-brik manufacture has also the most important effect on EC: more

Table 5
Bibliographic references of the characterisation factors for the impact categories considered

Impact category	References
Global warming (GWP)	J. T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P. J. van der Linden and D. Xiaosu (Eds.), 2001. IPCC Third Assessment Report: Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK.
Stratospheric ozone depletion (ODP)	WMO[a], 1992: Scientific assessment of ozone depletion: 1991. Global Ozone Research and Monitoring Project—Report No. 25, Geneva. WMO, 1995: Scientific assessment of ozone depletion: 1994. Global Ozone Research and Monitoring Project—Report No. 37, Geneva. WMO, 1999: Scientific assessment of ozone depletion: 1998. Global Ozone Research and Monitoring Project—Report No. 44, Geneva.
Acidification (AP)	Huijbregts, M., 1999. Life cycle impact assessment of acidifying and eutrophying air pollutants. Calculation of equivalency factors with RAINS-LCA. Faculty of Environmental Science, University of Amsterdam, The Netherlands.
Eutrophication (EP)	Heijungs, R., J. Guinèe, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, H.P. de Goede, 1992. Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Science (CML), Leiden University, Leiden.
Photo-oxidant formation (POCP)	Derwent, R.G., M.E. Jenkin, S.M. Saunders & M.J. Pilling, 1998. Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism. Atmospheric Environment 32: 2429–2441. Jenkin, M.E. & G.D. Hayman, 1999: Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters. Atmospheric Environment 33: 1775–1293.
Depletion of abiotic resources (ADP)	Guinèe J.B. (ed.), 2001. Life cycle assessment an operational guide to the ISO standard. Volumes I, II, III.

[a] WMO = World meteorological organisation.

than 50%. Both farm and dairy electrical consumptions are the following item with almost 20% of global consumption. Whereas tetra-brik consumption can be considered as a parameter with low variability, electrical consumption is significantly unstable and should be defined with more precision to establish its potential impact more accurately.

4.2. Normalisation

In order to make substantial improvements in the environmental performance of Galician milk production, it is necessary to address the activities of major contribution to environmental impact.

The normalisation phase allows us to compare all environmental impacts using the same scale (Fig. 4). In the present study, the situation in West Europe has been taken as the reference for all the impact categories (data from year 1995 in Table 7) as this is the most complete list available (Guinèe et al., 2001). Regarding the energy consumption, the CML methodology does not include it, therefore this flow indicator has been only considered at the characterisation step.

According to these outcomes, the categories can be arranged in the following order:

1. Very significant: EP.
2. Significant: AP and GWP.
3. Not significant: PCOP, ADP and ODP.

Bearing in mind this classification, some alternatives to reduce the environmental impact of milk production can be proposed (Table 8):

Action 1: Implementation of the best operatives practices that reduce milk losses at milking. These losses result in two negative aspects: (i) the high organic load level in the wastewaters generated and (ii) the economical problem to the yield of the farm. One option to reduce the high organic load of wastewater generated at farms could be the implementation of a simple treatment system, such as a small anaerobic reactor which normal elimination yield of 90% of COD (Méndez, Blázquez, Lorenzo, & Lema, 1989).

Action 2: The crops and harvesting of the animal feed are responsible for an important percentage of several impact categories such as EP and AP. One of the main aims of nutritional experts and veterinarians should be to find the most sustainable combination of these elements capable of producing less impact to the environment and, at the same time, maintaining the requirements of protein and energy supplement in the final mixture. The raw milk production system shows great variability with regard to the quantity of all elements, except fodder, and an brief study of diverse food ration combinations has identified the use of more maize and less silage as a good option to decrease the environmental impact of the global milk production process. Therefore, the final feeding per litre of raw milk considered was: maize 625.3, fodder 443.7, silage 306.8 and alfalfa 110.6 g.

Table 6
Characterisation stage of 1 L of packaged liquid milk (FU)

	GWP		ODP		AP		EP		PCOP		ADP		EC	
	kg CO_2	% of total	kg CFC_{11}	% of total	kg SO_2	% of total	kg PO_4^{3-}	% of total	kg C_2H_4	% of total	kg Sb	% of total	MJ LHV	% of total
Farm	0.84	80.32	1.83×10^{-8}	35.65	4.98×10^{-3}	58.35	3.91×10^{-3}	73.58	1.10×10^{-4}	31.28	1.63×10^{-5}	15.22	1.39	22.38
Maize	1.54×10^{-2}	1.46	0.00	0.00	6.9×10^{-4}	8.17	3.05×10^{-4}	5.74	1.08×10^{-6}	0.31	1.82×10^{-7}	0.17	1.35×10^{-2}	0.22
Fodder	1.39×10^{-1}	13.23	1.30×10^{-8}	25.36	9.14×10^{-4}	10.72	2.00×10^{-3}	37.67	7.38×10^{-6}	2.24	1.53×10^{-5}	14.29	5.40×10^{-1}	8.70
Silage	3.07×10^{-1}	29.19	0.00	0.00	2.47×10^{-3}	29.00	1.20×10^{-3}	22.52	4.42×10^{-6}	1.26	5.84×10^{-7}	0.55	5.31×10^{-2}	0.86
Alfalfa	6.03×10^{-2}	5.73	0.00	0.00	6.49×10^{-4}	7.61	1.69×10^{-4}	3.18	1.98×10^{-5}	5.65	5.14×10^{-8}	0.05	7.60×10^{-4}	0.01
Cleaning elements	2.85×10^{-3}	0.27	5.21×10^{-11}	0.10	3.13×10^{-5}	0.37	1.50×10^{-6}	0.03	2.94×10^{-7}	0.08	0.00	0.00	2.40×10^{-2}	0.39
Diesel	1.09×10^{-3}	0.10	5.55×10^{-10}	1.08	5.72×10^{-6}	0.07	2.20×10^{-7}	0.00	5.16×10^{-7}	0.15	1.77×10^{-7}	0.17	1.62×10^{-1}	2.61
Electricity	3.16×10^{-2}	3.01	4.67×10^{-9}	9.11	2.06×10^{-4}	2.41	1.14×10^{-5}	0.21	6.24×10^{-7}	0.18	0.00	0.00	5.95×10^{-1}	9.58
Impacts associated to milk production	2.88×10^{-1}	27.33	0.00	0.00	0.00	0.00	2.24×10^{-4}	4.22	7.50×10^{-5}	21.42	0.00	0.00	0.00	0.00
Dairy	0.21	19.68	3.30×10^{-8}	64.35	3.55×10^{-3}	41.65	1.40×10^{-3}	26.42	2.41×10^{-4}	68.72	9.07×10^{-5}	84.78	4.82	77.62
Tetra-brik	9.61×10^{-2}	9.14	5.18×10^{-9}	10.11	8.03×10^{-4}	9.42	5.97×10^{-5}	1.12	2.02×10^{-5}	5.77	9.00×10^{-5}	84.10	3.36	54.11
Other pack. elem.	5.37×10^{-2}	5.10	1.84×10^{-10}	0.36	3.51×10^{-4}	4.12	2.30×10^{-5}	0.43	5.79×10^{-6}	1.65	2.79×10^{-15}	0.00	3.01×10^{-1}	4.85
Sterilisation elem.	4.86×10^{-3}	0.46	4.60×10^{-9}	8.98	9.66×10^{-7}	0.01	1.37×10^{-7}	0.00	5.93×10^{-7}	0.17	3.67×10^{-7}	0.34	7.86×10^{-4}	0.02
Cleaning elements	1.89×10^{-3}	0.18	0.00	0.00	2.64×10^{-5}	0.31	1.58×10^{-6}	0.03	3.19×10^{-8}	0.01	3.73×10^{-14}	0.00	3.60×10^{-2}	0.58
Fuel	2.26×10^{-3}	0.21	1.15×10^{-9}	2.24	1.18×10^{-5}	0.14	4.56×10^{-7}	0.01	1.07×10^{-6}	0.31	3.65×10^{-7}	0.34	3.35×10^{-1}	5.39
Transport	2.13×10^{-2}	2.02	179×10^{-8}	34.93	2.22×10^{-4}	2.60	4.86×10^{-5}	0.92	3.36×10^{-6}	0.96	0.00	0.00	2.80×10^{-1}	4.51
Electricity	2.69×10^{-2}	2.56	3.96×10^{-9}	7.73	1.75×10^{-4}	2.05	9.67×10^{-6}	0.18	5.30×10^{-7}	0.15	0.00	0.00	5.06×10^{-1}	8.15
Impacts associated to milk processing	0.00	0.00	0.00	0.00	1.96×10^{-3}	22.99	1.26×10^{-3}	23.72	2.09×10^{-4}	59.70	0.00	0.00	0.00	0.00
Total	1.05	100.00	5.12×10^{-8}	100.00	8.53×10^{-3}	100.00	5.31×10^{-3}	100.00	3.50×10^{-4}	100.00	1.07×10^{-4}	100.00	6.21	100.00

Action 3: As was mentioned before, item named "impacts associated to milk production" include emissions from steam production in boilers with gas oil. Currently, national legislation insists on compulsory analysis of combustion gases twice a year in this type of units, and the data shown are the average of a three years period (1999–2001). Although these data are beneath the legal level, they are responsible for considerable damage to the atmosphere, so an economic and technical study of gas treatment system should be carried out to determine the viability of options such as a combination of a semi dry type SO_2 removal system with 80% of average yield (Kawasaki, 2002) and a selective catalytic NO_2 removal (SCR) system with 90% of average yield (RJM, 2002).

Actions 1+2+3: All the actions proposed are independent and thus they can be executed simultaneously. The consequence of their implementation has a significant reduction in the majority of the impact categories. In terms of relative impact reduction, the consideration of the three actions implies a total decrease around 22%, which is the accumulated reduction of the three individual actions.

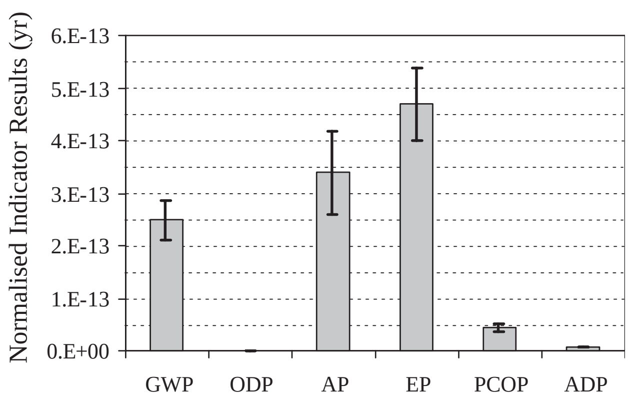

Fig. 4. Normalisation data for each impact category considered in this work. Mean values and variability due to more significant standard deviations are shown.

Table 7
Normalisation figures for each impact category[a]

Category	Factor	Category	Factor
GWP	4.73×10^{12}	EP	1.25×10^{10}
ODP	8.30×10^{7}	POCP	8.24×10^{9}
AP	2.74×10^{10}	ADP	1.06×10^{10}

[a] Reference: Guinèe, J. B. (final editor), Gorrée, M., Heijungs, R. Huppes, G., Kleijn, R., de Koning, A., van Oers, L., Wegener Sleeswijk, A. Suh, S., Udo de Haes, H. A., de Bruijn, H., van Duin, R., Huijbregts, M. A. J., Lindeijer, E. Roorda, A. A. H., Weidema, B. P. (2001). *Life cycle assessment: An operational guide to the ISO standards*, Ministry of Housing, Spatial Planning and Environment. The Netherlands.

5. Discussion

Milk is an example of a staple food and its industrial framework is assumed as essential for the Galician economy. Milk production has been considered as a case study for the application of life cycle assessment (LCA) as a powerful environmental tool to identify the environmental burdens associated and to propose actions for further environmental improvement.

A quantitative analysis about the contribution of each step to the global environmental impact or the specific reduction attained for each action has been performed in the previous section. Taking these results into consideration, a qualitative discussion will be presented to better understand the conclusions of this study.

5.1. System boundaries

The consideration of specific system boundaries is limited to the accessibility of data. In fact, very few food studies have attempted to include the whole life cycle; the sub-system most often omitted is the consumer phase (Andersson, 2000). Consumption phase and waste management have been excluded from the scope of the present work. Representative data about recollection and recycling of waste are still lacking due to the fact that Galicia has a limited experience in the sustainable management of urban solid waste. Nowadays, tetra bricks are being recollected and sorted to ulterior recycling and, although not enough data are still available, according to statistics from year 2001 the percentage of recycling was 14.16%.

Table 8
Normalisation data for each impact category and total environmental impact associated after the different improvement actions

	EP ($\times 10^{13}$)	AP ($\times 10^{13}$)	GWP ($\times 10^{13}$)	PCOP ($\times 10^{14}$)	ADP ($\times 10^{15}$)	ODP ($\times 10^{16}$)	Total ($\times 10^{13}$)	Impact reduction (%)
Action 1	4.26	3.16	2.19	4.28	7.15	6.15	10.12	1.65
Action 2	4.07	2.84	1.89	4.26	7.13	6.15	9.30	9.55
Action 3	4.09	2.51	2.19	3.12	7.15	6.15	9.18	10.75
Actions 1+2+3	3.56	2.19	1.89	3.10	7.13	6.15	8.03	21.95

5.2. Allocation rules

According to ISO 14040 (ISO, 2000), allocation is defined as the partitioning of material and energy flows from an activity to the product system under study. An allocation problem arises when a multifunctional process fulfils one or more functions in the system considered and another function in other system.

At the farm level, the allocation procedure was made according to economic criteria (partition of the total economic turnover). The analysis of the worst-case, which involves allocating all the environmental effects to the product under study (milk), shows that the main contributors to the environmental impact were basically the same, although the final figures were logically superior.

At the dairy level, it was not necessary to apply any allocation rule because the dairies chosen were basically mono-functional and the cream obtained as a co-product represents less than 2.5% of the total annual production.

5.3. Data quality

The inventory of high quality data is one of the key points of this LCA study, which was only attained by means of an exhaustive fieldwork. We have considered data from two different dairies and farms, which were collected for long periods of time. As a consequence of the industrialisation and modernisation actions that have characterised this sector in the last decade, the number of farms has been drastically reduced; however, other parameters as average herd size or average surface have increased. Hence, the existing farms in Galicia are bigger not only in size but also in number and they answer to a renovated livestock concept. Since 1993 the Autonomous Government of Agriculture and Livestock has been carrying out a dairy cow management program in which participated about 1500 farms (Barbeyto, 1993). In this statistical study, the average herd size was 24 dairy cows in 1997. Concerning the value of average milk production, the farms under study present high production values, which is also a desirable feature. Besides, the location of both farms is in the area of the highest livestock production. Considering the representatives of the selected dairies, they belong to the 8 main factories in the Galician sector with an economic balance around 75 millions € (1999) with a modern productive technology, indicative of the tendency of the sector (IDEGA, 2001). In the case of other components of the system, such as Diesel or Electricity, we considered the data from the available databases, which are well recognised by the LCA community since they have a complete inventory analysis. However, standard deviations shown at the inventory tables imply an overall uncertainty that can be stated in the range 13–17%.

5.4. Impact categories

The inclusion or exclusion of impact categories depends on the objective and the scope of the study. In this analysis, six categories have been considered (global warming, stratospheric ozone depletion, acidification, eutrophication, photo-oxidant formation and depletion of abiotic resources) as well as a flow indicator, energy consumption; on the contrary, others such as eco and human toxicity and land use were not analysed. In a qualitative way, we consider that potential damage over those categories should not be very significant if the nature of emissions (with the exception of pesticides at agricultural phase) and the Galician land characteristics (low population density and low industrial character) are borne in mind.

Among these six categories, three have been reported as significant: eutrophication, acidification and global warming. Several actions focused on these categories (specifically on EP and AP) have been proposed and the percentages of reduction have been measured. However, it is necessary to indicate that there is an action that, although it cannot be quantified, had to be pointed out due to its importance at GWP. Methane emitted by cows at farms is responsible of more than 30% greenhouse gases emissions, so it has an outstanding weight. Currently, some works are being carried out looking for modifications at food elements degradability in order to decrease methane emissions (Kurihara, Nishida, & Purnomoadi, 2002).

5.5. Improvement actions

Other LCA studies about dairy products are focused on the entire life cycle of the product, detecting points with major contribution to the global environmental impact and, from time to time, identifying possible alternatives to reduce the environmental impact (Berlin, 2002a; Høgaas, 2002b). None of them includes the quantification of the impact reduction associated to each improvement action proposed and from our point of view, this is a valuable aspect that must be taken into account, therefore we have considered this point in this work.

The selection of the improvement actions was based on the study of the main contributors of each step to the global environmental impact. On one hand, the elements involved at animal feed turned out to be accountable for an important percentage of all the impact categories at the farm level. In addition, the item "impacts associated to milk production", which includes emissions to air as well as to water, were identified as responsible for certain categories (GWP and PCOP). On the other hand, at the dairy level, air emissions from boilers were found as a remarkable focus of environmental impact, mainly in those categories that turned out to be more significant at the normalisation stage (EP and AP). Bearing in mind these facts, three actions were proposed being focused on each individual aspect.

Among these, a hierarchy can be established by means of the following factors: the environmental impact reduction attained, the economic investment and the technical feasibility. From the point of view of economic and technical feasibility, the change at the food ration formulation (action 2) seems to be the costless activity to be implemented; however, its success depends on maintaining the requirements of protein and energy supplement in the final mixture. Regarding the implementation of a gas treatment system at dairies (action 3), which supposes the higher impact reduction, an economic study will be necessary to evaluate the viability of its execution. Finally, the operation of an anaerobic small reactor at farms (action 1) implies not only a lower investment but also a less environmental impact reduction.

6. Conclusions

In this work, a simplified LCA methodology has been applied to analyse Galician milk production. Different sub-systems were identified and thoroughly studied: farms, fodder factories and dairies, and even though when the recollection of their inventory data took place throughout one complete year, some values were found to vary considerably. Consequently, these uncertain data should be taken into account in the handling of outcomes obtained.

Raw milk production, specifically agricultural phase, and packaging manufacture have been identified as the crucial elements. However, other aspects such as formulation of animal food at farms and emission from boilers at dairies are also decisive when improvement actions are to be set up.

The definition of different improvement actions and the quantification of the environmental impact reduction have permitted the demonstration that different activities could result in important enhancements on the environmental behaviour of a system or a product.

Acknowledgements

A. Hospido would like to express her gratitude to the Spanish Ministry of Education for financial support (AP2001-3410). We are also grateful to farms, fodder factories and dairies managers for their kind collaboration and contribution with technical data.

Appendix. A

AP	acidification potential
BUWAL	bundesamt für Umweltschutz, Wald und Landschaft (German)
COD	chemical oxygen demand
EC	energy consumption
EP	eutrophication potential
GWP	global warming potential
IDAE	The Spanish Institute for Diversification and Energy Saving (Spanish)
ISO	International Organization for Standardization
LCA	life cycle assessment
LCI	life cycle inventory
LCIA	life cycle impact assessment
ODP	ozone depletion potential
SETAC	society for environmental toxicology and chemistry
TSS	total suspended solids

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