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Environmental performance of a Portuguese mature cheese-making dairy mill

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ABSTRACT

An environmental assessment was carried out in order to quantify the environmental consequences of the life cycle of mature cheese production from a cradle-to-gate perspective and to identify the environmental hotspots. To do so, an international cheese-making dairy factory located in Portugal was assessed in detail and inventory data for the different production steps (milk production at dairy farm, cheese manufacturing and whey transformation at industrial dairy factory) were taken on-site.

The production line at the industrial dairy factory presents two main products: mature cheese and whey powder. The environmental burdens were allocated between both products based on an economic allocation approach as baseline. However, different methodological approaches, mass allocation and no allocation (assigning the whole environmental load of the production line to the cheese), were also applied in this study.

Dairy-farm-related activities play an important role concerning different environmental impact categories, namely acidification (91%), eutrophication (86%), global warming (82%), land competition (99%) and photo-oxidants formation (69%) due to on-farm emissions such as methane from enteric fermentation, ammonia from manure management, combustion emissions from agricultural machineries as well as land requirements for animal fodder production.

From cheese-making, the most important contributions are related to abiotic depletion (55%), ozone layer depletion (51%) and cumulative energy demand (55%) mainly due to the energy requirements in the different production processes and to the distribution of input goods up to the dairy gate.

Improvement alternatives for the environmental key factors within the limits of the dairy factory were proposed based on a reduction of energy consumption, the use of a more environmentally friendly fuel in the boilers and the use of new trucks with lower exhaust emissions. According to the results, it has been demonstrated that it should be possible to slightly reduce the environmental profile in some impact categories (acidification, eutrophication, global warming and photo-oxidants formation) without involving significant economic investment.

1. Introduction

The food sector – one of the most important manufacturing and economic sectors in Europe – is an important source of environmental impact and over the years, it has developed from traditional to intensive performances to satisfy the population's demand (Garnett, 2009; Iribarren et al., 2011).

Milk and other dairy products are important ingredients in the diet for a healthy development in Europe. Fresh milk is a highly perishable product, commonly processed in the region where it is produced due to the high transport cost associated. This is the main product of the European dairy sector since it is the raw material for the production of the derived milk products. Within the dairy products, cheese production is receiving special attention and growing demand due to the ready-meals sector growth (Bachmann, 2001).

The dairy industry is an example of industrial process characterised by the connection of different production sectors: agriculture, dairy farm and dairy factory (Hospido et al., 2003). Moreover, meat and dairy products have been identified as the foods that present the highest environmental burdens (Garnett, 2009), accounting for more than 50% of the total GHG emissions from the food sector mainly due to the enteric fermentation-derived emissions (Kramer et al., 1999). The environmental impacts of this sector are also related to water consumption, energy requirements and

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generation of wastewater with high organic load (Korsström and Lampi, 2008). Cleaning and cooling operations involve high water requirements. Cheese is a generic term for a diverse group of milk-derived food products and it is produced all over the world in a huge range of flavours, textures, forms and fat content. Cheese is manufactured by means of the coagulation of the casein, a milk protein, by addition of rennet to the milk.

Due to the high demand for cheese and the relevance of the environmental effects derived from the dairy sector, the investigation and quantification of environmental impacts from its production should be encouraged. Life Cycle Assessment (LCA) is an internationally standardised methodology that allows identification of the environmental consequences of the life cycle of a product by evaluating the potential environmental impacts over its whole life cycle production chain (ISO 14040, 2006). This environmental methodology has widely been applied for the evaluation of the environmental performance of different agro-food products such as fish (Ziegler et al., 2003; Hospido and Tyedmers, 2005; Vázquez et al., 2010), eggs (Mollenhorst et al., 2006; Williams et al., 2006) or meat (Cederberg and Stadig, 2003; Basset-Mens and van der Werf, 2005). Special attention has also been paid to the dairy sector where raw milk at dairy farms (Castanheira et al., 2010; Cederberg and Mattsson, 2000; Cederberg and Stadig, 2003; Iribarren et al., 2011), industrial liquid milk (Høgaas Eide, 2002; Hospido et al., 2003; Bartl et al., 2011; Fantin et al., 2012), semi-hard cheese (Berlin, 2002) and milk powder (Ramírez et al., 2006) production were assessed in detail.

No environmental information is available about Portuguese cheese production, even though this milk-derived product is the third-most consumed dairy product in this country. For this reason, it was decided to undertake this study paying attention to this dairy product.

The agro-food sector is an important industrial sector in Portugal, representing 12% of the business volume, 15% of market distribution and generating a turnover of €13.5 million (2009) (INE, 2012; Portugal Foods, 2012). Portugal is traditionally a raw milk producer country with an average annual milk production of 2.0 million tonnes (2010), of which 95% is derived from cows.

Portugal is one of the top five countries in Europe in terms of origin-labelled product manufacture, paying special attention to cheese (Poppe et al., 2008). As in other European countries, milk and dairy products are important elements of the Portuguese diet and their consumption has increased around 6% from 2003 to 2008 (INE, 2012).

Concerning the Portuguese dairy products manufacture, sterilised (ultra-high temperature – UHT) milk in its different forms (whole, semi-skimmed and skimmed milk) is the main product, followed by yoghurts and cheese with average annual productions of 890,000 t, 215,000 t and 107,000 t respectively which reflects the consumption trends (INE, 2012).

Therefore, this paper focussed on cheese production in Portugal, and may be interesting not only for the Portuguese but also for the European dairy sector since. To the best of our knowledge, it presents for the first time a detailed life cycle inventory and environmental consequences identification of mature cheese production from cow milk by analysing a cheese-making dairy mill using most of the Best Available Technologies (BAT) of the sector according to the industrial production permit[1] and the BREF for the food, drink and milk industries.[2]

2. Materials and methods

2.1. Goal and scope definition

The main objective of this study was to assess the environmental impacts and energy balance derived from the manufacture of mature cheese derived from cow milk in a Portuguese dairy factory. The study intended to identify the environmental hotspots of the life cycle under assessment in order to propose improvement options. A cheese mill using a significant number of processes, technologies management practices considered as BATs (Agência Portuguesa do Medio Ambiente, 2012) was selected for detailed assessment under a cradle-to-gate approach. Moreover, this factory is one of the manufacturing leaders of mature cheese production in Portugal. Thus, the study was focussed on the cheese-making mill from the production of the different inputs involved up to the treatment of waste generated at the dairy. Moreover, liquid whey is co-produced after the coagulation and curd formation. Its corresponding post-treatment and conversion into powder whey has also been considered in this study. Fig. 1 shows the scheme of the production process under analysis with the corresponding processes involved.

The functional unit (FU) considered in this study was 1 kg of mature cheese, which agrees with other related dairy studies focussed on semi-hard cheese production (Berlin, 2002).

2.2. Allocation approach

The cheese-making dairy under assessment is a typical multi-output system where not only cheese is produced but also whey powder. ISO 14040 (2006) recommends the subdivision or the expansion of the system boundaries instead of allocation. In this study, it was not possible to identify the specific consumptions of mass and energy flows for each production process due to the lack of information. Therefore, the system was considered as a black box with two main co-products: mature cheese and whey powder. Consequently, subdivision was not possible. Moreover, system expansion requires an alternative way of generating the products, which would involve an increasingly complex system. Thus, an allocation approach was needed in this study for the partitioning of the environmental burdens between the co-products at the cheese-making dairy mill.

Economic allocation is commonly used in food product-related studies (Berlin, 2002; Feitz et al., 2007). Thus, using the current dairy's prices for the different products has been considered as a baseline. The dairy's prices considered were 4 €/kg and 0.60 €/kg for the cheese and whey powder respectively. Economic allocation is vulnerable to fluctuating prices and demand (Feitz et al., 2007). For this reason, other approaches of allocation should be proposed. In terms of production volume, the cheese is the principal product with an average ratio of 67% of the total production. Therefore and in order to discuss the differences in the environmental results depending on the allocation approach considered, additional partitioning methods were discussed and compared: a mass allocation approach and a no allocation approach. The latter means that the cheese takes the whole environmental load (100%) of the production system.

An alternative allocation approach based on fat content of the products was not considered as the results would be very close to the no allocation approach alternative due to the fat content of the cheese and whey powder being 52% and 1% respectively.

Moreover, the dairy farm produces not only milk but also meat. Thus in accordance with Castanheira et al. (2010), an economic allocation approach was applied in order to partition the environmental loads between both products. To do so, this allocation was done based on historical market prices for milk and meat in

[1] http://sniamb.apambiente.pt/LAdigital/ (accessed October, 2012).
[2] http://eippcb.jrc.es/reference/BREF/fdm_bref_0806.pdf (accessed October, 2012).

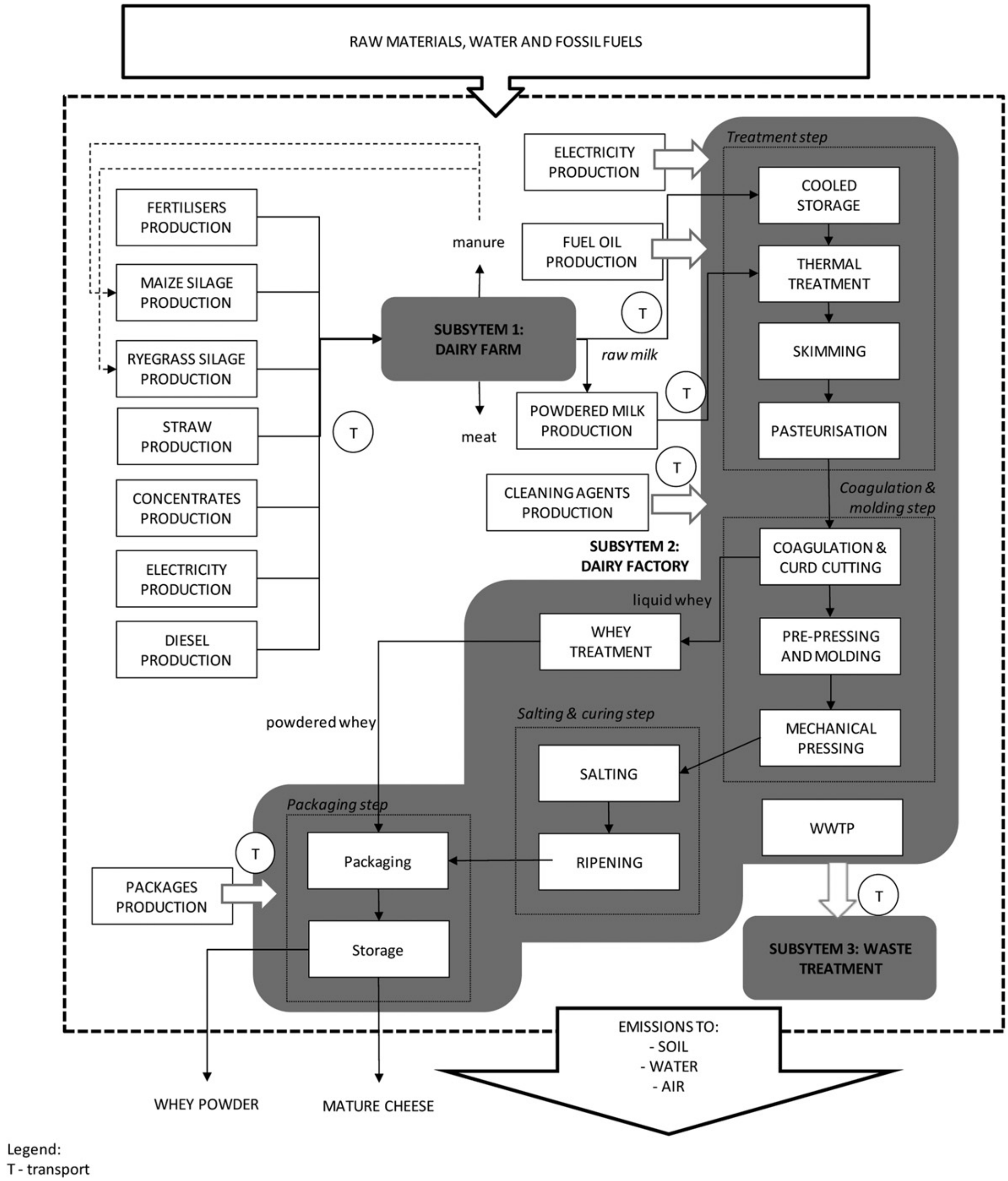

Fig. 1. System boundaries and flow chart of the cheese-making dairy life cycle. Dark grey boxes delimit the subsystems. White boxes correspond to processes included in this study.

Portugal from 2002 to 2004 (Castanheira et al., 2010). Concerning the manure, it was not considered as a co-product since it has no economic value for the dairy farms. However, it its use as organic fertiliser was considered for the production of agricultural inputs on the dairy farm such as maize and ryegrass.

2.3. Description of the system under study

The cheese-making dairy factory under assessment is characterised by a large experience of mature cheese manufacture, using modern and automatic processes and equipment. The production line can be divided in four main steps: milk treatment step; coagulation and moulding step; salting and curing step; and finally, packaging step according to Fig. 1.

The main raw material for cheese production is milk (raw and powdered milk). The raw milk received in the dairy factory from the dairy farm is stored under cold conditions in storage tanks for the upcoming activities. Powdered milk is received in the dairy and is mixed with warm water at 55 °C. The result of this mix is liquid milk with the required characteristics in order to be used as raw material in the cheese production processes.

Firstly, the milk is subjected to a thermal treatment where it is heated before sending to the skimming process. Skim is removed according to technical requirements. After the skimming, the skimmed milk remains in the thermal treatment tanks until it is sent to the pasteurisation process where it is heated to 77 °C. After pasteurisation, the cooled milk is sent to the coagulation tanks where different additives are added: rennet, starter culture, calcium chloride and saltpetre. Rennet includes the enzyme chymosine, which allows the coagulation of the milk – i.e. the formation of the curd – which is controlled with calcium chloride, and saltpetre prevents fermentation problems (Berlin, 2002). The main goal of the starter culture is the acid development in the curd that gives cheese its specific characteristics. The curd is cut and put into moulds where it is separated from the whey. The whey is the co-product of the cheese production line. It is transformed into whey powder in the dairy factory in an independent transformation line by means of concentration, drying and packaging processes. The curd after being pressed is sent to the salting process where it is mixed with brine or salt in tanks in order to improve the taste of the cheese. Next, it is ripened in a room for 12–15 days at 11 °C. At this point, the cheese is ready for consumption, and so it is packaged for its final distribution to the retailers.

Dairy factories produce large amounts of wastewater with a high organic load. The cheese-making dairy under assessment has a wastewater treatment plant (WWTP) that consists on an anaerobic digestion system and an activated sludge system with denitrification. The biogas produced in the anaerobic digester is burnt in a flare without any energy-saving system. Derived emissions have been taken into account in the calculations.

The study includes production of all inputs to the dairy factory, waste treatments and all outflow emissions from the system. The system was divided into three main subsystems (Fig. 1):

- Subsystem 1 – Dairy farm: a well-managed and typical farm located in Portugal was considered as a representative farm in order to evaluate all inputs and outputs related to the production of all raw milk required in the cheese-making factory (Castanheira et al., 2010). This subsystem included agricultural activities related to animal feed (i.e. maize silage, ryegrass silage, straw and concentrates production) and raw milk production. Detailed information of this farm can be found in Castanheira et al. (2010). As in other studies, cleaning agents required in this subsystem for disinfection were not considered (Castanheira et al., 2010; Cederberg and Mattsson, 2000) due to the lack of data.
- Subsystem 2 – Dairy factory: this subsystem includes all the activities which take place in the cheese-making factory, from the milk treatment to cheese and whey powder packaging and storage. In addition, the WWTP was included in this subsystem where wastewater is treated before release into the river. The raw milk transport between the dairy farm and the dairy factory was considered and included in this subsystem.
- Subsystem 3 – Waste treatment: this subsystem includes treatment processes related to the waste management of packaging materials and sludge from the WWTP as well as their transport to the waste management destination.

The cheese production process requires the addition of some components for its coagulation: rennet, starter culture, calcium chloride and saltpetre. The production of all of these compounds was considered as out of the system boundaries due to the small amount of these materials required and unavailable information concerning the starter culture production. Land use and soil quality changes caused by the agricultural activities were excluded from assessment according to Høgaas Eide (2002).

2.4. Inventory analysis

When it was not possible to get real data, inventory data were collected from literature and the Ecoinvent database as described below. The same database was used in order to achieve consistency in the results.

The information regarding the foreground data for the production of the raw milk in a typical Portuguese dairy farm (Subsystem 1) was mainly obtained from Castanheira et al. (2010) also taking into account the production of the different inputs to (e.g. feed and diesel production) and outputs from (products, co-products and emissions) the subsystem and were completed with literature when necessary (e.g. alfalfa production required for the cattle fodder was taken from Gallego et al., 2011). The main input in the dairy mill is the raw milk but the addition of powdered milk is also required. Powdered milk consists of milk with a low content of water. Inventory data for its manufacture was taken from Nielsen et al. (2003) but adapting the milk input to the Portuguese scenario (Castanheira et al., 2010).

The foreground inventory data for the cheese-making dairy factory (Subsystem 2) consisted of average annual data from the year 2008 obtained by on-site measurements in the dairy mill. Table 1 shows the detailed global inventory data collected for this subsystem.

It is important to point out that the different transport activities required for the supply of the inputs to the production line have been taken into account. Table 2 shows a description of the different transport options, average transport distance and data sources considered.

Information concerning background processes such as cleaning agents, electricity, fossil fuel and packaging materials production were obtained from the Ecoinvent database and bibliographic sources and is summarised in Table 3.

Concerning the electricity requirements, they are taken directly from the Portuguese grid. The Portuguese electricity profile mostly

Table 1
Global inventory for the cheese-making dairy mill (Subsystem 2) per 1 kg of cheese.

Inputs from Technosphere			
Materials		Energy	
Raw milk (from dairy farm)	8.24 kg	Electricity	1.08 kWh
Powdered milk	0.129 kg		
Water	23 kg	*Transport*	
Cleaning agents		Truck 16–32 t	6930 kg km
Nitric acid	0.037 kg		
Sodium hydroxide	0.101 kg		
Packaging materials			
Cardboard	0.115 kg		
HDPE	0.015 kg		
Fossil fuels			
Fuel oil	0.401 kg		
Outputs to Technosphere			
Products		Waste to treatment	
Mature cheese	1 kg	Cardboard to recycling	6.00 g
Whey powder	0.49 kg	Plastics to recycling	0.075 g
		Cardboard to incineration	1.20 g
		Plastics to incineration	0.045 g
		Sludge to incineration [a]	0.199 kg
		Waste to composting	0.552 g
		Cardboard to sanitary landfill	4.27 g
		Plastics to sanitary landfill	0.159 g
Outputs to environment			
Air emissions		Water emissions	
Carbon monoxide	6.63 g	Chemical oxygen demand	83.52 g
Nitrogen oxides	4.63 g	Suspended solids	17.68 g
Particulates	18.02 g	Nitrogen total	2.12 g
Sulphur dioxide	5.66 g	Phosphorous	1.42 g
Organic substances	0.249 g	Nitrate	0.074 g
		Oils	4.50 g

[a] It includes other organic solid waste such as residual cheese.

Table 2
Average distances, transport mode and data sources.

Material	Transport mode	km	
Raw milk	Truck 16–32 t	160	Real data
Powdered milk	Truck 16–32 t	2400	Real data
Sodium hydroxide	Truck 16–32 t	55	Real data
Nitric acid	Truck 16–32 t	726	Real data
Packaging materials	Truck 16–32 t	100	Real data
Waste from dairy factory	Truck 3.5–16 t	50	Assumption

depends on fossil fuels and it was adapted to the production model provided by the International Energy Agency (IEA, 2009) for this country.

Different waste types are generated at the dairy factory mainly derived from packaging step and WWTP. Waste management (Subsystem 3) was included in the system boundaries as well as the waste transport up to the management scenario. For the plastic waste, it was considered to be an average ratio for the waste management systems supplied by Plastic Europe (2012) and the Portuguese Environmental Agency (2010). Therefore, it was considered that 25% of this plastic waste is sent to recycling, 15% to energetic valorisation, 54% to sanitary landfill and 6% to composting. In the case of the paper and cardboard waste, the disposal ratios were taken from the Portuguese Paper Industry Association (CELPA, 2011) and the Portuguese Environmental Agency (2010): 45% is sent to recycling, 32% to sanitary landfill, 9% to energetic valorisation and 4% to composting. For all the waste, it was assumed an average transport distance of 50 km. Data for the waste treatment systems were taken from Doka (2007) (Table 3).

Table 3
Summary of data sources considered in this study.

Energy	Electricity (Portuguese electricity profile)	Ecoinvent database (Dones et al., 2007) and International Energy Agency (IEA, 2009)
	Fuel oil	Ecoinvent database (Dones et al., 2007)
Milk products	Raw milk	Castanheira et al. (2010) and Gallego et al. (2011) [a]
	Powdered milk	Nielsen et al. (2003) and Castanheira et al. (2010)
Packaging materials	Cardboard: boxes and labels	Ecoinvent database (Hischier, 2007)
	Plastic: bags, film and ribbon	Ecoinvent database (Hischier, 2007)
Cleaning agents	Nitric acid	Ecoinvent database (Althaus et al., 2007)
	Sodium hydroxide	Ecoinvent database (Althaus et al., 2007)
Others	Tap water	Ecoinvent database (Althaus et al., 2007)
Transport	Trucks 3.5–16 t	Ecoinvent database (Spielmann et al., 2007)
	Truck 16–32 t	Ecoinvent database (Spielmann et al., 2007)
Waste treatment	Incineration (plastics and cardboard)	Ecoinvent database (Doka, 2007)
	Recycling (plastics and cardboard)	Ecoinvent database (Doka, 2007)
	Composting (plastics and cardboard)	Ecoinvent database (Doka, 2007)
	Sanitary landfill (plastics, cardboard and sludge)	Ecoinvent database (Doka, 2007)

[a] Production of alfalfa required for the production of the concentrates for the dairy cow feed.

The distribution of the cheese to the retailers was not included within the system boundaries since this step is variable and out of reach for the cheese-making factory.

3. Results and discussion

3.1. Life Cycle Assessment results

Among the steps defined within the life cycle impact assessment stage of the standardised LCA methodology, only classification and characterisation stages were undertaken in this study (ISO 14040, 2006). Normalisation and weighting were not conducted as these optional elements were not considered to provide additional robust information for the objectives established in this study. The characterisation factors reported by the Centre of Environmental Science of Leiden University (CML 2001 method) were used (Guinée et al., 2001). The following impact potentials were evaluated according to the CML method: abiotic depletion (ADP), acidification (AP), eutrophication (EP), global warming (GWP), ozone layer depletion (ODP), land competition (LC) and photochemical-oxidants formation (POFP). Furthermore, an energy analysis was carried out based on the cumulative non-renewable fossil and nuclear energy demand (CED) computed according to Hischier et al. (2009) as an additional indicator. The software SimaPro 7.3.2 was used for the computational implementation of the inventories (PRé Consultants, 2012). Concerning the GWP, the characterisation model developed by the Intergovernmental Panel on Climate Change (IPCC) was selected for development of the characterisation factors (year 2001), expressed as the global warming potential for a time horizon of 100 years (GWP100).

The characterisation results are displayed in Table 4 for each impact category under assessment as well as the flow indicator (CED) for the production system under study. These results were classified per subsystem and the contributions (in %) are displayed in Fig. 2. It is clear that the production of the raw milk at the dairy farm (Subsystem 1) contributed most to the environmental impact in almost all the categories and flow indicator with remarkable contributions in categories such as AP (91%), EP (86%), GWP (82%), LC (99%) and POFP (69%). Therefore, this subsystem can be considered as the main environmental hotspot when mature cheese production is assessed from an LCA perspective.

The contribution of the dairy-farm activities to the AP is mainly due to ammonia emissions from the volatilisation of the nitrogen contained in manure ($\approx$81% of total). With regard to the EP, the main eutrophying emissions that contribute to this category were the ammonia emissions ($\approx$49% of total) and leaching of nitrate ($\approx$29% of total) derived from the manure application on the field. The GWP was mainly affected by the emission of three greenhouse gases (GHG): methane, carbon dioxide and dinitrogen monoxide. The methane emissions derived from the enteric fermentation accounted for 69% of the GWP. Fossil carbon dioxide emissions

Table 4
Impact assessment results (characterisation step) associated with to the production of 1 kg of mature cheese considering an economic allocation method for the partitioning of the environmental burdens.

Impact category	Unit	Total
ADP	kg Sb_{eq}	0.031
AP	kg SO_{2eq}	0.180
EP	kg PO_{4eq}^{3-}	0.065
GWP	kg CO_{2eq}	7.49
ODP	kg CFC-11_{eq}	$5.53 \cdot 10^{-7}$
LC	m^2 a	2.03
POFP	kg C_2H_{4eq}	0.002
CED	MJ_{eq}	68.43

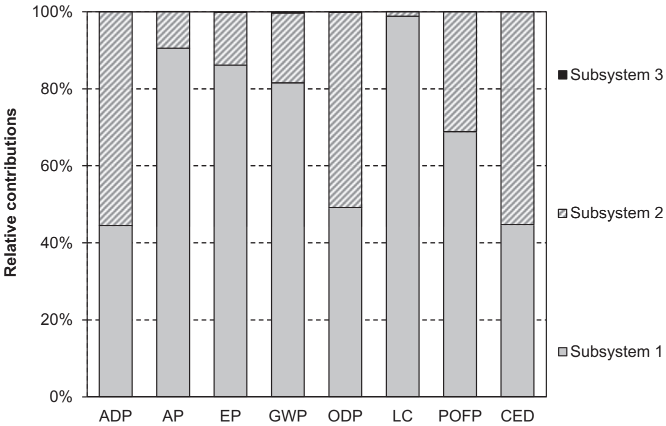

Fig. 2. Relative contributions per subsystems (in %) to each category under study. Impact category acronyms: ADP = Abiotic Depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand. Subsystem 1: Dairy farm; Subsystem, 2: Cheese-making factory, Subsystem 3: Waste treatment.

derived from the combustion of diesel in the farm-related activities contributed to more than 18% of the contributions to this impact category. About 99% of the contributions to LC were due to the dairy-farm subsystem. This result is associated with the production of the cattle feed, specifically the production of the concentrates used as fodder (maize grain, gluten and barley). Finally, concerning the POFP, the farm subsystem was responsible for most of the contributing substances mainly due to the methane from enteric fermentation ($\approx$56% of total) and sulphur dioxide emissions from diesel combustion in farm-related machinery ($\approx$7% of total).

Although the main environmental hotspot for most of the impact categories is the production of the raw milk at the farm, it is also interesting to analyse the results excluding that subsystem from the assessment. This analysis is thus focused on the activities that are within the control of the dairy factory. Fig. 3 displays the contributions to each impact category and energy indicator from the different processes involved in the mature cheese life cycle excluding the raw milk production contribution. The contributions from all these processes to the categories under assessment are discussed in detail below. In Fig. 3, *Energy* involves the production of electricity at the Portuguese grid and the production of the fuel oil required in the heating boilers. The corresponding air emissions derived from the combustion of the fuel oil were included in the *On-site emissions* contribution together with water emissions derived from the WWTP.

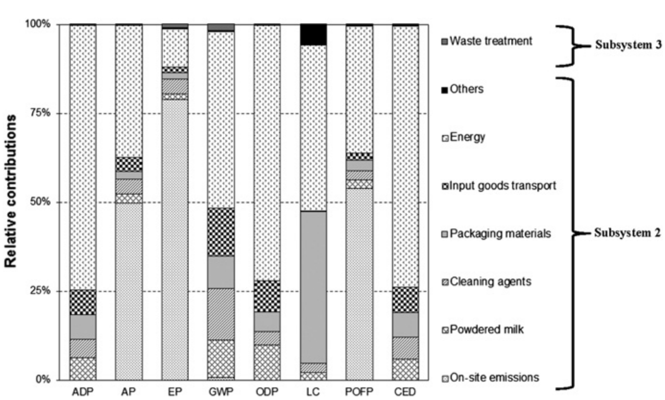

Fig. 3. Relative contributions to each category (in %) per process involved in the dairy factory (Subsystem 2) and waste treatment (Subsystem 3) excluding milk production (Subsystem 1). Impact category acronyms: ADP = Abiotic depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand. *Energy* includes electricity and fuel oil production but not the emissions derived from fuel oil combustion at boilers, which were included in *On-site emissions*.

The production of energy requirements in the dairy factory is the main hotspot for ADP with a remarkable contribution of more than 74%, mainly due to the fuel oil requirements in the boiler for the heating system (around 68% of that ratio). The following most important processes contributing to ADP are the input goods delivery from the corresponding retailers and packaging materials production, both with contributions of 7%.

On-site emissions derived from the mature cheese production at the dairy factory were the main hotspot for AP (50%), mainly due to sulphur dioxide emissions derived from the combustion of the fuel oil in the boilers. Production of energy requirements accounts for 37% of total acidifying emissions and in this case, due to the production of the electricity requirements (67% of that contribution) and the derived sulphur dioxide emissions.

In the case of EP, there is a clear contributor responsible for the eutrophying emissions and it is the on-site emissions derived from the activities carried out in the cheese-making factory (79% of total). In particular, it is important to point out the emissions of phosphorous and chemical oxygen demand from the WWTP. Energy requirements and cleaning agent production are the other major contributors to EP with 11% and 4% respectively.

Three processes can be considered key actors in terms of GWP: the production of cleaning agents (15%), the input goods delivery (14%) and, in particular, the energy requirements production (49%) due to fossil carbon dioxide emissions derived from the combustion of diesel in the trucks and from electricity production, which mostly depends on non-renewable sources.

Regarding ODP, once again the production of energy requirements – mainly the fuel oil required for the boilers – is the main hotspot, contributing up to 72% of the total. The second most important contributor to ODP is the production of the powdered milk (10%). Input goods delivery up to the dairy factory contributes 9% mainly due to the long distance travelled from the suppliers of the powdered milk (2400 km for the powdered milk).

The production of the energy requirements and packaging materials are the main contributors of LC with contributions of 47% and 43%, respectively. However, it is important to highlight that 99% of the total contributions to this impact category, which includes the milk production process, are due to the farm activities.

On-site emissions derived from the dairy factory account for 54% of POFP, mainly due to carbon monoxide and sulphur dioxide emissions derived from the heating boilers. Energy requirements production, mainly electricity, contributes 36% and once again is due to sulphur dioxide emission.

The flow indicator CED is mainly affected by the production of the energy requirements (74%): electricity taken from the National grid and fuel oil for the heating boilers, both considerably depend on non-renewable sources. This contribution is followed by far for the input goods delivery contribution (7%).

3.2. Discussion of results

The results obtained in this study are in-line with other LCA studies where different dairy products (milk ready for consumption or hard cheese) were assessed from an environmental point of view (Høgaas Eide, 2002; Berlin, 2002; Hospido et al., 2003; Fantin et al., 2012) considering a cradle-to-gate perspective and regardless of the allocation approach assumed. In all of them, the activities carried out at the farm and related to the production of the main raw material – i.e. the raw milk – were the main contributor to the environmental loads with remarkable contributions to the impact categories such as AP, EP, GWP and energy requirements.

Høgaas Eide (2002) assessed the production of packaged milk from a cradle-to-grave perspective. In that study, the dairy farm contributed most to the total energy consumption mainly due to the fodder production. Moreover, the farm was the main factor in terms of EP and AP due to the leakage of nutrients and ammonia losses from manure and also related to the fodder production. Concerning GWP, the methane emissions from the cattle were the main contributors to GHG. Hospido et al. (2003) and Fantin et al. (2012) also assessed the production of packaged milk and both achieved similar results, with the identification of the farm activities as the main hotspot in terms of AP, EP and GWP.

Berlin (2002) assessed, from a cradle-to-grave perspective, the environmental profile of hard cheese production and according to her results, the raw milk production is by far the largest contributor to AP, EP, GWP and POFP. The contributing substances to all these impact categories identified by Berlin (2002) are in-line with our results.

The proposal of improvement alternatives in the dairy-farm subsystem should be interesting from an environmental point of view for the dairy sector regardless of the dairy product under analysis. Unfortunately, this subsystem is commonly out of reach for the dairy factories and the introduction of improvements is difficult. Hospido et al. (2003) and Castanheira et al. (2010) proposed alternatives focussed on changes on the food ration and on the manure management (conversion by means of an anaerobic digestion into biogas for energy use). Therefore, the proposal of improvements in the environmental profile of mature cheese production must be focussed on the dairy factory, which represents the second most important key subsystem according to Figs. 2 and 3.

According to the results of this study, the production of energy requirements for the cheese-making process and the distribution of the different input goods from the corresponding retailers to the dairy factory gate were identified as environmental key factors (excluding the dairy farm). Energy requirements in the dairy factory are in the form of electricity, which is taken directly from the Portuguese grid, and in the form of heat, which is produced from fuel oil combustion in heating boilers. Activities carried out at the dairy factory such as the milk reception/thermization, the cheese treatment/storage and the cleaning activities also present high-energy consumption (Ramírez et al., 2006). The on-site emissions generated at the dairy factory, mainly derived from the combustion of the fuel oil in the boilers, were another important environmental factor. Therefore, the total contributions from these processes range from 64% of GWP to 91% of AP, EP and POFP. Only in LC, the key process was the production of the packaging materials due to the manufacture of the cardboard.

According to Berlin (2002), the quality of the data specifically concerning the activities that have the greatest environmental impact is very important. As mentioned, inventory data for the dairy farm were taken from a previous recent study (Castanheira et al., 2010) performed by this research team and completed with bibliographic sources. Concerning the data for the mature cheese production, they are site specific and they are average annual data taken from a cheese-making mill using several BAT as previously mentioned.

Another main factor that influences the results is the allocation method considered (Cederberg and Stadig, 2003; Feitz et al., 2007). In our study, and in accordance with Berlin (2002), economic allocation was considered for partitioning the environmental loads between the different co-products. Therefore, an allocation factor of 93% was assigned to the mature cheese and 7% to the whey powder. The results change if other allocation methods are considered. In terms of mass production, the mature cheese is the main co-product ($\approx$2 kg cheese is produced per kg whey powder). If mass allocation was considered, an allocation ratio of 67% should be assigned to the mature cheese and the environmental profile should be improved in all the categories under assessment by around 18%. Since the main product for the dairy is the mature cheese, if it was assumed that the cheese takes the whole environmental burden of the production system (allocation ratio of 100%), the environmental profile should be worse, with an increment of 8% in all the categories assessed compared to the economic allocation method.

Other allocation approaches based on valuable components of the products such as fat content could be proposed. The mature cheese and whey powder present an average fat composition of 52% and 1%, respectively. Thus, the allocation factors corresponding to each product should be 99% and 1%. That is, the environmental profile should be similar with the profile obtained when all the inputs and outputs in the dairy factory are inputted to the mature cheese production. In conclusion, the choice of the allocation method for the cheese-making system is of major relevance if the results are going to be compared with related studies.

If the results of this study using the economic allocation method (the basis) are compared with the results from Berlin (2002) and considering in both studies a cradle-to-gate perspective, there are several differences in all the categories under comparison (e.g. 32% higher in AP, and 15% and 2% lower in GWP and POFP, respectively). Berlin (2002) considered an economic ratio for the hard cheese of 67.8% as well as the distribution of the product to the retailers and household stage. However, these last stages were not environmental hotspots with contributions lower than 1% in all the categories assessed by the author. If the same allocation ratio was assumed in our study, similar results should be achieved in comparison with Berlin (2002) in terms of AP (0.131 kg SO_{2eq}/FU vs. 0.136 kg SO_{2eq}/FU) and POFP (0.0018 kg C_2H_{4eq}/FU vs. 0.0026 kg C_2H_{4eq}/FU).

The proposal of alternatives to improve the environmental profile of the mature cheese production should be based on reduction of energy consumption, the use of a more environmental friendly fuel in the boilers and the use of new trucks with lower exhaust emissions.

Concerning the energy consumption, Berlin et al. (2008) reported that the energy efficiency in a dairy factory is closely related to the product. If the product is UHT milk, the production line requires less energy supply than yoghurt production. In contrast, the cheese manufacture should show the highest energy demand. In that study and in accordance with Karlsson et al. (2004), it was established that it should be possible to identify options that increase the energy efficiency by up to 8% in Swedish factories without the necessity of major investments or advanced technical equipment. Therefore, the environmental improvements derived from the reduction of 8% in the total energy requirements in the dairy factory were assessed here. Global improvements throughout the life cycle under assessment of $\approx$3% in categories such as ADP, ODP, POFP and CED could be obtained with this increment of the energy efficiency. If the production of the raw milk is excluded from the assessment, the corresponding results are displayed in Fig. 4 and reductions ranging 4–7% should be obtained in all the categories.

The use of an alternative fuel instead of fuel oil in the heating boilers may be interesting since the extraction of this fossil fuel is responsible for remarkable contributions to categories such as ADP, AP, GWP ODP and CED. An alternative option could be the use of natural gas. This potential substitution has been proposed by other authors (Lopes et al., 2003; Jawjit et al., 2007) in other sectors (e.g. pulp and paper industries). Slight improvements throughout the life cycle could be obtained in categories such as AP, EP and POFP according to the results. The substitution of light fuel oil by natural

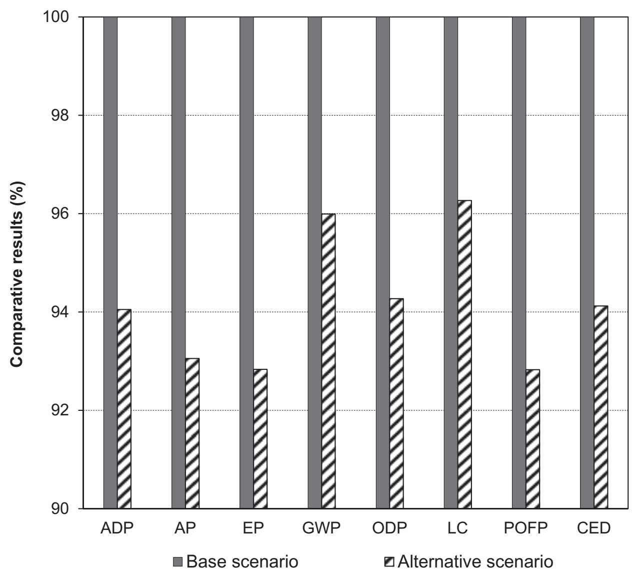

Fig. 4. Comparative results (in %) excluding raw milk production between the current scenario (Base scenario) and the alternative scenario based on a reduction of 8% in the energy requirements. Impact category acronyms: ADP = Abiotic depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand.

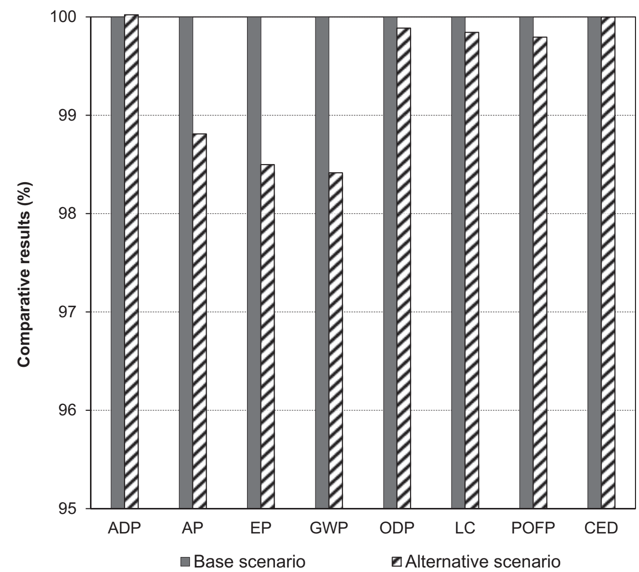

Fig. 6. Comparative results (in%) excluding raw milk production between the current scenario (Base scenario) and the alternative scenario based on the use of trucks with lower tailpipe emissions. Impact category acronyms: ADP = Abiotic depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand.

gas in the boilers reduces combustion-derived emissions such as SO_2, NO_x and CO by around 70%, 44% and 30%, respectively.

The results excluding from the assessment the production of the raw milk are displayed in Fig. 5 and interesting environmental reductions could be achieved in some categories. With this alternative, reductions of 2% in EP, 7% in AP and 7% in POFP can be obtained. In contrast, increments of 10% in ADP and 55% in ODP could be achieved with this potential alternative.

Another possible alternative could be replacing trucks with others with lower emissions such as Euro 5 although this option would involve an economic investment. Slight reductions throughout the whole life cycle of the system under study should be got only in terms of AP and EP (less than 1%). Fig. 6 shows the results excluding the production of the raw milk from the assessment, showing reductions of 2% in AP, EP and GWP.

If all the proposed alternatives were executed simultaneously, the consequences of their implementation are shown in Fig. 7, excluding the dairy-farm activities from the assessment since no changes have been done in this subsystem. Reductions of 1%, 9% and 15% could be obtained in GWP, EP and AP, respectively. In terms of POFP, it is possible to reduce the contributing substances

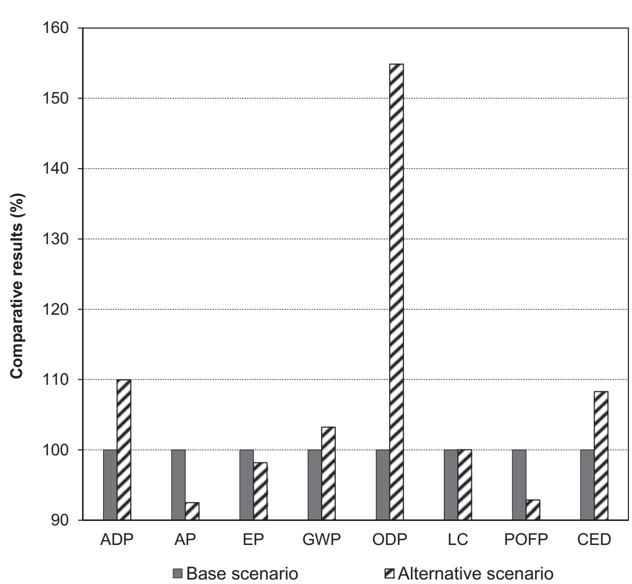

Fig. 5. Comparative results (in %) excluding raw milk production between the current scenario (Base scenario) and the alternative scenario based on the use of natural gas as combustion fuel in the boilers. Impact category acronyms: ADP = Abiotic depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand.

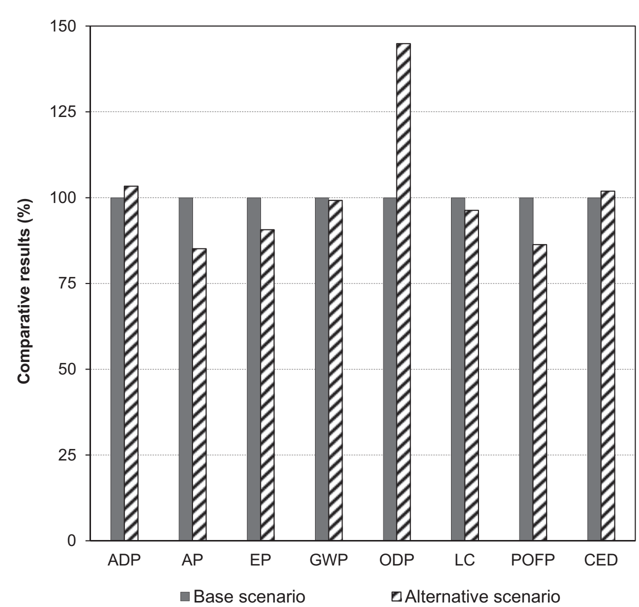

Fig. 7. Comparative results (in %) between the current scenario and the alternative scenario based on the execution of all the proposed improvement strategies, excluding dairy farm (Subsystem 1). Impact category acronyms: ADP = Abiotic depletion, AP = Acidification, EP = Eutrophication, GWP = Global warming, ODP = Ozone layer depletion, LC = Land competition, POFP = Photo-oxidants formation and CED = Cumulative energy demand.

emission flows by up to 14%. Categories such as ADP, ODP and CED should not present improvements mainly influenced by the substitution of fuel oil by natural gas, which requires larger amounts of energy in its extraction (Dones et al., 2007).

4. Conclusions

In this study, the production of mature cheese in a Portuguese dairy factory from an environmental point of view has been assessed. The main conclusion from this study is that the dairy-farm-related activities are important sources of environmental impacts specifically in terms of AP, EP, GWP, LC and POFP due to on-farm emissions such as methane from enteric fermentation, ammonia from manure management, combustion emissions from agricultural machineries as well as land requirements for animal fodder production. Contributions from the dairy factory resulted remarkable due to the energy requirements in the different cheese-making-related processes and to the distribution of input goods up to the dairy gate. Environmental results identified in this study could be extended to other cheese- and dairy product-making factories according to the consulted literature.

Improvement alternatives for the environmental key factors within the limits of the dairy factory were proposed based on a reduction of energy consumption, the use of a more environmentally friendly fuel in the boilers and the use of new trucks with lower exhaust emissions. According to the results, it should be possible to slightly reduce the environmental profile in some impact categories (AP, EP, GWP and POFP) by means of these proposed actions, which do not involve a high economic investment.

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