

Life cycle assessment of cheese production process in a small-sized dairy industry in Brazil

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Abstract Current research identifies, analyzes, and suggests improvements for minimizing environmental impacts in the manufacture of cheese using the life cycle assessment. Data collection and development of the inventory were performed in a small-sized dairy industry in Brazil. A cradle-to-gate approach was conducted based on the primary data from cheese production and secondary data from databases. The ReCiPe method was used for the impact assessment, considering the categories climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation, particulate matter formation, water depletion, and fossil depletion. A sensitivity analysis was performed including evaluations of different fuels for generating thermal energy, strategies for cleaning of dairy plant and utensils, variations in the way of cheese production based on the fat content, and production percentage changes. The results showed that the skimmed milk and thermal energy productions, electricity usage, and water consumptions were the main elementary flows. The pallet residues showed the best to be used as fuel for thermal energy. Detergent combinations did not influence the impact categories. There was a direct relationship between fat content range (20 to 30%) and the contribution in six impact categories. Changes from 20% in cheese allocation factor influenced the impact assessment results. LCA allowed

identifying the main elementary flow of cheese production, providing valuable information with the potential to verify opportunities for on-site improvements.

Keywords Life cycle assessment · Cheese · Environmental impact assessment · Food industry · Dairy products · Environmental management

Introduction

The interest in environmental impacts of food production is increasing. The rising world population, the consumer preference for greener products, and the growing demands of regulatory agencies, as well as the business-to-business relationships, are contributing to production practices that aim to reduce the environmental impacts.

From 1983 to 2013, there was an increase of 49% in world milk production (considering kinds of milk from cow, goat, sheep, and camel). In 2025, there may be an increase up to 23% mainly due to the higher yield milk production in developing countries (OECD/FAO 2016; FAO 2015).

Fresh milk is preferably consumed (42.9%) worldwide. Among dairy products, cheese is the most preferred (25.2%), followed by butter (23.1%), skimmed milk powder (5.1%), and whole milk powder (3.7%) (FAO 2015). Following such tendency, Brazilian cheese production from 2012 to 2014 reached approximately 700,000 t, surpassing other dairy products. Average consumption during the same period was 3.71 kg/per capita/year, which is higher than average by emergent countries (0.81 kg/per capita/year) and below the average of developed countries (11.88 kg/per capita/year). Ten years show a 20.5% production growth with 867,100 t, and a 10% consumption increase in 2024, with 4.08 kg/per capita/year (CONAB 2015).

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Cheese production in Brazil is predominantly industrialized in dairies. In 2014, approximately 70% of national production came from small, medium and large sized factories (IBGE 2015). The small and medium sized dairies have their market share increasing (SEBRAE 2015).

As in all human activity, cheese and other dairy production coupled to milk processing also have great negative impacts directly affecting several environmental levels. Life cycle assessment (LCA) is one of the methodological approaches that may be employed to identify and quantify product environmental impacts. Since LCA provides a deeper analysis of the item under analysis, its use related to the investigation of agro-industrial products has increased in several areas.

LCA is defined as the compilation and evaluation of inputs, outputs, and potential environmental impacts of a product system throughout its life cycle. Its goal is to identify and describe the environmental consequences related to a product, process, or activity using quantitative measures of materials, water, energy, and emissions to air, water, and soil (ISO 2006a).

According to ISO 14040:2006 (ISO 2006a) and ISO 14044:2006 (ISO 2006b), there are four phases in an LCA study: (1) the goal and scope definition, (2) the inventory analysis, (3) the impact assessment, and (4) the interpretation phase. According to ISO, the scope of an LCA, including the system boundary and level of detail, depends on the subject and the intended use of the study. The life cycle inventory analysis phase (LCI phase) consists of an inventory of input/output data related to the studied. The purpose of life cycle impact assessment phase (LCIA) is to provide additional information to help assess a product system's LCI results as well as better understand their environmental significance. Finally, in life cycle interpretation, the results of an LCI or an LCIA, or both, are summarized and discussed as a basis for conclusions, recommendations, and decision-making according to the previous defined goal and scope (ISO 2006a).

During the last 15 years, studies employing LCA in Europe and in the USA have demonstrated the possible environmental impacts associated with milk processing and its by-products throughout their life cycles under different scopes. Cradle-to-grave approach studies include cheese produced in Sweden (Berlin 2002), milk produced in Norway (Eide 2002), yogurt produced in Portugal (González-García et al. 2013a), and cheese produced in the USA (Kim et al. 2013). Studies on milk (Hospido et al. 2003) and cheese (González-García et al. 2013b) produced in Spain may be identified; similarly, milk produced in Italy (Fantin et al. 2012); UHT milk (González-García et al. 2013c) and cheese (González-García et al. 2013d) produced in Portugal; and milk, butter, yogurt, and cheese produced in Serbia (Djekic et al. 2014) are all under the cradle-to-gate approach.

Despite the most and main relevant impacts come from the raw-milk production, previous studies allowed to conclude that manufacturing in the dairy factories is responsible for a significant share of the impacts in the life cycle of dairy products. Regardless of the milk product, the most salient environmental impacts comprised the production and use of thermal and electrical energies, the production of organic and inorganic effluents, the emission of atmospheric pollutants by vehicles for the transport of raw material, products and other inputs, and the manufacture of plastic and carton packs. In fact, the impacts related to the production of dairy products should be continuously investigated, in order to contribute to the improvement of the industrial processes involved.

During the last 5 years, Brazilian cradle-to-gate LCA studies have focused mainly on agroindustrial systems, whose social and economic importance are noteworthy for the country (Willers and Rodrigues 2014). Trends and drivers for labeling and certification requirements in international markets were identified in a study that researched applications of LCA in agribusiness (Ruviano et al. 2012). To the best of our knowledge the main LCA studies for Brazilian agroindustrial systems are related to crop and energy production (Carvalho et al. 2016; Maranduba et al. 2015); the beef production in northern (Willers et al. 2016) and southern (Ruviano et al. 2015; Dick et al. 2014); and broilers (Silva et al. 2014), pork (Cherubini et al. 2015), and milk (Léis et al. 2015) production in southern.

Nigri et al. (2014) used LCA to assess the environmental impacts on cheese production in the Brazilian state of Minas Gerais. Research focuses on the context of the producing region under analysis, considering its productive, technological, and system management aspects. Due to Brazil's geographical dimensions, results may vary not merely because of regional features but also by characteristics employed in the manufacture and production practices used.

LCA studies on industrial cheese production in different Brazilian regions may provide an overview of the environmental impacts associated with the activity in the country, as well as of the specific possibilities for their mitigation. The current study evaluates the main environmental impacts related to cheese production in the state of Bahia, in the northeastern region of Brazil.

Materials and methods

The dairy industry

A dairy industry from the mid-southwest region in the state of Bahia, Brazil (Fig. 1), was selected to represent same-size industries in the region due to its technological and production characteristics. The dairy lies within an urban area, close to the residential zone of Itapetinga city.

Fig. 1 Geographic region where the study was performed



The dairy's processing capacity is 5000 L per day. Research occurred during a very dry period, which reduced daily processing by approximately 2000 L. According to current legislation, the dairy may be classified as a small-sized food industry due to the milk volume processed (Bahia 2009).

Raw milk is obtained from small producers which are located 65 km distance from the dairy, in average. The milk obtained is used for the production of cheeses, butter, cottage cheese, yogurt, and ricotta. Eight types of cheeses are produced, which have similar nutritional compositions. On average, the fat content of the cheeses is 25%.

When compared to other dairy products, the cheese production has highest demands for resources such as raw materials, energy, and water. It also can be considered as the main product of the dairy industry due to its highest volume of production and greater economic value.

Electricity, water, and sewage system are provided by the corresponding utilities. Thermal energy comes from a tubular boiler (150 kg of hot steam per hour), installed in the dairy industry. The waste wood pallet is used as fuel, and when unavailable, is replaced by eucalyptus/pine firewood.

The cheese production generally consists of nine steps. After receipt of the raw milk and checking their physicochemical quality and legal documentation, the first step is the filtering (Fig. 2). At this stage, the milk flowed through a metal filter that retains the extraneous insoluble materials. Following, the milk is pasteurized at 65 °C during 30 min. Concomitantly, the fat content of raw milk (approximately 3.5%) is standardized to 3.0% using skimmed milk produced in the dairy. The rennet is added to the milk separating the curd from the liquid whey. Then, the curd is cut into pieces and heated with the whey to 45 °C. After achieving temperature, the heated curd (cheese) is placed in molds and salted using

sodium chloride. When the process is finished, the cheeses are packaged and stored in the cold room and ready for sale.

A collection system is integrated to the boiler in order to reduce the soot spreading in the air due to the wood burning. The system comprised water jets expelled on the boiler's chimney so that soot would be transported to the 260-L storage tank. When production activities end, the soot is separated from the water and placed in the sunlight to dry. The dry waste is used as domestic fertilizer.

Plastic wastes generated at the factory are collected by a recycling firm. The whey, which was not employed in the manufacture of ricotta, is given to swine breeders to be used as animal feed supplement.

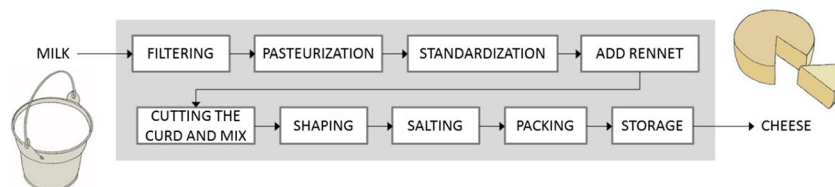
Goal and scope definition

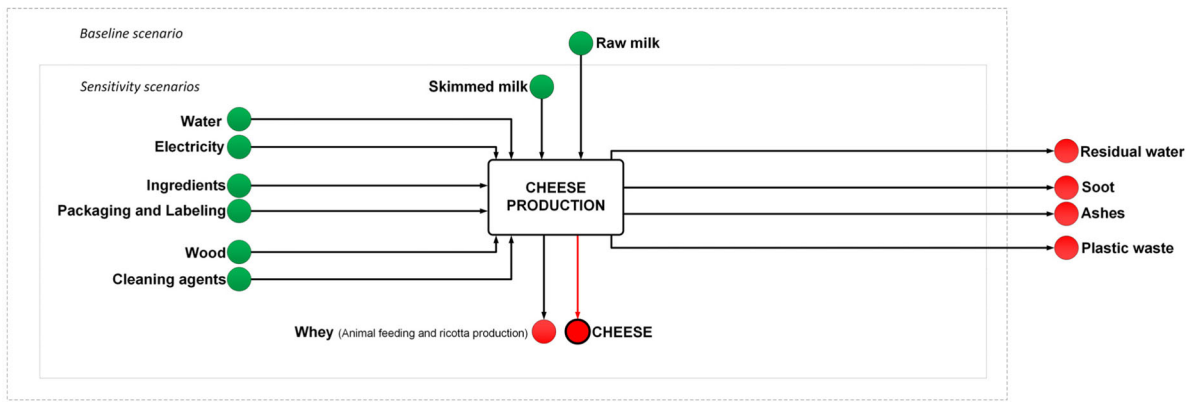
The current research identified, analyzed, and proposed improvements to minimize the environmental impacts by cheese manufacture. It was triggered by the need to assess the consequences of industrial activities linked to the production sector of milk derivatives in Brazil and to contribute towards the development of a database for the life cycle inventory of Brazilian agricultural and livestock products. Results may be used by the academic community and by manufacturers and producers, supporting environmental product declaration.

The evaluation of the product system comprised the following determinations:

- Function, cheese production from bovine raw milk
- Functional unit (FU), 1 kg of product
- System boundary, cradle-to-gate (Fig. 3).

Fig. 2 Steps for cheese production





SYMBOLS AND REPRESENTATIONS:

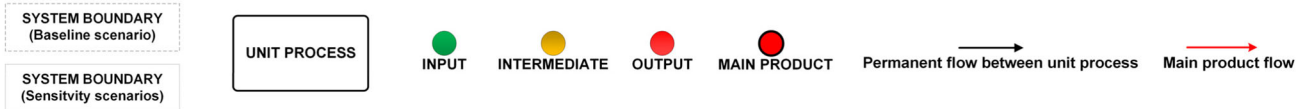


Fig. 3 Product system

In allocation procedure, economic method was used, with 82.2% allocation factor for the cheese. The remaining (17.8%) is related to other dairy products as yogurt (10.4%), butter (4.6%), cheese cottage (2.4%), and ricotta (0.4%). The use of mass allocation as an alternative to the economic approach would not reach the purpose of this study. Once 8–9 L of whey for each kilogram of cheese is produced, the mass allocation will transfer most environmental impacts to whey, underestimating the results of impacts of cheese.

The economic allocation factor was determined by Eq. 1.

$$AF_{(economic)} = \frac{[EV \times PR]_{cheese}}{\sum [EV \times PR]_{all\ dairy\ products}} \quad (1)$$

where *EV* is the economic value (R\$/kg) and *PR* is the production (kg/year).

The values of *EV*, *PR*, and the *AF* for the cheese are presented in Table 1.

- In data quality requirements, information and data in current research were divided into primary and secondary data. Primary data on the consumption of milk, wood, energy, ingredients, tap water, package, label, and cleaning agents were retrieved from the dairy’s registers. Secondary data were retrieved from databases of life cycle inventories.
- Impact categories considered were climate change (kg CO_{2eq}), ozone depletion (kg CFC-11_{eq}), terrestrial

Table 1 Allocation factor calculated for the cheese using the economical method

Product	Production ^a		Economic value		Allocation factor
	(kg/year)	(%)	(R\$/kg) ^b	(US\$/kg) ^d	
Cheese	66,188.85	(52.95%)	21.07 ^c	6.44	82.17%
Yogurt	50,301.00	(40.24%)	3.50	1.07	–
Butter	5,556.16	(4.44%)	14.00	4.29	–
Cottage cheese	2,084.86	(1.67%)	20.00	6.13	–
Ricotta	875.98	(0.70%)	8.00	2.45	–

^a The dairy factory production data from July 2014 to June 2015

^b Market value, in Brazilian currency, of dairy products from March to September 2015

^c Average market value of the eight cheese types

^d Conversion based on the exchange rate of the US dollar published by the Central Bank of Brazil on 19 September 2016

acidification (kg SO_{2eq}), freshwater eutrophication (kg P_{eq}), photochemical oxidant formation (kg NMVOC), particulate matter formation (kg PM_{10eq}), water depletion (m³), and fossil depletion (kg oil_{eq}). Such impact categories were chosen according to the goals defined in the study and the lower degree of uncertainty associated with their LCIA models.

- Assumptions were (i) due to the similarity in the manufacture stages, the eight types of cheese produced in the dairy were considered a single product (cheese) and (ii) environmental impacts due to infrastructure, production of machinery, and devices used were not considered.

Inventory analysis

Inventory consisted of information retrieved between February and September 2015 by evaluating the dairy's production, meetings with the manager, and analysis of production registers between July 2014 and June 2015 (Table 2).

The conversion of milk mass to volume was based on the values shown in the database FAO/INFOODS (Charrondiere et al. 2012).

Water and energy consumptions were retrieved from information of the corresponding monthly bills between July 2014 and June 2015.

Table 2 Inventory of 1-kg cheese production

Item	Quantity	Quality ^b	σ ^{2c}
Inputs			
Raw milk	7.74 kg	Verified	0.0013
Skimmed milk	1.64 kg	Calculated	0.0046
Tap water	0.013 m ³	Measured	0.0026
Electricity	0.510 kWh	Measured	0.0026
Waste wooden pallets for thermal energy production	0.613 kg	Estimated	0.0032
Ingredients			
Calcium chloride	0.00201 kg	Verified	0.0046
Sodium chloride (salt)	0.0655 kg	Verified	0.0046
Yeast	9.07 × 10 ⁻⁵ kg	Verified	0.0046
Rennet	3.63 × 10 ⁻⁶ m ³	Verified	0.0046
Packaging and labeling			
LDPE film (package)	0.00698 kg	Measured	0.0026
Biaxially oriented polypropylene film ^a (label)	0.000566 kg	Measured	0.0026
Cleaning agents			
Nitric acid	2.58 × 10 ⁻⁶ m ³	Estimated	0.0106
Sodium hydroxide	9.68 × 10 ⁻⁷ m ³	Estimated	0.0106
Sodium hypochlorite	4.53 × 10 ⁻⁶ m ³	Estimated	0.0106
Outputs			
Cheese	1.00 kg	–	
Whey	8.46 kg	Calculated	0.0013
Wastewater	0.013 m ³	Estimated	0.0046
Soot	0.016 kg	Measured	0.0026
Ashes	0.597 kg	Calculated	0.0032
Plastic waste (polyethylene and polypropylene)	0.0030 kg	Verified	0.0046
Others			
Transport of raw milk (from the farm to the factory)	492.83 kg km	Estimated	0.162
Transportation of raw materials to the factory ^a	162.17 kg km	Verified	0.124
Transportation of waste production (whey)	38.35 kg km	Estimated	0.162

^a Raw materials calcium chloride, sodium chloride, yeast, rennet, LDPE film, biaxially oriented polypropylene film, wood waste pallets, nitric acid, sodium hydroxide, and sodium hypochlorite

^b Measured data, high confidence rates from surveys or direct measures that represent 1-year production at the factory. Verified data were not measured directly; they are rates that integrate the factory production records. Estimated data, measured for a time less than 1 year and that have been extrapolated, or rates obtained by estimates of the factory's employees. Calculated data, values obtained by applying a mass balance in the system

^c Weidema et al. (2013)

In order to determine wood mass used in the boiler, the wood density (274.35 kg/m³) was calculated. Following, the volume of wood used in the boiler was measured during 30 days. Finally, the results were converted into mass per density.

Impact assessment

Environmental impacts were evaluated with SimaPro 8.0.5.13 (PRé Consultants 2015), employing characterization models of the method ReCiPe Midpoint 1.12 with the hierarchical model (H). The advantages of this method include (i) the broadest set of midpoint impact categories and (ii) the use of impact mechanisms that have global scope (PRé Consultants 2016). The ReCiPe is an update of the CML method used in other similar studies that assessed dairy products (Berlin 2002; González-García et al. 2013a, b, c, d). The hierarchical model is considered as the default mode, often found in scientific models (PRé Consultants 2016).

Nine processes were selected from SimaPro to represent the life cycle inventory (Table 3). Four databases were used (Ecoinvent, USLCI, Industry data, and Agri-footprint), once none of them contained all the items of the cheese inventory.

Sensitivity scenarios

The following sensitivity scenarios do not consider the raw milk as an input in cheese production, except in the scenario for cheese formulations based on the fat content.

Fuel alternatives for thermal energy production

The thermal energy production is among the main hot spots identified in the milk production (Djekic et al. 2014; González-García et al. 2013b, d). A sensitivity study was performed considering the impacts due to the use of three fuels commonly used in dairy industry, mainly in Brazil (Table 4). The results were compared to the current fuel used in the dairy industry studied (waste wooden pallet). The current operating conditions were maintained.

The production of 1 kg of cheese requires 7.95 MJ of thermal energy. This was determined from the waste wooden pallet mass used as fuelwood. The conversion of energy in wood mass considered the net heating value for picked wood with 300 kg/m³ (EPE 2015).

Replacing the detergents used to clean the dairy industry

The process of cleaning in a food industry may use different types of detergents. Some of them have predominantly acid composition and other more alkaline composition, both having specific functions. The most common materials used in detergent formulations are nitric or phosphoric acids and hydroxide or sodium metasilicate.

The impacts of cheese production due to the use of different detergents in cleaning processes were analyzed. Four scenarios were considered (Table 5), as well as the processes chosen to replace the standard scenario are shown (Table 6).

Table 3 Processes selected for impact assessment of cheese production

Item	Process	Database ^{a,b,c}
Thermal energy	Wood waste, unspecified, combusted in industrial boiler/USA	USLCI
Electricity	Electricity, medium voltage {BR} market for Alloc Def, U	Ecoinvent 3
Skimmed milk	Standardized milk, skimmed, from processing, at plant/NL economic	Agri-footprint
Sodium hypochlorite	Sodium hypochlorite, without water, in 15% solution state {GLO} market for Alloc Def, U	Ecoinvent 3
Sodium hydroxide	Sodium hydroxide, without water, in 50% solution state {GLO} market for Alloc Def, U	Ecoinvent 3
Nitric acid	Nitric acid, without water, in 50% solution state {GLO} market for Alloc Def, U	Ecoinvent 3
Oriented polypropylene film	Oriented polypropylene film E	Industry data 2.0
Packaging film, LDPE	Packaging film, low-density polyethylene {RoW} production Alloc Def, U	Ecoinvent 3
Sodium chloride	Sodium chloride, powder {GLO} market for Alloc Def, U	Ecoinvent 3
Tap water	Tap water {RoW} tap water production, conventional treatment Alloc Def, U	Ecoinvent 3
Raw milk	Cow milk {RoW} milk production, from cow Alloc Def, S	Ecoinvent 3

^a <http://www.ecoinvent.org/>

^b <http://www.agri-footprint.com/>

^c US Life Cycle Inventory Database (2012), National Renewable Energy Laboratory (<https://uslci.lcacommons.gov/uslci/search>)

Table 4 Selected processes for the sensitivity study of thermal energy production

Fuel	Process	Database ^a
Firewood	Heat, central or small-scale, other than natural gas {RoW} heat production, mixed logs, at furnace 100 kW Alloc Def, U	Ecoinvent 3
Fuel oil	Heat, central or small-scale, other than natural gas {RoW} heat production, light fuel oil, at boiler 100 kW condensing, non-modulating Alloc Def, U	Ecoinvent 3
Natural gas	Heat, central or small-scale, natural gas {RoW} heat production, natural gas, at boiler condensing modulating <100 kW Alloc Def, U	Ecoinvent 3

^a <http://www.ecoinvent.org/>

Cheese reformulation based on fat content change

On average, the fat content of the cheese types produced in the dairy industry is $25\% \pm 2\%$. Three cheese formulations were assessed, based on the amount of skimmed milk to obtain the corresponding fat content. The three levels of fat content were set, 20% (2.72 kg of skimmed milk and 6.4 kg of raw milk), 25% (1.64 kg of skimmed milk and 7.74 kg of raw milk), and 30% (0 kg of skimmed milk and 9.38 kg of raw milk). The calculations were made by mass balance considering the nutritional properties of the raw milk (approximately 3.5% fat) that come to the dairy industry.

Cheese production percentage changes

Four allocation factors were obtained based on changes in annual cheese production. From a standard value (where 70% of production is cheese), increments of 10% up to the upper limit (100%) were proposed, which is a hypothetical scenario where only cheese is produced.

Results and discussion

Environmental impacts in cheese production

The potential environmental impacts related to cheese production are shown (Table 7).

Raw milk contributed 70 to 98% in the eight impact categories considered (Fig. 4). The skimmed milk contributed 30% in terrestrial acidification (TA) and less than 21% in the

other categories. The maximum contributions of thermal energy and electricity were 15 and 9%, respectively.

Other case studies have reported that raw milk presented high contributions for impact categories. A LCA study by González-García et al. (2013b) of a cheese variety in Spain reported that the raw milk production contribution range from 67 to 89% for impact categories acidification (88%), eutrophication (89%), global warming potential (82%), ozone depletion (67%), and photochemical oxidant formation (75%). González-García et al. (2013d) registered above 82% contributions in the categories acidification (91%), eutrophication (86%), and global warming potential (82%), coupled with approximately 69% in the category photochemical oxidant formation for mature cheese manufactured in Portugal. Water depletion was not assessed by both studies.

When the results of research developed for other dairy products were taken into account, Fantin et al. (2012) recorded above 62% contributions in the raw milk production in Italy for the categories global warming (85%), ozone depletion (62%), photochemical oxidant formation (84%), acidification (92%), and eutrophication (97%). González-García et al. (2013c) registered 81% contribution in acidification, 90% for eutrophication, and approximately 60% for global warming for a LCA of UHT milk manufactured in Portugal. Hospido et al. (2003) registered 80% contributions for global warming, 36% for ozone depletion, 58% for acidification, 74% for eutrophication, and 31% for photochemical oxidant formation when they performed a LCA of milk manufactured in Spain.

Environmental impacts of cheese production excluding raw milk

The production of skimmed milk was the main contributor in most of the categories considered, climate change (CC)

Table 5 Scenarios for replacement of acid and alkaline detergent in dairy

Scenario A (standard)	Nitric acid and sodium hydroxide
Scenario B	Phosphoric acid and sodium hydroxide
Scenario C	Phosphoric acid and sodium metasilicate pentahydrate
Scenario D	Nitric acid and sodium metasilicate pentahydrate

Table 6 Selected processes to replace the detergent acid and alkaline used to clean the dairy industry

Detergents	Process	Database ^a
Phosphoric acid	Phosphoric acid, industrial grade, without water, in 85% solution state {GLO} market for Alloc Def, S	Ecoinvent 3
Sodium metasilicate pentahydrate	Sodium metasilicate pentahydrate, 58% active substance, powder {RoW} production Alloc Def, S	Ecoinvent 3

^a <http://www.ecoinvent.org/>

(92.7%), TA (98.2%), freshwater eutrophication (FE) (91.1%), photochemical oxidant formation (POF) (63.5%), particulate matter formation (PMF) (81.4%), and fossil depletion (FD) (75.2%) (Fig. 5). The elementary flow is related to raw milk production and comprises both emissions from livestock (production of manure, enteric fermentation, etc.) and those from animal feed production (silage, soybean, etc.).

In the CC category, emissions of biogenic methane (CH₄) and nitrous oxide (N₂O) accounted for 40.4 and 28.8%, respectively, of impacts the skimmed milk. Phosphorus emissions from manure and fertilizer used in dairy farm accounted for 70 and 27.8%, respectively, of skimmed milk contribution in FE category. In POF category, the main elementary flow was from N₂O emissions (55.6%). Ammonia emissions (NH₃) accounted for 98% of skimmed milk contribution in TA category and 93.8% in PMF category. In FD, the production of energy for operation the milk separator accounted for 88.9% of skimmed milk contribution.

Production of thermal energy contributed with 83.3% in ozone depletion (OD) category. Emission of carbon tetrachloride (CFC-10) was the main elementary flow. Its emission during thermal energy production may be associated with the use and maintenance of fire extinguishers in the boiler room.

In POF and PMF categories, the contributions of thermal energy production were 23.2 and 15.9%, respectively. The main elementary flows were the emissions of nitrogen oxides

(NO_x) (86.6%) and emissions of particle matters 2.5 μm (PM_{2.5}) to 10 μm (PM₁₀) diameter (89.9%), in POF and PMF categories, respectively.

In water depletion (WD) category, the main contributors were electricity (31.7%), skimmed milk (35.4%), and tap water (31.1%) due to the water consumption to produce hydro-electric electricity, to milk production, and to cleaning and sanitizing of equipment and dairy plant, respectively.

González-García et al. (2013b) described electricity and thermal energy as important sources of environmental impact in San Simon da Costa cheese produced in Spain. In the impact categories, global warming and acidification, electricity amounted to 20 and 29%, respectively. The generation of thermal energy from fuel oil accounted for 25% of total impact within the cheese production for global warming, 27% for depletion of abiotic resources, and 39% for ozone depletion.

Djekic et al. (2014) performed an LCA of six dairy products, in Serbia, including cheese, and recorded that the consumption of electricity was one of the main elementary flows. Their conclusion was based on the emission of carbon dioxide released in the process of energy production from non-renewable sources. The cheese was the product that required the greatest amount of energy for its manufacture. For mature cheese production in Portugal, González-García et al. (2013d) indicated that the production energy requirements (thermal and electricity) were the main hot spots for abiotic depletion potential (74%) and acidification potential (37%) categories. The thermal energy production fuel oil contributed 54% for the category photo-oxidant formation and 72% for ozone depletion.

Research on other dairy products such as pasteurized and UHT milk showed that the energy production was a relevant hot spot (Fantin et al. 2012; González-García et al. 2013c; Hospido et al. 2003).

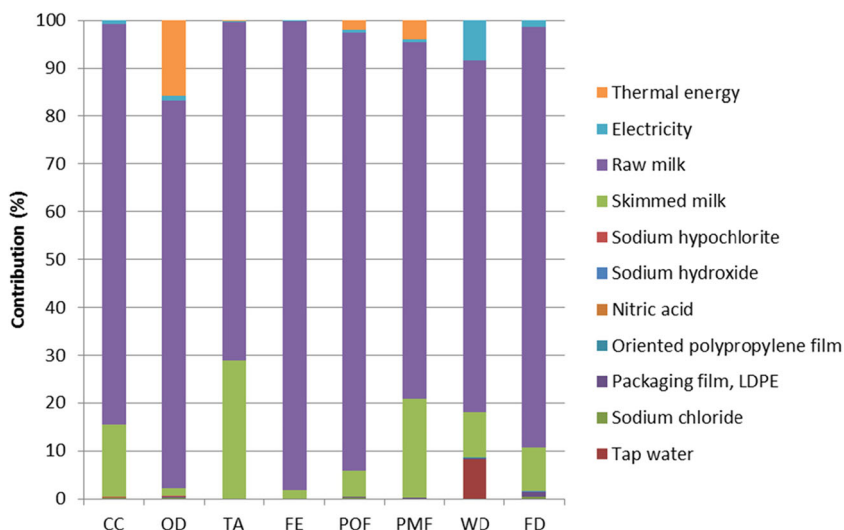
Whereas current research revealed that packing contributed with 36% in FD category, González-García et al. (2013b) and González-García et al. (2013d) showed that there was a 10% contribution for the category abiotic depletion potential (ADP). It must be underscored that assessments developed by the authors included such processes as waste treatment, cheese smoking, and production of milk powder, which were not included in current research and which contributed for the category ADP.

Table 7 Environmental impacts of cheese production

Impact categories	Total	Unit
CC	14.447	kg CO _{2eq}
OD	5.71E - 07	kg CFC-11 _{eq}
TA	0.200	kg SO _{2eq}
FE	0.0191	kg P _{eq}
POF	0.038	kg NMVOC
PMF	0.038	kg PM _{10eq}
WD	0.161	m ³
FD	1.254	kg oil _{eq}

CC climate change, OD ozone depletion, TA terrestrial acidification, FE freshwater eutrophication, POF photochemical oxidant formation, PMF particulate matter formation, WD water depletion, FD fossil depletion

Fig. 4 Relative contribution of inputs in the cheese production for each impact category. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *WD* water depletion, *FD* fossil depletion



Nigri et al. (2014) evaluated the environmental impacts of cheese through endpoint categories which will not be compared and discussed with those in the current study, which considered midpoint impact categories.

Fuel alternatives employed for thermal energy production

There was a rise in the contribution of the thermal energy production in the impact categories CC, OD, and FD when waste wooden pallets replaced fuel oil (Fig. 6). Variations in the contribution of the four types of fuel were below 5% for the category WD and TA.

In CC category, the replacement by any of the three alternative fuels resulted in emissions of carbon dioxide (CO₂) from the fossil source. This was previously nulls when waste wooden pallets were used. When compared to firewood, the fossil CO₂ emissions were approximately three times higher than those with fuel oil and approximately two times higher with natural gas. Emissions of fossil CO₂ in the use of

firewood originate from upstream processes in the extraction and transport of timber.

In the OD category, the replacement by firewood and natural gas provided a 99% reduction in CFC-10 emissions. In spite of a similar reduction (−99%) on CFC-10 by fuel oil, there was a rise of approximately 25 times on the bromotrifluoromethane emissions (Halon 1301), a compound used as a fire extinguisher on the offshore platforms.

In FE category, the replacement of any fuel resulted in phosphate emissions (PO₄³⁻) for water with firewood as the largest contributor.

In POF category, replacement by firewood provided an 81% increase in nitrogen oxides (NO_x). Among the assessed fuels, firewood contributed most on the impact for this category. Emissions of non-methane volatile compounds (NMVOCs) caused a 61 and 53% reduction in the use of natural gas and fuel oil, respectively, when compared to firewood. In the case of waste wooden pallets, the emissions were

Fig. 5 Relative contribution of inputs in the cheese production for each impact category excluding raw milk. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *WD* water depletion, *FD* fossil depletion

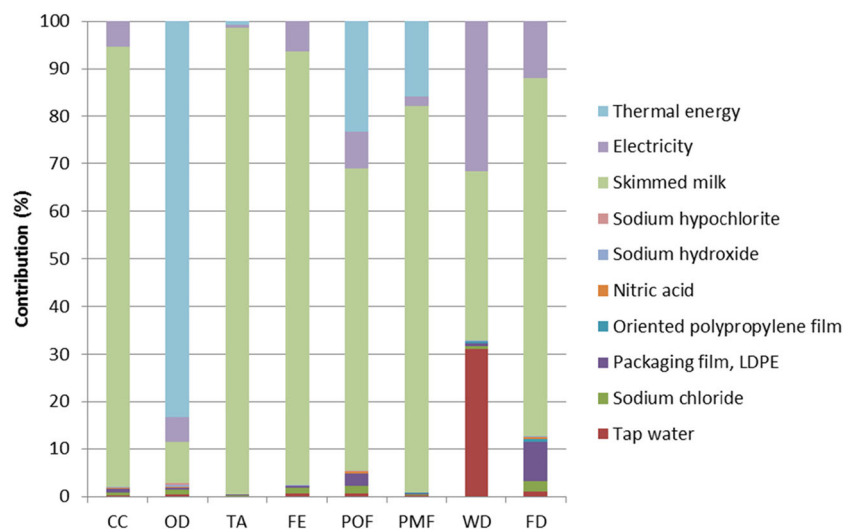
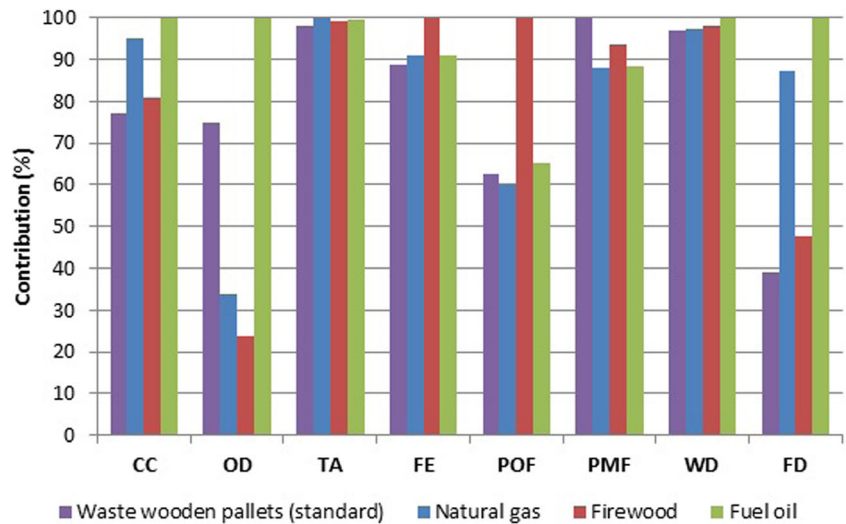


Fig. 6 Results in replacement of the standard fuel used for thermal energy production in dairy for natural gas, firewood, and fuel oil. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *WD* water depletion, *FD* fossil depletion



nil. NMVOC emissions were related to the use diesel oil used as fuel in tractors and chainsaw for wood extraction.

In PMF category, replacement by the three alternative fuels provided a 98% (fuel oil and natural gas) and 96% (firewood) decrease in PM_{2.5} to PM₁₀ emissions. There was an 81% increase in the emissions of NO_x due to the use of firewood, whereas reductions reached 44 and 12%, respectively, when natural gas and fuel oil were employed.

In the FD category, fossil fuels, such as fuel oil and natural gas, required greater resources (coal, natural gas, and crude oil), while firewood provided an 8% higher contribution than that required by waste wooden pallets due to activities prior to combustion for the production of energy, such as extraction and transport which used fossil fuel.

Waste wooden pallets resulted in the lower results among the fuels in three (CC, FE, and FD) out of the eight impact

categories. Natural gas had the lowest contribution in the POF and PMF categories, with differences of 5% (POF) and 10% (OD) from the contribution by firewood. Firewood had the lower results in the OD category, whereas in CC and FD categories, there was a 3.6 and 8.3% variation, respectively, for results by waste wooden pallets. In categories FE and POF, firewood had the greatest impact contribution among the fuels.

Replacing the detergents used to clean the dairy industry

Detergent combinations showed similar contributions (Fig. 7). In all impact categories, changes were below 2%.

Eide et al. (2003) indicated that the use phase is the most critical in detergents’ life cycle. The authors assessed the impacts of four clean in place (CIP) techniques. Stages of production and transport of detergents had a lower contribution

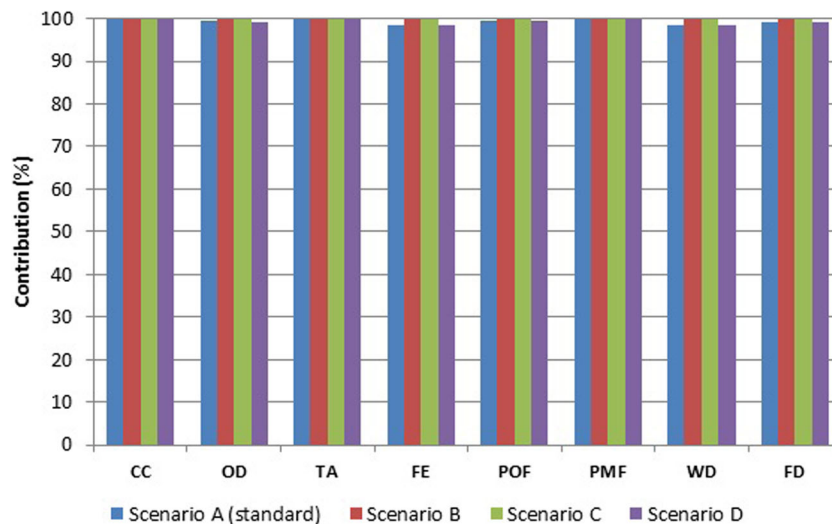
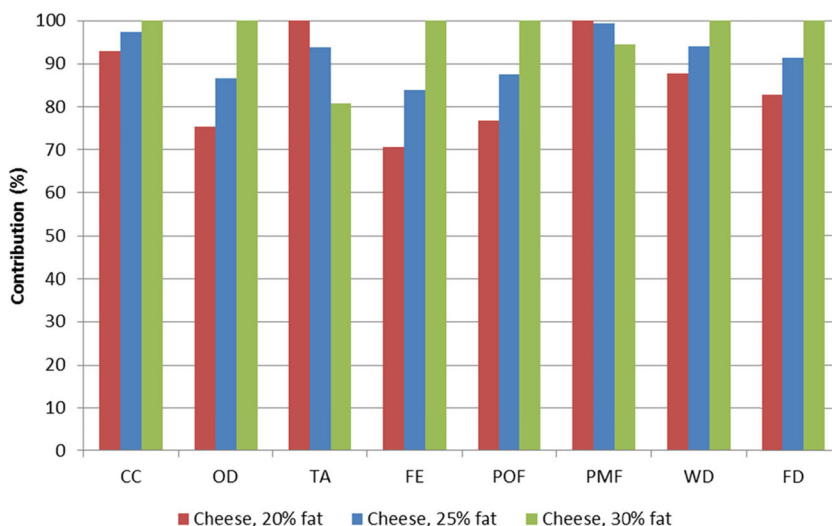


Fig. 7 Results for different combinations of acids and alkaline detergents for cleaning the dairy factory. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation,

WD water depletion, *FD* fossil depletion. *Scenario A* nitric acid and sodium hydroxide, *scenario B* phosphoric acid and sodium hydroxide, *scenario C* phosphoric acid and sodium metasilicate pentahydrate, *scenario D* nitric acid and sodium metasilicate pentahydrate

Fig. 8 Impact results for different ways of cheese production relying on its fat content. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *WD* water depletion, *FD* fossil depletion



compared to the use phase. The authors concluded that cleaning technique contributed most to the impacts than the type of detergent used.

An alternative to increasing the efficiency of cleaning procedures is the use of monitoring tools (Asselt et al. 2002). This technique would provide the best control on the time required to complete the cleaning, avoiding unnecessary consumption of energy and resulting in cost reducing.

Formulation changes based on the content of fat cheese

The changes in fat cheese content influenced all impact categories (Fig. 8). The most perceived changes occurred in the categories OD, FE, and POF. Changes in fat content from 20 to 30% resulted in higher contributions in OD (25%), FE (29%), and POF (23%). In the other categories, the changes did not exceed 20%.

The cheese’s fat content and the contribution on impact categories are related to the quantities of skimmed and raw

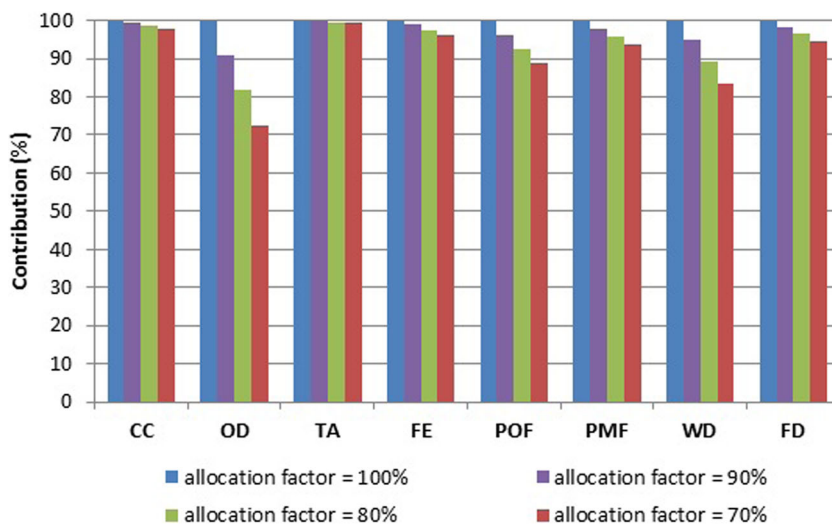
milk. Fatter cheese requires small amounts of skimmed milk and large amounts of raw milk. The TA and PMF categories underwent the larger variations due to skimmed milk production, while CC, OD, FE, POF, WD, and FD categories were more influenced by raw milk.

Cheese production percentage changes

Changes from 70 to 100% in cheese production resulted in increases higher than 10% in OD (28%), POF (11%), and WD (16%) impact categories (Fig. 9).

Increments by 10% (i.e., from 70 to 80, from 80 to 90, or from 90 to 100%) resulted in increases in OD (9.2%), WD (5.5%), POF (3.7%), and PMF (2.1%). In the other categories, the contributions were less than 2%. If 20% allocation are considered (from 70 to 90 or 80 to 100%), a maximum increasing of 9.2% is reached, except in OD categories (18%) and WD (11%).

Fig. 9 Sensitivity of allocation factor used in cheese evaluation. *CC* climate change, *OD* ozone depletion, *TA* terrestrial acidification, *FE* freshwater eutrophication, *POF* photochemical oxidant formation, *PMF* particulate matter formation, *WD* water depletion, *FD* fossil depletion



Conclusions

This LCA study could provide valuable information with the potential to verify opportunities for the improvement of cheese production in a small-sized dairy industry. It was possible to identify the hot spots of cheese production, as well as the fuel with best results for reducing the environmental impacts. The effects of different ways of producing cheese (changes on fat content and percentage of cheese production) on the impact results were also assessed. The lesser fat content in cheese resulted in low contributions in six impact categories, and the changes in cheese production percentage did not alter all impact categories. These results can be useful to support some adjustments in production practices aiming its quality improvement.

Most of the environmental impacts of cheese life cycle are not from the dairy industry but in the production of its raw materials (raw milk). In this study, the contribution of the production of the cheese at the dairy was lower than 29%. The production of raw milk, moreover, presented contributions ranging from 70 to 98%.

At the dairy factory level (excluding raw milk contribution), the production of skimmed milk and thermal energy, the electricity usage, and water consumption were the hot spots of cheese production.

From the four fuels evaluated for thermal energy, pallet wood residue showed the best results in the impact categories considered. Natural gas can be used as an alternative, once it resulted in good results in ozone depletion, photochemical oxidant formation, and particulate matter formation categories.

The type of detergent used for cleaning the dairy plant and equipment did not result in changes to any impact categories. Therefore, any of the combinations proposed can be used, without changing the impacts in the cheese production.

An increase 10% in cheese allocation factor caused a decrease in performance up to 9.2% on the assessed impact categories. Above this range, there was worsening performance up to 28%, and the categories OD, POF, and WD were the most influenced.

The integration of strategies that decrease wastes and avoid losses during the manufacture of raw material (accidental spilling or spillovers during storage) is crucial for the best performance of the process. Pre-requisite quality programs adopted by food industry such as good manufacturing practices (GPM), standard operating procedures (SOP), and sanitation standard operating procedures are a great asset in control due to the avoidances of liabilities by contamination. Other options may be included in the development of new ingredients that partially substitute the use of milk in cheese manufacture or in the use of high-nutrient milk.

Proper use of water for cleaning operations and the use of dry cleaning where it is possible, can contribute to preserving water resources and reduces the volume of wastewater to be treated.

Current research focused on the main Brazilian dairy product, employing primary data for energy consumption and inputs for its manufacture. It is expected that results presented may be an asset for the academic community and could serve as a basis for the development of studies as those related to Environmental Product Declarations in environmental labeling of dairy products. Further, they may be of great help in the development of a database for the life cycle inventory of agricultural and livestock products in Brazil.

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