ESCUELA TÉCNICA SUPERIOR DE INGENIEROS
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Trabajo Fin de Grado

Análisis del ciclo de vida de la producción de la leche: aplicación a la industria láctea.

(Life Cycle Assessment of milk production: application to dairy industry)

Para acceder al Título de

Graduada en Ingeniería Química

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TÍTULO	Life Cycle Assessment of milk production: application to dairy industry.		
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KEY WORDS

Life cycle Assessment (LCA), environmental impact, Milk production, Dairy products.

SCOPE

Milk is one of the commodities most produced in the world due to its nutritional and immunological properties. Milk needs to pass through a series of processes before being ready for human consumption, in order to avoid diseases caused by the presence of pathogens. The environmental impacts associated to the milk farming and dairy processing are analysed in this project by using the Life Cycle Assessment (LCA) methodology. LCA measures the potential impacts associated to an activity or product, from its raw materials extraction to the residues disposal.

This study analysed from cradle to gate the potential environmental impacts associated to 1 L of packaged milk in two dairy industries, one in Portugal (González-García et al. 2013) and one in Spain (Hospido, Moreira y Feijoo 2003), identifying the milk farming and production stages that affect more the environment. For this analysis, the method CML 2001 and the Gabi software 6 were used.

RESULTS

The environmental impacts studied in both systems are shown in Table 1. Most impacts are very similar between both industries, even though the characteristics of the system, the stages of the processes and waste management systems were not identical. In both cases Marine Aquatic Ecotoxicity Potential (MAETP) followed by Global Warming Potential (GWP) presented the greatest values. Regarding the stages that causes the most impact, milk farming and transport is the highest, continued by tetrabrik manufacturing and transport. The impact generated in milk farming is due to the emissions caused by cow secretions, the use of fertilizers based in animal manure and the energy consumption at farm, whereas tetrabrik manufacturing is due to the use of aluminium as raw material.

Table 1. Comparison of milk production from the two case studies.

Enviromental Impacts	Units	Total milk production from Spain	Total milk production from Portugal
Acidification Potential (AP)	[kg SO_2-Equiv.]	2.07E-02	1.55E-02
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	9.48E-03	7.54E-03
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3.92E-02	3.17E-02
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	1.10E+00	9.26E-01
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	1.08E-01	9.81E-02
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6.17E+01	6.61E+01

This project applied a mass allocation based on its annual production in order to be able to compare the total impact of the milk production in both systems. Later on, the contribution of each type of milk to GWP impact is compared (view Figure 1), being whole UHT milk from Spanish system (0.78Kg CO_2-equiv.) and semi-skimmed UHT milk from Portuguese industry (0.71Kg CO_2-equiv) the highest contributors to GWP impact.

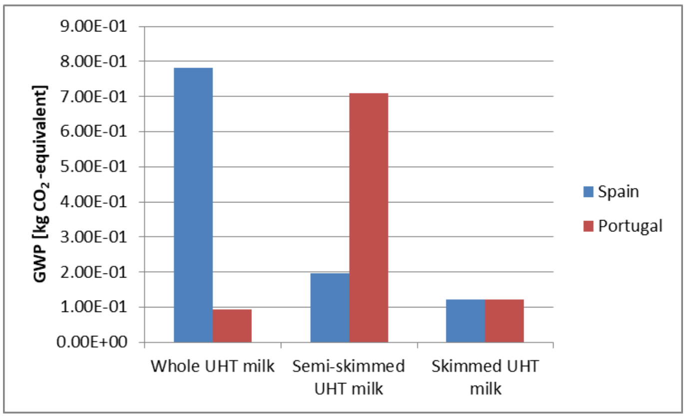

Figure 1.Global Warming Impact associated to each kind of milk.

CONCLUSIONS

To sum up, milk farming and tetrabrik manufacturing are the stages that more impact generated. Milk farming impact can be reduced with the use of chemical fertilisers with low nickel content, through improvements in the cow diet, using equipment with higher efficiency and with the use of energy and fuel from renewable energies. On the other hand, the impact generated by tetrabrik manufacturing can be reduced using pyrolysis to recycle the aluminium or by using aluminium free containers.

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1. INTRODUCTION

1.1 MILK AND OTHER DAIRY PRODUCTS

From the beginning, milk has been a substance created to feed the mammalian infant, but many centuries ago human started to consumed it daily; even nowadays dietary guidelines recommend dairy products as a necessary component in a balanced diet (Food and Agricultural Organisation of the United Nations 2016). It is the fifth largest provider of energy and the third largest in terms of protein and fat for human beings. In the past, dairy products weren't eaten globally; northern countries have been traditional consumers of dairy products, while they were not usually eaten in tropical regions due to the refrigeration requirements for milk stability (Goff 2018). Cow milk represents 87% of global milk production, nevertheless, milk can also be obtained from other animals sources such as buffaloes, goats, sheep or camels; and it be transformed into a high variety of dairy products like drinking milk, butter, cream, yoghurt or cheese (Food and Agricultural Organisation of the United Nations 2016).

Raw milk is one of the commodities mostly produced in the world, being consumed among the top five agricultural commodities in the majority of countries. One of the main reasons of milk being so consumed is its immunological and nutritional properties (Goff 2018); dairy products are energetic foods with significant amounts of protein and micronutrients including calcium, magnesium, selenium, riboflavin and different vitamins (FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS 2016).

Nevertheless, the consumption of dairy products, can provoke diseases due to the presence of presence of pathogens; therefore, it is really important to obtain them with hygienic quality in order to be consumed safely (Goff 2018).

1.2 THE DAIRY INDUSTRY

In 2013, raw milk was ranked as the top agricultural commodity in the world with a total production valued in USD 328 billion. Moreover, it is predicted that the world's milk production will increase by 177 million tonnes from 2015 to 2025 with a growth rate of 1.8%

each year, while the annual increment of dairy products will be between 0.8% and 1.7% in developed countries (FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS 2016).

Among the European countries, Spain is the seventh cow milk producer; generating 4% of the EU total cow milk; with Galicia being the biggest milk provider over all the Spanish regions. In Spain, as in other EU countries, cow milk production from livestock holding was limited by a milk quota until 2015, being fined the holdings that did not fulfil that quota (INLAC 2016). Its abolition incremented the milk production in countries such as Ireland, expecting to rise its production up to a 50% by 2020 compared to the production of 6.4 billion litres in 2015 (Finnegan et al. 2017).

Within Europe, Spain stands out by producing milk from different origins: sheep milk leaded the ranking in 2015 with 17% of the European total, and goat milk reached the second place that same year, producing 22% of the total goat milk (INLAC 2016).

A factor that influences directly the production of dairy products, is the number of cows and the yield of each of them. The Eurostat livestock survey indicated that at the end of 2017, there was a drop near to 1 % in the number of dairy cows compared to the same period in 2016 and it is expected to keep declining during 2018 and 2019. Despite of the general declining of dairy cow number, EU milk production was incremented (view Table 1) by more than 2 million tonnes in 2017. The productivity gain can be due to a higher number of young cows, the improvement of cow diet with feed concentrates or the implementation of techniques for keeping each cow relaxed and healthy (EUROPEAN COMMISSION 2018a).

Table 1. Dairy products production from 2014 to 2018 (EUROPEAN COMMISSION 2018a).

Year	2014	2015	2016	2017	2018
Raw milk (1000 t)	159.700	162.900	163.000	165.400	167.400
Drinking milk (1000 t)	31.366	31.305	30.850	30.639	30.425
Cream (1000 t)	2.639	2.745	2.764	2.792	2.848
Whole milk powder (1000 t)	756	717	728	746	760
Skim milk powder (1000 t)	1.457	1.538	1.561	1.519	1.558

Considering other dairy products, skim milk powder (SMP) production in Europe remained well-above during the last 5-year and a bigger growth of production (3%) is predicted the followed years due to the high global demand. On the other hand, EU production of whole milk powder (WMP) increased in 2017 comparatively to the previous year (+3 %) driven by rising exports. A further 2 % production growth is projected for 2018 as the demand from the food industry and world markets remain strong (EUROPEAN COMMISSION 2018a).

The activities of dairy production and processing also create jobs. In fact, the global number of jobs expected to be created in the lactic sector between 2016 and 2030 is 470 million; considering direct and indirect employment. In Spain, this sector generates 11.820 million of euros and provides employment to 80.000 people each year (FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS 2016; INLAC 2016).

1.3 THE MARKET FOR DAIRY PRODUCTS

Considering the different dairy products available on the market, whole milk powder (WMP) and skimmed milk powder (SMP) are the most traded agricultural commodities globally due to the easy transportation and maintenance of the milk in powder format. Fresh dairy products, on the other hand, are the least traded commodity (FOOD AND AGRICULTURAL ORGANISATION OF THE UNITED NATIONS 2016).

EU exports of dairy products increased by 10 % in 2017, achieving the first position in the ranking of world exporter(EUROPEAN COMMISSION 2018a). However, the importation in Europe increased also during 2018 as compared to 2017. The trade balance (exports - imports relation) depends on which country and type of dairy product is considered (EUROPEAN COMMISSION 2018b). For example, Spain doesn't export big quantities of butter but its imports of it are high, showing a negative trade balance in this dairy product whereas Portugal presents a positive trade balance exporting more butter than what it imports.

This trade balance is a key factor in the dairy product price movements, since it reflects the market demand. The movements on the price of dairy products depend on the volume of milk collection and the demand of dairy products. The volume of milk collection is not always stable, for instance, if there has been any long periods of cold weather, it could lead to keep cows longer in-doors and delays on the grass development that would itself decrease milk collection levels.

As Figure 1 shows, the price of EU raw milk increased up to 38 €/100 kg at the end of 2017, 20% above previous year level and 10 % above the period 2012-2016, caused by the decrement of milk recollection and high dairy products demand. Moreover, it is expected to keep increasing the prices on the second half of 2018 due to the cold temperatures registered during winter-spring (EUROPEAN COMMISSION 2018a).

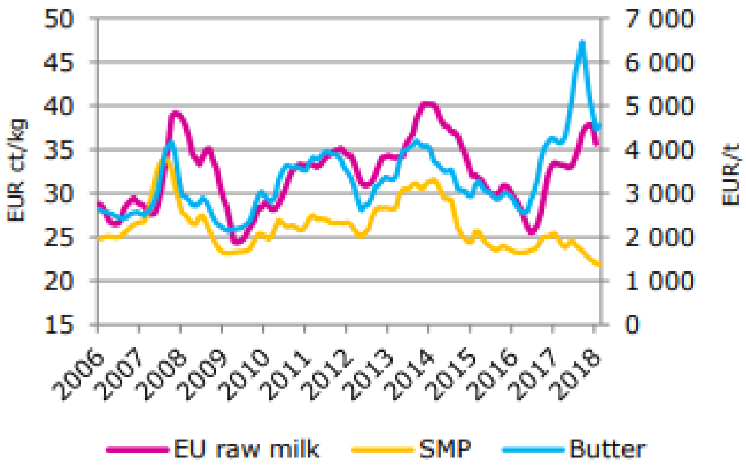

Figure 1. Monthly EU dairy prices (EUROPENA COMMSSION 2018a).

1.4 MILK PROCESSING

Milk production can involve different unit processes depending on the alternatives chose. In general the process implies the following steps (view Figure 2): reception and storage of raw milk; clarification and skimming process; homogenization; thermal treatment (pasteurization and/or Ultra High Temperature (UHT) treatment) and aseptic packaging.

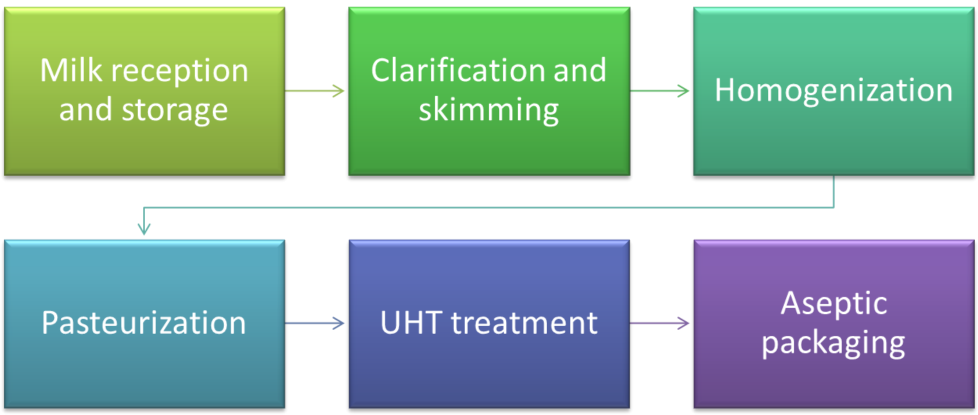

Figure 2. General milk processing.

Sometimes all these processes are continued by the recycling of some residues or by a wastewater treatment. There are other processes auxiliary to the milk production, for example, the cleaning after the storage tank is emptied or after UHT treatment is finished. These processes are usually known as Clean In Place (CIP).

1.4.1 Milk reception and storage

The first operation in a dairy plant is the reception of milk, which arrives in trucks from the farm. Afterwards milk is chilled and stored at temperatures lower than 5ºC up to 72 hours for preventing any deterioration. Usually when the truck arrives, the raw milk is tested, emptied, weighted and cooled. The tested milk is pumped from the dump tank to the storage tank through a filter and a chiller.

Storage tanks consist of a stainless steel inner shell with a layer of insulation or chilled water circulation to maintain the low temperatures during holding period, an outer jacket and necessary fittings for inspection control and cleaning. Also, agitation should be done to achieve an adequate homogeneous mixing but avoiding air incorporation (Sabikhi et al. 2012).

1.4.2 Clarification and skimming

The clarification is the action of removing solid impurities from milk and it is normally followed by skimming, which is the separation of skim milk and cream. In general, the clarifiers are quite similar to cream separators; allowing the processes to be done simultaneously through centrifugation, even if the removal of impurities or foreign matter from milk can also be done independently by straining, which requires filters. Clarification (through centrifugation forces) is more efficient than filtration because it removes leucocytes, udder tissues, other large cells and fine dirt; while filtration only removes the visible sediments to improve the aesthetic quality of milk (Sabikhi et al. 2012).

In terms of the process's outlets, clarification just releases milk (the particles removed remain on the clarifier until it is cleaned), while the separation provides the cream and the skim milk. Considering this, it is easy to perform simultaneously clarification and separation since it is just necessary to add a second outlet to the clarifier to transform it into a separator. Sometimes, after using a clarifier and a filter, an aeration tank is used to remove the occluded oxygen and volatile compounds that are not eliminated through clarification and could bring ulterior problems (Hospido, Moreira y Feijoo 2003).

After clarification and skimming, standardization allows to produce milk with a specified fat content by a recombination of skim milk and cream (Goff 2018).

1.4.3 Homogenization

Homogenization is an optative process that standardizes the size of the fat globules dispersed on milk to 1.0 µm in order to avoid the flocculation of globules and the cream accumulation at the top of the container, provoked by the variable size of the fat globules that could vary from 0.20 to 2.0 µm. Homogenization is a high-pressure process that forces the milk at a high velocity through a small orifice to break the fat globules and decrease its diameter.

This process could include a second step that implies sending the milk through a second valve at a lower the pressure than the previous one. With this methodology is achieved the regrouping of the globules and therefore a more stable emulsion(Goff 2018; COLLEGE OF AGRICULTURE AND LIFE SCIENCE n.d.).

1.4.4 Thermal treatment

The most common thermal treatments are pasteurization and UHT. Usually milk is pre-heated before skimming, increasing the temperature up to 65-70ºC or even can reach 80-95ºC in some industries that take the advantage of the UHT hot outlet to heat the incoming cold raw milk.

On one hand, pasteurization is one of the thermal treatments used for the inactivation of pathogens by applying heat temperatures below its boiling point. This process is made to prevent health problems and to improve the sensory quality of milk products. Minimum temperature and time requirements for milk pasteurization are based on thermal death time studies for the most heat resistant pathogens found in milk (Coxelliae burnettii and Listeria monocytogenes), also taking into account not overpass temperatures that would diminish nutritional quality of milk. Usually, pasteurization is a continuous process with high temperatures by heat exchangers (76ºC-78ºC) and short times such as 15 seconds, which allows time and energy saving. These conditions provide fresh tasting milk with good sensory quality, maintaining the vitamins and destroying the pathogens (Goff 2018 ; Ordóñez 1999).

On the other hand, UHT treatment consists in the elimination of microorganisms found in raw milk, sporulated or not, in order to achieve the microbiological stability of the product. Possibly, microorganisms are not removed completely but the ones that survive are not likely to grow during storage because of the temperature shock that they suffer; the UHT treatment implies rising the milk temperature up to 140-150ºC for 2-5 seconds and then, immediately be cooled until room temperature, which allows a reduction in time holding compared to pasteurization. During the thermal treatment, the nutritive quality decreases. Scientists demonstrate that treatments with higher temperatures and smaller holding times increase sporicidal effects, while chemical changes are not so noticeable. Therefore, UHT treatment significantly reduces its chemical changes compared to pasteurization. In spite of the minimization of chemical changes, the sensory or nutritional quality can change, for example, milk UHT is a product whiter than raw milk due to the protein denaturalization. Also, the UHT milk acquires a sulphur taste because of lactoglobulin denaturalization and the nutritive value decreases due to the lysine lost along the warm-up (Goff 2018 ; Ordóñez 1999).

1.4.5 Aseptic packaging

Aseptic packaging is the process where the milk previously sterilized, is filled in an aseptic contain under hygienic conditions; it is able to protect the product for long periods without the need of refrigeration (Goff 2018). Several packaged forms are used for aseptic packaging such as tetrabrik, which contains aluminium in order to protect the product from light and air.

Some products processed by UHT treatment are not aseptically packaged, which provides them with a longer shelf life at refrigeration temperatures compared to pasteurization, even though it does not provide a stable product at ambient temperatures (Goff 2018).

1.4.6 Clean in place

Cleaning in place (CIP) is the mechanical or chemical process necessary to clean the equipment before food processing, without dismantling the system and having secures barriers between food flow and cleaning chemicals in order to ensure quality requirements. The advantage of CIP is that, since there is very limited human interaction, more aggressive chemicals can be used and hence the time of cleaning is greatly reduced. This also leads to an increase in productivity, as the time previously required for cleaning tasks can now be dedicated to milk processing, hence CIP incurs in lower costs overall than traditional cleaning (Lelièvre et al. 2002).

In food industry, caustic soda (NaOH) and nitric acid (HNO_3) are the most common alkaline and acid detergents. Firstly, NaOH is used for breaking up protein deposits; followed by HNO3 that removes milk-stones and calcium deposits. Usually NaOH concentration is around 0.5-2% at temperatures up to 85ºC, whereas nitric acid is between 0.5-1.5% is at temperatures up to 50ºC (Lelièvre et al. 2002).

1.5 ENVIRONMENTAL PROBLEMS

Nowadays, the model of European dairy farm is becoming a huge structure where intensive cattle raising is a common practice. Cow numbers are decreasing over time, but the herd sizes are bigger since milk production is concentrated in larger farms, at least 40% of EU dairy cows are in herds of 50 heads minimum. This current model is driven by economic issues due to the necessity of modern technology that requires a great economic investment.

In the farming step, the environmental impacts can be assigned to several factors. For instance, the intensive production increases the use of chemical fertilizers, pesticides and feed additives that are starting to be greater than the ability of the soil to retain them. As a consequence, invasive herb grows easily and nitrate pollutes the water reserves. The increase in nitrate directly contributes to eutrophication (CENTRE FOR EUROPEAN AGRICULTURAL STUDIES and THE EUROPEAN FORUM ON NATURE CONSERVATION AND PASTORALISM 2000).

Moreover, the cow secretions emit high levels of both methane and ammonia to the air. With the intensive production model the ammonia emissions have increased but the methane emissions have decreased versus traditional farming practices.

Most of Nitrous Oxides (NOx) and Carbon Dioxide (CO_2) generation are an indirect impact caused by the energy usage during the milk treatment. After the milk is collected, it is treated industrially by modern techniques that require high quantities of energy, both electric and thermal, and use of chemicals for cleaning the structure once the process is completed.

CO_2 is a long-lived climate pollutant (up to 200 years atmospheric residence time) while methane is short-lived, but traps 84 times more heat than carbon dioxide over the first two decades after it is released into the air. Hence the methane emissions produced during the farming process are more dangerous for the environmental in a short period of time (CENTRE FOR EUROPEAN AGRICULTURAL STUDIES and THE EUROPEAN FORUM ON NATURE CONSERVATION AND PASTORALISM 2000).

1.6 LIFE CYCLE ASSESSMENT

The environmental problems from the dairy industry can be analysed using the Life Cycle Assessment (LCA) methodology. LCA is a tool that measures the potential environmental impact associated to products, processes or services, doing an analysis from “cradle to grave”, in order to try to mitigate then by implementing an eco-alternative (ISO 14040 2006).

The International Organization for Standardization (ISO) developed the ISO 14040 and ISO 14044 for the standardization of LCA methodology. This methodology can be used to identify different potential environmental improvements together with the optimization of the production process (ISO 14040 2006).

Figure 3 shows the LCA methodology according to, which consists on the following stages (ISO 14044 2006):

- Goal and scope definition: The goal presents the reasons to perform the study while the scope describes functional unit, system boundaries, description, assumptions, allocation procedures and level of detail.

- Life cycle inventory (LCI) analysis: It consists in the data collection of the material and energy that enters to the system along with the product, wastes and emissions generated. All the inflows and outflows are referenced to the functional unit. These data also constitute the input to the life cycle impact assessment .
- Life Cycle Impact Assessment (LCIA): In this step is evaluated the significance of the potential environmental impacts. During LCIA is done the transformation of the data collected into the potential environmental impact by using the characterization factors. This coefficient varies in value depending on the importance of the component for the environmental impact.
- Interpretation of results: During this step, the inventory analysis and impact assessment are combined in order to get a conclusion of the results. According to the norm ISO 14044, "the interpretation phase may involve the iterative process of reviewing and revising the scope of the LCA, as well as the nature and quality of the data collected consistent with the defined goal"(ISO 14044 2006).

There are numerous Life Cycle Assessment softwares than can be used to make the analysis easier, one of the most used is Gabi due to its updated database and ease to use.

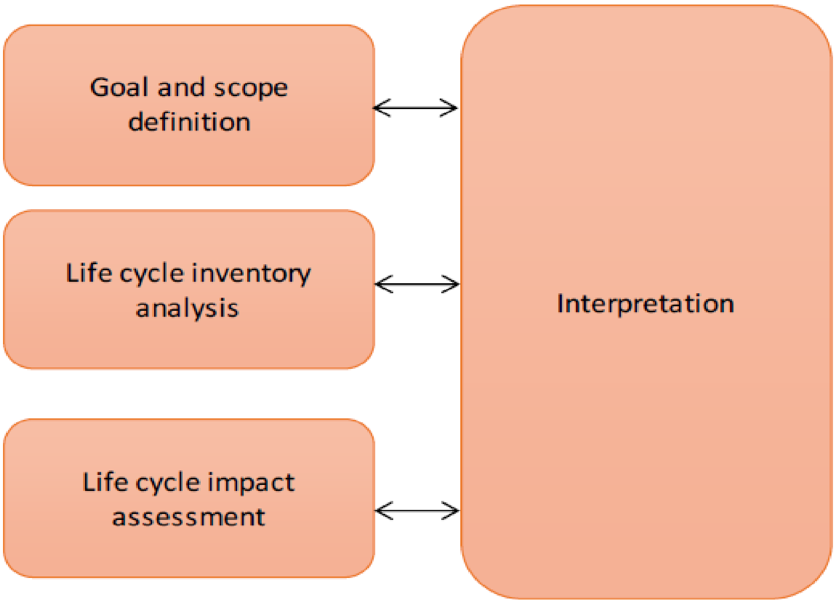

Figure 2. Interaction between the stages of a LCA (ISO 14040 2006).

1.7 OBJECTIVES

The principal goal of this study is to determine the environmental performance of milk production in order to identify the stages with the highest environmental impact and its contribution to the global using the Life Cycle Assessment methodology. Two different case studies were evaluated and compared in an attempt to better understanding the dairy industry as a whole. To accomplish the principal aim of this project the following specific objectives will be performed:

- Diagnosis of the current situation of the milk product and state of the art of previous LCA studies.
- Definition of the functional unit, system boundaries, assumptions and allocations of the study.
- Collection of the inventory based on the set of materials and energy inputs and outputs of the process.
- Modelling the two different case studies with LCA software Gabi 6 to obtain the environmental impact.
- Analyse and interpretation of the LCA results to get conclusions about the milk production.
- Comparison of both dairy industries in order to get results that are representative of the milk industry.

2. METHODOLOGY

2.1 GOAL

The goal of this study is to evaluate and compare the environmental impact of the milk processes on two dairy industry case studies. After the evaluation of these systems, different alternatives will be provided in order to mitigate their impact and improve the processes.

2.2 SCOPE

2.2.1 Functional unit

The functional unit (FU) is a reference unit which quantifies the performance of the production system (ISO 14040 2006); some common functional units used for milk production are 1 kg ECM (Energy Corrected Milk formula), 1 kg FPCM (Fat and Protein Corrected Milk formula) or 1L of packaged milk. This study will compare a factory from Spain and another from Portugal, in which is necessary a common FU in order to contrast both systems, selecting 1L of packaged milk as functional unit.

2.2.2 System boundaries and description

This study consists on a cradle to gate analysis of the Spanish and Portuguese dairy industry. Spanish production is based on two industries from Galicia that belong to the 8 main factories of Galician sector. In conjunction they produce 200 million annual liters of milk and 4.617.000 kg of cream each year (data from 2001) (Hospido, Moreira y Feijoo 2003). On the other hand, Portuguese industry is on state-of-art dairy factory that produces 519 miles tonnes in different dairy products (data from 2008). This plant produces cream, butter and UHT milk (including whole, semi-skimmed, skimmed) and cocoa milk. (González-García et al. 2013)

The system boundaries from both case studies are similar (view Figure 4 and 5), although they are not identical. Their boundaries start with the production of milk at farm and ends with the treatment of its residues. In both cases it is included the transport and process of packing materials (such as cardboard corrugated, tetrabrick and low-density polyethylene), fuel, electricity, chemicals for Clean In Place (CIP) and H_2O_2. Tetrabrik and cardboard recycling are included in both systems.

Both case studies also cover the cardboard and tetrabrik recyling process, and the Portuguese production includes in addition the plastic recycling and wastewater treatment processes. The delivery and consumption of products were excluded of the boundaries. Tetrabrik production details together with the recycling processes and wastewater treatment are in Annex 1.

The description of the Spanish milk processing (stages inside the rectangle, view Figure 4) starts with the reception of the trucks, which are emptied and cleaned with Clean in place (CIP) processes. Once the milk passes the quality control, it is stored at low temperatures.

Before pre-heating, milk is introduced in a filter and in a clarifier to exclude particles and impurities, and continues to an aeration tank to remove the volatile compounds. After the milk is pre-heated, it goes through the skimming and homogenisation processes. The next step is the pasteurization process, where it is heated up to 78ºC for 15s and then cooled down to 4–6ºC. The milk undergoes again the pre-heating and homogenization process.After that, the UHT treatment is performed with a rapid heating up to 132ºC followed by rapid cooling to room temperature, which destroys the bacteria by temperature shock.

Later, milk passes through an aseptic packaging process that consist in filling the tetrabrik with milk at aseptic conditions, where hydrogen peroxide (H_2O_2) is used as sterilising agent. After that, the peroxide will be removed by evaporation. It is then when the tetrabriks are packed in a cardboard box and film (low-density polyethylene). UHT, pasteurization and packaging facilities are cleaned in the CIP using NaOH (0.5%) and HNO_3 (1%).

The outputs of the process are the products and residues. For this case study, packaged milk is the main product, whereas cream is a by-product from the separation stage. The solid residues will be transported to external recycling stages. Figure 5 shows the flow diagram of the Portuguese case study for milk and dairy processing. The difference with the Spanish plant is that the Portuguese plant includes degasification before the homogenization, while it skips the clarification process and the aeration tank stage.

On the whole, the processes conditions only vary in the UHT treatment, achieving 145ºC during 2-3 seconds in Portugal, whereas in Spain the temperature reached 132ºC. Regarding the dairy products, the Portuguese plant also produces butter and Cocoa milk as by-product apart from the dairy products manufactured in the Spanish plant. The diagram in Figure 5 includes these two by-products, however it does not cover in detail the manufacturing process in order to make easier the visualization of the milk production processes.

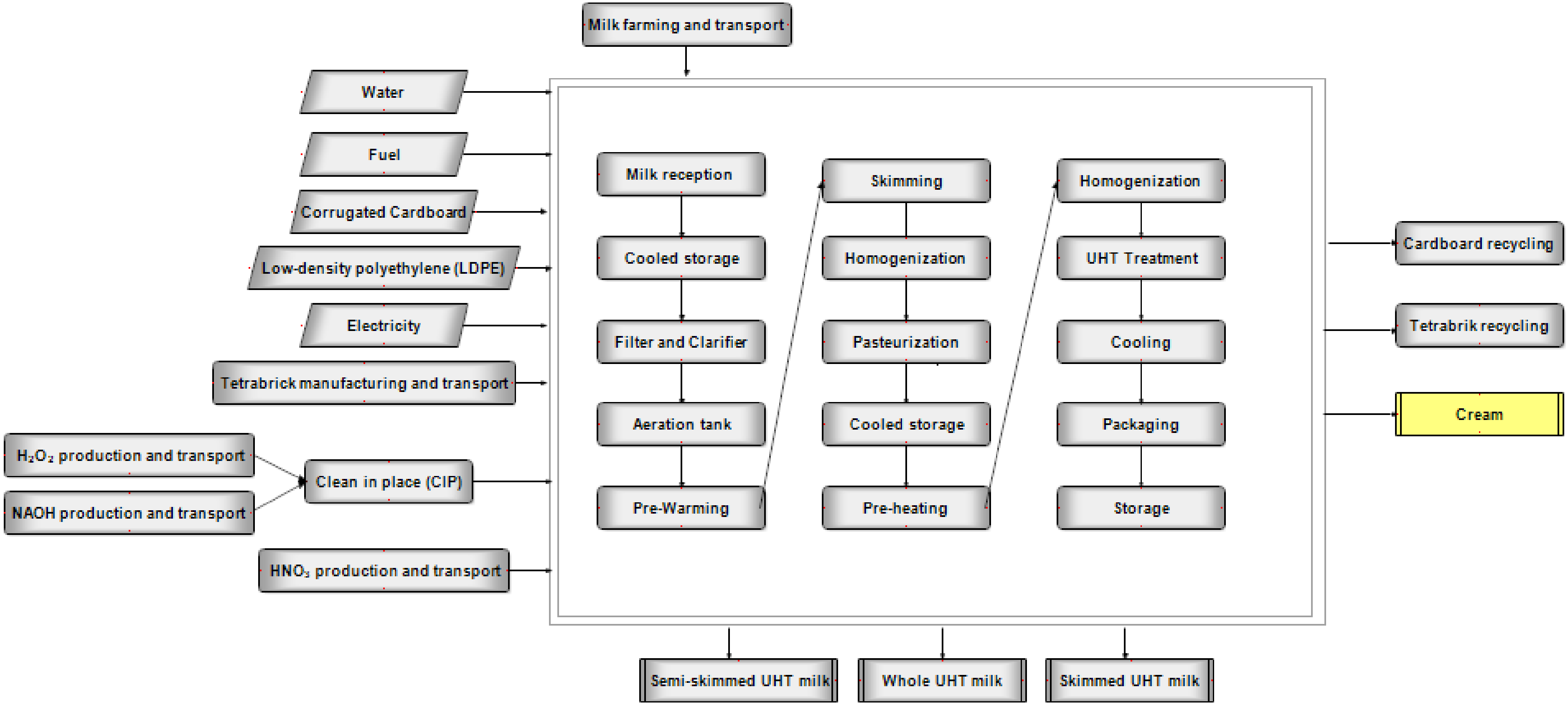

Figure 3. Flow Diagram from Spanish industry.

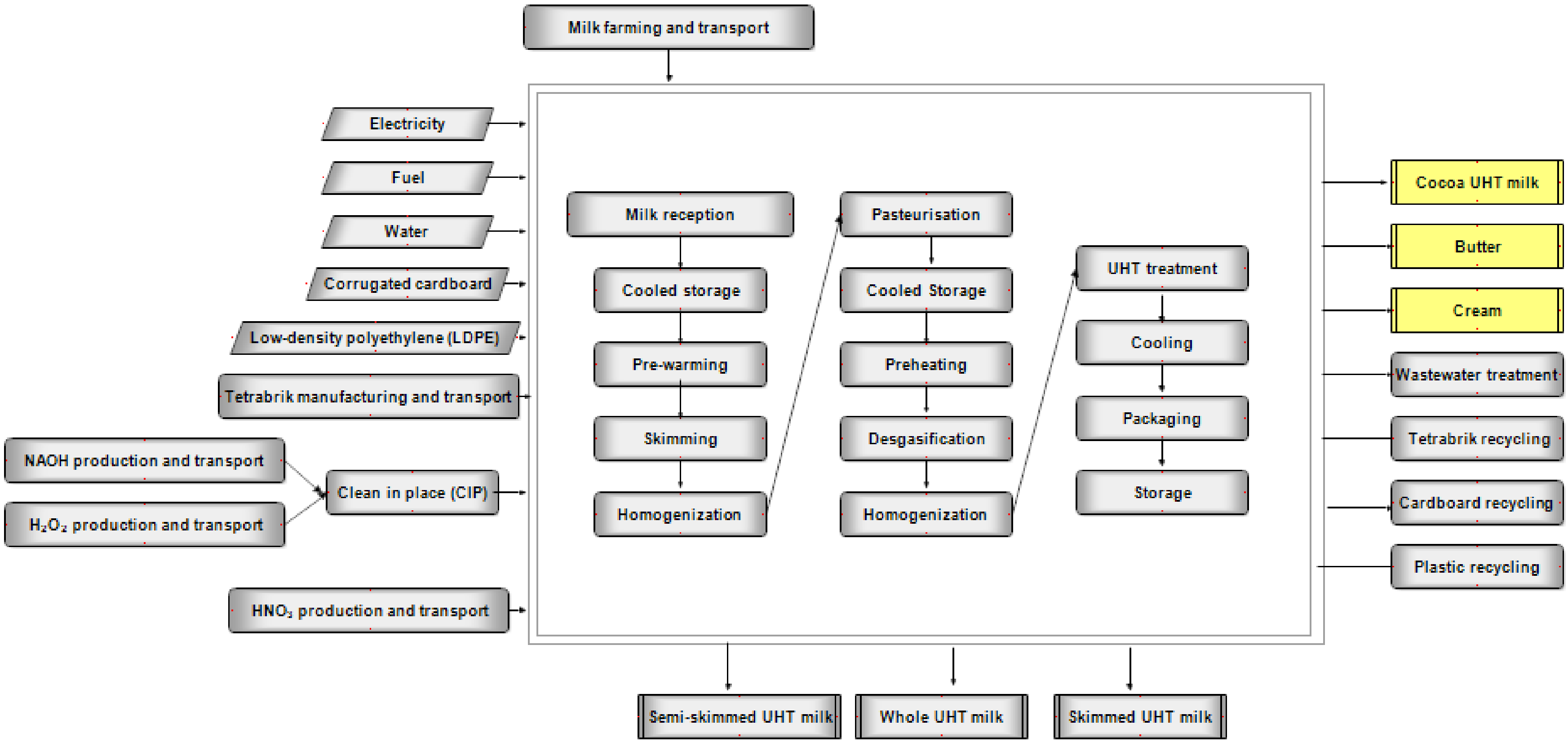

Figure 4. Flow Diagram of the Portuguese industry.

2.2.3 Assumptions

This LCA study uses some simplifications in order to make easier the modelling of the systems, and make assumptions when detail information is not available:

- Water specification was not available in the Spanish case study. Tap water is assumed along the whole system, given its easy availability and the fact that is likely going to be used for human consumption.
- The concentrations of CIP chemicals and the sterilization agent are assumed to be low (NaOH (0.5%), HNO_3 (1%), H_2O_2 (0.05%)), since higher concentration may cause corrosion in the facilities(Lelièvre et al. 2002) .
- The transport of the raw materials that were not implicitly said during the inventory, are assumed to be negligible.
- When not explicitly defined, it is considered that the residues are not being recycled or treated, and they are discarded to the landfill. The used oil filters that are discarded to landfill weren't considered due to its low quantity (1.0E-7 units).
- The close of tetrabrik is considered a cap of High-Density Polyethylene (HDPE) due to the lack of information from the tetrapack source (TETRAPACK n.d.).
- To simplify the plastic recycling phase, all the recyclable residues are assumed to be Low-Density polyethylene (LDPE). LDPE is the main raw material used in both case studies. It is assumed during the analysis that 80% of the necessary LPDE pellets for producing a new product can be sourced from recycled material (Toto 2017).
- It is also assumed during the analysis that 70% of the necessary cardboard fibers for producing a new product can be sourced from recycled material (RAJAPACK, 2015).
- Cream by-product from Spanish system is considered negligible, as it only represents 2.5% of the total milk production by year (Hospido, Moreira y Feijoo 2003).
- The average milk density considered for the calculations done during the study is 1.03Kg/L (González-García et al. 2013).
- Milk processing step is considered as a black box in both systems since no

information is available on the mass and energy flows within that stage. Only the milk processing input and output flows are considered.

- The Wastewater Treatment Plant (WWTP) in Portugal is included, however the inputs and outputs data were not disaggregated. Meanwhile, in the Spanish case study the WWTP needs an external stage apart from milk processing. As there was not sufficient information to include it in the system, the external WWTP for the Spanish industry is not modelled.

2.2.4 Allocation procedure

The systems that are analyzed during this study do not produce the same by-products; Spanish factory only includes the production of UHT milk (whole, semi-skimmed and skimmed) while Portuguese system also produces butter, cream and cocoa UHT milk, as summarized in Table 2. As a result, a mass allocation based in its annual production will be applied in order to compare UHT milk production from both sources.

Table 2. Mass allocation factors description.

Dairy product	Spain-Mass allocation (%)	Portugal-Mass allocation (%)
Total UHT milk	100	86.4
Whole UHT milk	71	7.9
Semi-skimmed UHT milk	18	60.2
Skimmed UHT milk	11	10.4
Cocoa milk	-	7.9
Cream	-	11.9
Butter	-	1.7

2.3 LIFE CYCLE INVENTORY

The foreground inventory data was collected from the literature by bibliography research, while the background process was taken from Gabi database. The same database has been use in order to obtain consistency in the results.

The foreground inventory of Spanish dairy was based on the work of Hospido et al. (2003), whereas the Portuguese data came from González-García et al. (2013). The inventories are exposed in Annex 2. On the other hand, the stage of milk production at farm is taken from Gabi database.

Moreover, the information of previous references was completed with the followed additional documents:

- Tetrabrik production inventory, needed to model Edge Tetrabrik (1000 ml), was obtained from Tetrapack company (INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH 2017).
- Recycling stages from different residues were model in Gabi software using the inventory from (Fullana et al. 2008). Plastic recycling is from "Monomaterial plastics" section, cardboard recycling is from "Brik, cardboard for beverages" while cardboard recycling is found in "Cardboard" section.
- Portuguese factory included in his inventory the transport from the different raw materials, while the ones from Spain had to be searched on different sources. Table 3 shows the distances covered and the truck capacity for the transport of the raw materials.

Table 3. Truck capacity and distance covered by each raw material.

Material	Truck capacity (t)	Distance (km)
Raw milk	16	200
NaOH	16	450
HNO_3	16	560
H_2O_2	16	340
Packaging materials	16	600

2.4 LIFE CYCLE IMPACT ASSESSMENT

In the Life Cycle Impact Assessment (LCIA) has been used CML 2001-jan.2016 method, considering the followed environmental impacts studied.

- CML2001 - Jan. 2016, Acidification Potential (AP) [kg SO2-Equiv.]
- CML2001 - Jan. 2016, Eutrophication Potential (EP) [kg Phosphate-Equiv.]
- CML2001 - Jan. 2016, Freshwater Aquatic Ecotoxicity Pot. (FAETP) [kg DCB-Equiv.]
- CML2001 - Jan. 2016, Global Warming Potential (GWP) [kg CO2-Equiv.]
- CML2001 - Jan. 2016, Human Toxicity Potential (HTP) [kg DCB-Equiv.]
- CML2001 - Jan. 2016, Marine Aquatic Ecotoxicity Pot. (MAETP) [kg DCB-Equiv.]

The method CML 2001-Jan. 2016 was selected to be consistent with the principal sources (González-García et al. 2013) (Hospido, Moreira y Feijoo 2003). The impacts Eutrophication, Acidification and Global Warming Potential were also taken into account as the principal sources show the impact is not neglectable. Moreover, Freshwater Aquatic Ecotoxicity Pot. (FAETP), Human Toxicity Potential (HTP) and Marine Aquatic Ecotoxicity Pot. (MAETP) impacts were selected because they were identified as significant impacts in milk farming due to the use of fertilizers in the soil.

3. RESULTS AND DISCUSSION

3.1 ENVIRONMENTAL IMPACTS OF SPANISH MILK PRODUCTION

The environmental impacts data presented in Table 4 comes from the production of three different types of UHT milk: whole, semi-skimmed and skimmed milk. In the Annex 3, it is shown in detail the impact associated to each stage for both systems.

Table 4. Environmental Impacts from Spanish Factory.

Enviromental Impacts	Units	Total system
Acidification Potential (AP)	[kg SO_2-Equiv.]	2.07E-02
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	9.48E-03
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3.92E-02
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	1.10E+00
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	1.08E-01
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6.17E+01

Marine Marine Aquatic Ecotoxicity Potential (MAETP) and Global Warming Potential (GWP) are the highest impacts generated by the manufacturing and transport of the tetrabrik and the milk farming and transport. Marine Aquatic Ecotoxicity Potential (MAETP) is an impact that measures toxicity, giving more importance to the pollutants that are emitted to water; in particular water emissions of Nickel contribute 41% of this total impact.

Global Warming Potential(GWP) is linked to carbon dioxide emissions (65%) and Nitrous Oxides emissions (29%). Carbon dioxide emissions are associated to the milk processing at the farm (mainly on terms on energy consumption) while the methane and Nitrous Oxides are produced by the animal's secretions (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS 2013). Human Toxicity Potential (HTP) is related to the emission of aromatic hydrocarbons and metals. Freshwater Aquatic Ecotoxicity Potential (FAETP) is directly linked to the emission to fresh water, in fact, 92% of FAETP is due to the emissions of Nickel.

Nickel is an elemental compound for plant growing but it is just needed in low quantities. It can be found high quantities of nickel in fertilizers obtained from animal manure or sewage sludge, although can also be found in irrigation waters. Although all can contribute, due to the quantity found in fresh water, fertilizers from animal manure are the likely source (Buechel 2018).MAETP and FAETP impacts are greatly negatively affected by the presence of Nickel in water. On the other hand, in some impacts (such as HTP and FAETP, but also MAETP) finding certain amounts of metals leaked to the agricultural soil such as Chromium, Nickel, Lead or Zinc, contributes with a small positive impact.

The 82% of the Acidification Potential (AP) impact is produced by ammonia emissions from cow secretions along with Nitrogen Oxides emissions (16%). The smallest impact is the Eutrophication Potential (EP), which is associated to ammonia, nitrogen organic and phosphate emissions. Ammonia represents the 39% and nitrogen organic emissions the 15% of total EP impact.

Milk farming and transport is the stage that affects more to the categories of EP, AP, FAETP and GWP impact by 90%, 95%, 97% and 94%, respectively. HTP (57%) is predominantly influenced by the manufacturing and transport of tetrabrik due to the aluminium usage as raw material. On the other hand, MAETP is contributed by the last two processes equally, being affected by tetrabrik manufacturing in 48% and milk farming by 47%. Milk farming and not the transport itself is to blame for most of this impact, due to the ammonia and methane emissions from the cow secretions and fertilizers used in the fields.

Annex 4 shows in detail the impacts including the ones generated by milk farming transport while Figure 6 excludes this stage in order to analyse the rest of processes in more detail.

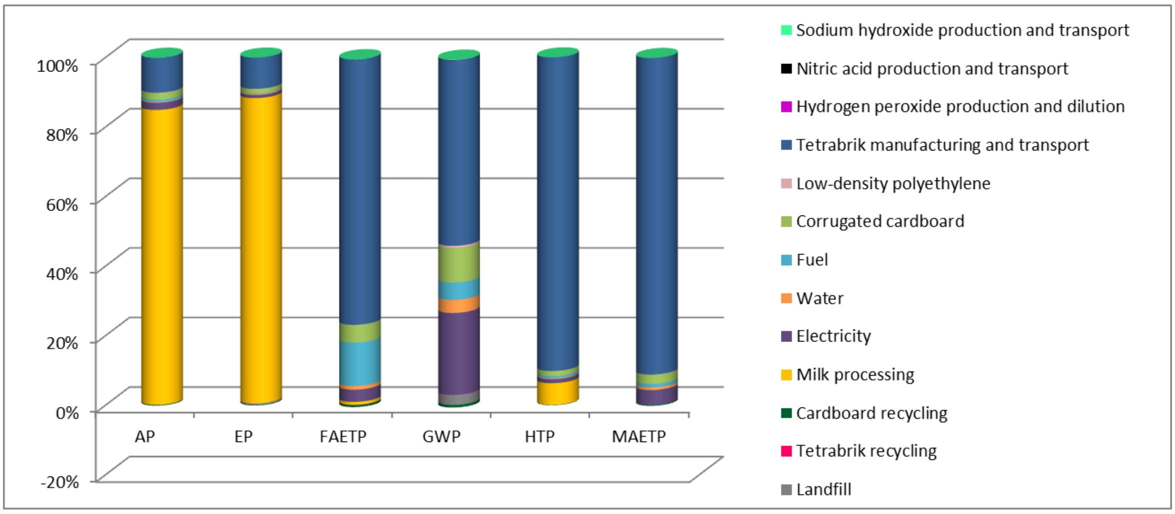

Figure 5. Environmental Impacts excluding Milk Transport.

Looking separately at each impact from left to right and the processes that are affecting them most, 82% of Acidification (AP) and 88% of Eutrophication Potential (EP) impacts are generated by milk processing. Furthermore, 73.1 % of FAETP is dominated by tetrabrik manufacturing and transport while 12% of the impact is due to fuel and 5% because of corrugated cardboard usage. In the Spanish system, the environmental impact generated by tetrabrik manufacturing and transport is mostly associated to the production, not to the transportation. Within tetrabrik manufacturing, the usage of High-Density Polyethylene (HDPE) as a raw material is responsible for the 71 % of FAETP impact.

Tetrabrik manufacturing and transport generates 51% of Global Warming Potential (GWP) along with electricity, which creates 22% of this impact. The rest of GWP is influenced by the use of corrugated cardboard (10%), fuel (5%) and tap water (4%). Within tetrabrik manufacturing, aluminium contributes by 37% in GWP while 31% is due to Low-Density Polyethylene (LDPE). In addition, 84% of Human Toxicity Potential and 85% of MAETP are generated by the aluminium used in tetrabrik production stage.

In summary, tetrabrik manufacturing and transport is the first major influential stage in the environmental impacts, once milk farming is taken out of the analysis. The rest of the stages do not contribute significantly on the environmental impacts.

3.2 ENVIRONMENTAL IMPACTS OF PORTUGUESE MILK PRODUCTION

The Portuguese factory produces cream, butter, UHT milk (whole, semi-skimmed, skimmed) and cocoa milk. Table 5 shows the environmental impacts for the Portuguese system.

Table 5. Environmental Impact of Portuguese milk Production.

Enviromental Impacts	Units	Total system
Acidification Potential (AP)	[kg SO_2-Equiv.]	1.98E-02
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	9.60E-03
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	4.04E-02
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	1.18E+00
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	1.25E-01
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	8.42E+01

Marine Aquatic Ecotoxicity Potential (MAETP) and Global Warming Potential (GWP) are the highest impacts identified in the Portuguese dairy industry. MAETP impact is associated to toxicity on water, and similarly to the Spanish system, nickel content in water contributes 30% of its total impact. On the other hand, Global Warming Potential is related with CO_2 and Nitrous Oxides emissions, being 69% and 27% respectively its contribution to the impact.

Human Toxicity Potential (HTP) and Freshwater Aquatic Impact Potential (FAETP) are linked to aromatic hydrocarbons and a high variety of heavy metals content, being 90% of FAETP impact due to again the nickel content in fresh water attributed to the use of fertilisers from animal manure (Buechel 2018). The smallest impacts are Acidification (AP) and Eutrophication Potential (EP), 86% of AP is provoked by ammonia emissions to the air while 39% of NH_3 along with 13% of nitrogen organics emissions contributes to EP impact. Both impacts can be related back to cow secretions because of its high contribution of ammonia (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS 2013).

Similarly to the Spanish system, milk farming and transport is the stage that influences the most in the environmental impacts, contributing to AP, EP, FAETP and GWP by 95%, 94%, 96% and 88% respectively. The high contributing of this stage is mainly due to the ammonia and methane emissions from cow secretions together with the fertilisers from animal manure, not because of the transport of the milk to the dairy industry. It is a key stage in the majority of environmental impacts, except for HTP and MAETP. On the other side, Human Toxicity Potential (HTP) impact is mainly influenced by tetrabrik manufacturing and transport

(62%) while Marine Aquatic Ecotoxicity Potential (MAETP) is affected by multiply stages: tetrabrik manufacturing (45%), milk farming (34 %) and electricity (17%).

The Annex 5 shows the influence of each stage on the different impacts including milk farming and transport while Figure 7 excludes this stage to be able to analyse the rest in more detail.

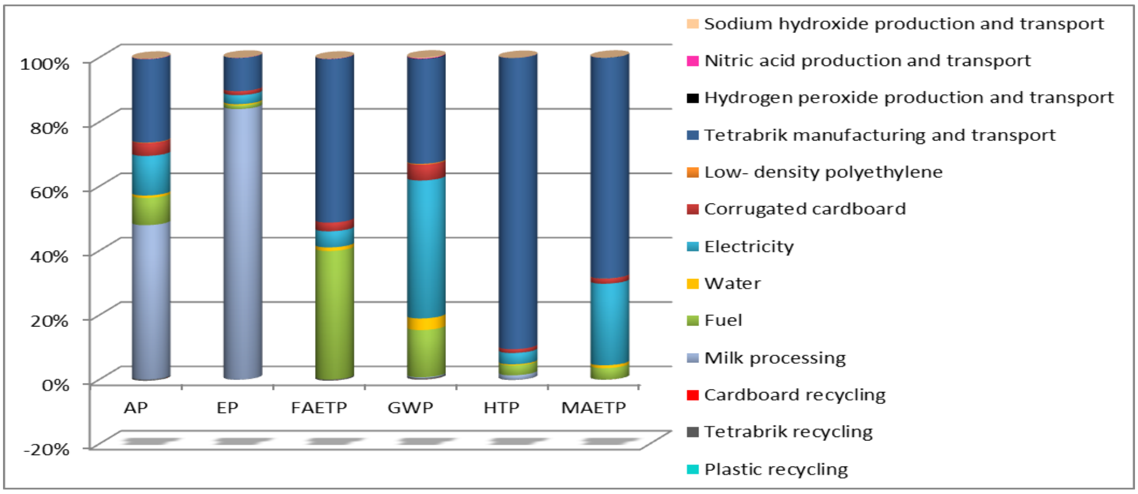

Figure 6. Environmental Impact excluding milk Transport.

Looking separately at each impact from left to right and the processes that are affecting them most, 47% to the total Acidification Potential (AP) impact can be attributed to the milk processing. This figure rises to 85% when looking at the Eutrophication Potential (EP) impact. Apart from milk processing, it can be observed that tetrabrik manufacturing and transport generates 26% of AP and 10% of EP. The rest of stages affecting the AP impact, from highest to lowest contribution are: electricity, fuel and corrugated cardboard.

Freshwater Aquatic Ecotoxicity Potential (FAETP) is mostly affected by tetrabrik manufacturing and transport but also fuel, in a 51% and 40% respectively. Within tetrabrik production, 71% of FAETP is due to High-Density Polyethylene (HDPE) usage to close the tetrabrik. Global Warming Potential (GWP) is generated by multiply stages, their mainly contributors are electricity (41%) and tetrabrik manufacturing and transport (32%), followed by fuel (14%), corrugated cardboard (5%) and tap water (4%). In tetrabrik manufacturing, stands out the aluminium (37%) and low-density polyethylene (31%) contribution.

Lastly, 90 % of Human Toxicity Potential (HTP) and 69% of Marine Aquatic Ecotoxicity

Potential (MAETP) are generated by tetrabrick manufacturing and transport stage due to the aluminium use. In HTP and MAETP, 94% of the total impact produced in tetrabrik manufacturing stage is caused by this raw material. Moreover, 25 % of total MAETP is derived from electricity.

To sum up, tetrabrik manufacturing and transport is the stage that produces the higher amount of impact when milk farming and transport are excluded from the system; although it only predominates clearly in HTP and MAETP. The rest of stages not listed above do not contribute significantly on the potential environmental impacts.

3.3 COMPARISON BETWEEN MILK PRODUCTION IN PORTUGAL AND SPAIN

To compare the UHT milk production in the Spanish and Portuguese plant, the cocoa milk, butter and cream were excluded for the Portuguese system, using an allocation factor of 78.5% (view Table 2).

Table 6 shows the total milk production from Spanish and Portuguese system. The total potential environmental impacts changes once the mass allocation is done but the proportions of the different processes contribution don't change, being possible compare Figure 6 and 7 as two milk production systems.

Table 6. Comparison of Spanish and Portuguese milk production.

Enviromental Impacts	Units	Total milk production from Spain	Total milk production from Portugal
Acidification Potential (AP)	[kg SO_2-Equiv.]	2.07E-02	1.55E-02
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	9.48E-03	7.54E-03
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3.92E-02	3.17E-02
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	1.10E+00	9.26E-01
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	1.08E-01	9.81E-02
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6.17E+01	6.61E+01

As can be seen in Table 6, the environmental impacts from both milk productions are similar, having the Portuguese plant a lower impact in all the categories except in MAETP.

In MAETP, the proportion of nickel in freshwater associated to Portugal (30%) is lower than in Spain (41%). The smaller proportion of Nickel content can be associated to the use of fertilizers with less nickel, but could also be the case that the quantity of Nickel is actually similar but there are other metals and hydrocarbons present that reduces the overall percentage of Nickel contribution to the impact. GWP impact from both factories is similar, contributing CO_2 emissions in Spanish system 65% and in Portuguese systemexa 69%, while Nitrous Oxides contributes in Spanish dairy 29% and in Portugal 27%.

HTP from both systems are almost identical. Nickel content contribution for FAETP impact is similar in both systems, being 92% in Portugal and 90% in Spain. AP and EP impacts are similar in both systems too. Looking at AP, the contribution of ammonia emissions is 82% in the Spanish system while is 86% in Portuguese i. Meanwhile, EP impact in both systems is affected by 39% of ammonia emissions and 15% by nitrogen organics. Previously, in Figures 6 and 7, the impacts associated with each stage (once milk farming and transport were excluded) were shown. Looking now at both simultaneously, some parallelism can be seen.

Tetrabrick manufacturing and transport is the main contribution for most environmental impact in both industries. However, the Portuguese system is more greatly affected by other stages, the greater electricity and fuel influence versus the Spanish system causes a relative reduction of the amount of impact (in percentage) created by tetrabrik manufacturing and transport.

To explain tetrabrik manufacturing in more detail, Table 7 shows each of the raw materials impact distribution (rounding up the number to the closest figure for better representation). The distribution followed in both systems is almost identical since the tetrabrik quantity necessary was nearly the same (0.0306 kg in Portuguese system, 0.0313 kg in the Spanish system). This support the proposed explanation for the lower tetrabrick manufacturing impact in the Portuguese system: it is not actually the impact decreases but its relative importance in the overall impact, since the electricity and fuel contributions are indeed higher than in the Spanish industry. The full details of environmental impact quantities of both systems are in Annex 3 and 6.

Table 7. Distribution of impacts in Tetrabrik manufacturing stage.

Enviromental Impacts	Aluminium (%)	High-density polyethylene (%)	Low-density polyethylene (%)	Liquid packaging (%)
Acidification Potential (AP)	**31**	9	20	**40**
Eutrophication Potential (EP)	8	3	5	**84**
Freshwater Aquatic Ecotoxicity Potential (FAETP)	12	**71**	1	16
Global Waming Potential (GWP)	**36**	15	**30**	19
Human Toxicity Potential (HTP)	**94**	4	0	2
Marine Aquatic Ecotoxicity Potential (MAETP)	**93**	1	2	4

Coming back to the rest of the stages involved in each impact, AP in the Spanish factory is dominated by the milk processing stage, it also contributes in the Portuguese production by a 47%. EP is also mainly affected by the milk processing stage in both systems (88% in Spanish system and 85% in Portugal system). FAETP is mainly constituted in both systems by the same stages, tetrabrik manufacturing and fuel; but the proportions are different. The tetrabrik stage is clearly predominant in Spanish system, where the contribution of fuel is 12%. Meanwhile, 51% of tetrabrik manufacturaring and 40% of fuel contributes to FAETP impact in Portuguese system.

The GWP impact is affected by tetrabrik manufacturing and electricity, with electricity contributing in Spanish production a 22% and in Portugal 32%. Lastly, HTP is dominated by tetrabrik manufacturing and transport in both systems. In the Spanish system this stage also predominates in MAETP.

As mentioned before, for both systems, tetrabrik manufacturing and transport is the second stage that more contributes to create environmental impacts, after milk farming and transport.

3.4 GLOBAL WARMING POTENTIAL OF DIFFERENT TYPES OF MILK

The production of each type of milk in both industries is shown in Table 8. The annual production of different types of milk in each country depends on the market demand. In this sense, 63% of milk consumers prefer whole milk in Spain (data from 2001)(Hospido, Moreira y Feijoo 2003), while 70% of milk consumers in Portugal drinks semi-skimmed milk (data from 2008) (González-García et al. 2013).

Table 8. Milk production from the two factories study.

Dairy products	Spanish Factory (L/year)	Portuguese Factory (L/year)
Whole UHT milk	142000	4517
Semi-skimmed UHT milk	36000	34597
Skimmed UHT milk	22000	6013
Total milk UHT production	**200000**	**45127**

Nowadays, Global Warming Potential (GWP) is one of the impacts that are more studied due to the importance of measuring greenhouse effect . For this reason, the contribution to GWP of each type of milk needs to be studied in more detail.

Figure 8 show the breakdown of the GWP impact for the different types of milk produced in the Spanish and Portuguese industry. This breakdown has been calculated using the allocation factors stated in Table 2, that show the split of the production in each factory.

The GWP impact from Spanish system is highly influenced by whole UHT milk (0.78 kg CO_2-equiv), whereas semi-skimmed milk is the type that affects more the GWP in the Portugal factory (0.71 kg CO_2-equiv).

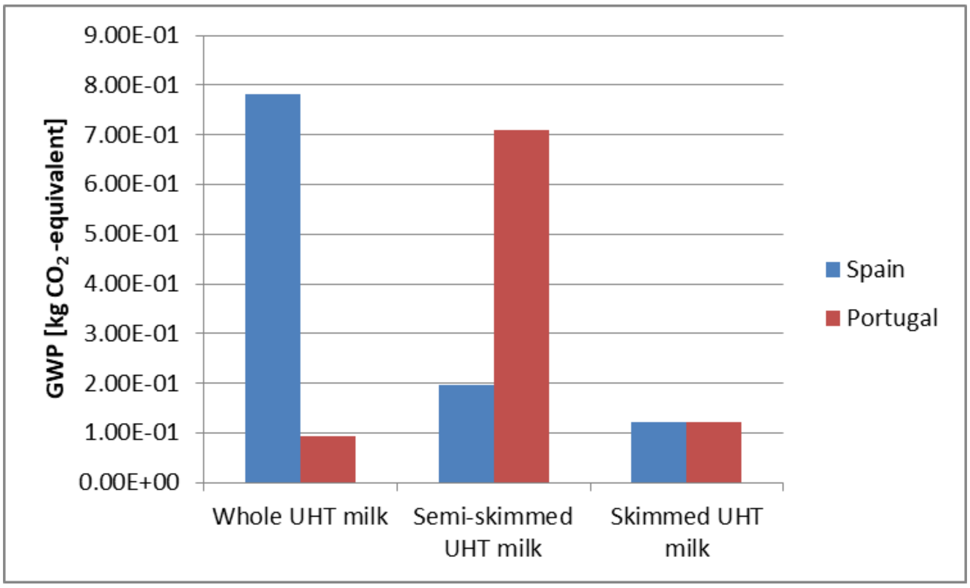

Figure 7. Global Warming Potential associated to each kind of UHT milk.

4. CONCLUSSIONS

This research project analysed the potential environmental impacts generated in the production of 1 L of packaged milk. The comparison of the results of both case studies showed that the main environmental impacts were the milk farming and the tetrabrik manufacturing.

Regarding milk farming, the main contributors to the impacts were the fertilisers from animal manure because of its high nickel content, as well as the emission of ammonia and methane from cow secretions and CO_2 emissions associated to the energy consumption at the farm.

To reduce the impact of milk farming, chemical fertilizers with low content in nickel can be used. Cow secretions can be stored and processed in order to transform the methane in biogas, obtaining energy and at the same time preventing methane emissions to the air. Also, ammonia emissions can be reduced by diets in low crude protein. CO_2 emissions can be diminished by using fuels and energy from renewable sources together with the use of equipments with higher efficiency, reducing the amount of energy used.

On the other hand, the impact of tetrabrik manufacturing is mainly due to the toxic substances emitted to the environment linked to the use of aluminium. In order to reduce the total environment impact, pyrolisis can be used to recycle the material. Another alternative is to replace the tetrabrik with other aluminium-free option, although this may lead to the need of maintaining the milk at refrigeration temperatures.

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6. ANNEX

6.1 ANNEX 1: TETRABRIK PRODUCTION, RECYCLING AND WASTEWATER TREATMENT

6.1.1 Tetrabrik production

The packaging manufactured during this study is aseptic Tetrabrik-Edge (1000ml) from Tetrapack company, which is composed by the materials listed in Table 9.

Table 9. Materials to manufacture tetrabrik-Edge (1000ml)

Materials	Quantity	Units
Liquid Packaging board	0.0216	Kg
LDPE	0.005	Kg
HDPE	0.003	Kg
Aluminium	0.0014	Kg

Tetrabrik is composed by layers of different components. Liquid packaging board is the main component, which is a material derived from cardboard that provides stability and strength to the container. Low-Density Polyethylene (LDPE) is used for varies aims. It is applied as adhesive between other layers and, when covering the exterior, it is also used as a protector against moisture.

To protect the container from light and air, an aluminium layer is incorporated to the tetrabrik. This allows the storage of the product at room temperature. Lastly, High-Density Polyethylene (HDPE) material is used to close the tetrabrik (Tetra Pak International S.A. 1999) .

6.1.2 Recycling

The residues from the milk processing can go to recycling plants, which meet the characteristics shown in Table 10. The cardboard, tetrabrik and plastic recycling processes are described below.

Table 10. Characteristics of Recycling process.

Recycling process	Effiency	Total Thermal Energy consume (MJ)	Total Electrical Energy consume (MJ)
Cardboard	85%	9.64	2.84
Tetrabrik	75%	1	0.5
Plastic	56%	1.454	1.7

6.1.2.1 Cardboard recycling

Cardboard recycling consists in the trituration of residues mixed with water in order to separate and obtain cardboard fibers, which is the final product of the process. All the residues from this stage are discarded to the landfill.

6.1.2.2 Tetrabrik recycling

Tetrabrik recycling can be made by separating the residues in paper, aluminium and polyethylene or by proceeding with the materials mixed. In this case, the described process follows the recycling with materials separated. If the mixed material method is used, the products obtained would have less viability in the market.

The process consists in the separation of cellulose fibers from polyethylene and aluminium by rubbing, obtaining as final product cardboard fibers. In this case the separation of polyethylene and aluminium wasn't taken into account (this is usually done by pyrolisis). All the residues from the complete process are discarded to the landfill.

6.1.2.3 Plastic recycling

Low-Density Polyethylene (LDPE) is the main plastic recycled in the process. The LDPE recycling starts with the crushing of the residues continued by a washing process and a clarification for removing impurities. Afterwards, the resulting plastic passes through an extrusion in order to obtain plastic pellets as final product. All the residues from the complete process are discarded to the landfill.

6.1.3 Wastewater treatment

The Wastewater Treatment Plant (WWTP) included in this study follows the classic scheme of this type of industries. The WWTP consists in a pre-treatment that removes the elements of bigger sizes from the wastewater, followed by a primary treatment with a clarifier for the separation of suspended particles; and a biologic treatment with a secondary clarifier to eliminate the contaminants presented in the water. Afterwards, the sludge produced during the previous stages suffers a dewatering, while the clean water can be directly discharged to the environment or it can pass through a tertiary treatment in order to be reused.

6.2 ANNEX 2: INVENTORIES

Table 11. Inventory in which is based Spanish dairy (Hospido, Moreira y Feijoo 2003).

Materials and energy	Quantity	Units
Raw milk	1.15E+00	L
Tap water	4.41E+00	L
Corrugated cardboard	1.68E-02	Kg
Film LDPE	1.83E-04	Kg
Tetrabrik	3.13E-02	Kg
H_2O_2	6.90E-04	Kg
HNO_3	5.30E-04	Kg
NaOH	1.69E-03	Kg
Fuel oil	7.07E-03	Kg
Electricity	4.63E+01	Wh
Products		
Packaged milk	1.00E+00	L
Cream	2.23E-02	Kg
Waste for recycling		
Cardboard	3.05E-04	Kg
Tetrabrik	9.30E-05	Kg
Waste for landfill		
Combustion waste	2.16E-03	Kg
Oil	4.00E-05	Kg
Oil filters	1.00E-07	units
Air emissions		
SO_2	1.90E-04	Kg
NO_2	3.47E-03	Kg
Combustion waste	3.82E-03	Kg
Water emissions		
Wastewater	1.82E-01	L
COD	2.00E-02	g/L
TSS	2.20E-02	g/L
Soil emissions		
Sludge	5.30E-02	L
Fe	1.30E-02	g/L
Cr	3.77E-04	g/L
Hg	8.00E-06	g/L
Zn	2.91E-03	g/L

Table 12. Inventory in which is based Portuguese dairy (González-García et al. 2013).

Materials and energy	Quantity	Units
Raw milk	1.19E+00	Kg
Tap water	8.63E+00	Kg
H_2O_2	2.77E-03	Kg
HNO_3	4.51E-03	Kg
NaOH	1.19E-02	Kg
Corrugated cardboard	1.68E-02	Kg
Film LDPE	1.83E-04	Kg
Tetrabrik	3.06E-02	Kg
Fuel oil	4.25E-02	Kg
Electricity	1.48E+02	Wh
Products		
Packaged milk	1.00E+00	L
Cream	1.02E-01	Kg
Butter	2.03E-02	Kg
Waste for recycling		
Plastic	1.17E-05	Kg
Tetrabrik	1.53E-03	Kg
Cardboard	1.31E-03	Kg
Air emissions		
Carbon monoxide	6.22E-03	Kg
Carbon dioxide	4.76E-01	Kg
Particulates	5.00E-04	Kg
Sulfur dioxide	2.87E-03	Kg
Nitrogen oxides	9.53E-04	Kg
Dinitrogen monoxide	1.01E-06	Kg
Methane	5.24E-06	Kg
Water emissions		
COD	3.05E-04	kg
Suspended solids	2.03E-04	Kg
Nitrogen total	6.56E-04	Kg
Phosphorus	2.01E-05	Kg
BOD	1.01E-04	Kg
Oils	6.04E-05	Kg

6.3 ANNEX 3: POTENTIAL ENVIRONMENTAL IMPACTS FROM SPANISH MILK PRODUCTION

Table 13. Potential environmental impacts from Spanish milk production (I)

Enviromental Impacts	Units	Total system	Milk farming and transport	NaOH production and transport	HNO_3 production and transport	H_2O_2 production and transport	Tetrabrik manufacturing and transport	Low-density polyethylene (LDPE)	Corrugated cardboard
Acidification Potential (AP)	[kg SO_2-Equiv.]	2,07E-02	1,86E-02	4,67E-07	8,39E-08	6,29E-08	2,06E-04	1,46E-06	3,96E-05
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	9,48E-03	8,97E-03	6,53E-08	2,59E-08	1,52E-08	4,61E-05	9,21E-08	6,70E-06
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3,92E-02	3,82E-02	6,25E-07	1,29E-07	1,02E-07	7,31E-04	2,03E-07	4,84E-05
Global Waming Potential (GWP)	[kg CO2-Equiv.]	1,10E+00	1,03E+00	7,98E-05	3,29E-05	1,94E-05	3,58E-02	3,92E-04	6,68E-03
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	1,08E-01	3,92E-02	4,11E-06	1,06E-06	8,28E-07	6,19E-02	2,43E-06	1,01E-03
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6,17E+01	2,87E+01	1,48E-03	4,01E-04	2,93E-04	3,02E+01	1,92E-02	8,73E-01

Table 14. Potential environmental impacts from Spanish milk production (II)

Enviromental Impacts	Units	Electricity	Fuel	Water	Milk processing	Cardboard recycling	Tetrabrick recycling	Landfill
Acidification Potential (AP)	[kg SO_2-Equiv.]	4,23E-05	1,40E-05	3,75E-06	1,74E-03	-3,80E-06	-1,59E-07	2,57E-07
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	4,68E-06	1,03E-06	1,09E-06	4,51E-04	-7,22E-07	-7,91E-09	2,10E-06
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3,37E-05	1,20E-04	1,01E-05	7,84E-06	-5,62E-06	-2,67E-07	3,46E-07
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	1,58E-02	3,35E-03	2,52E-03		-4,94E-04	2,73E-05	1,92E-03
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	8,12E-04	4,39E-04	1,45E-04	4,28E-03	-5,28E-05	-3,99E-06	2,01E-06
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	1,41E+00	3,28E-01	2,50E-01	1,20E-03	-8,01E-02	-3,42E-03	8,08E-03

6.4 ANNEX 4: SPANISH SYSTEM INCLUDING MILK FARM AND TRANSPORT STAGE

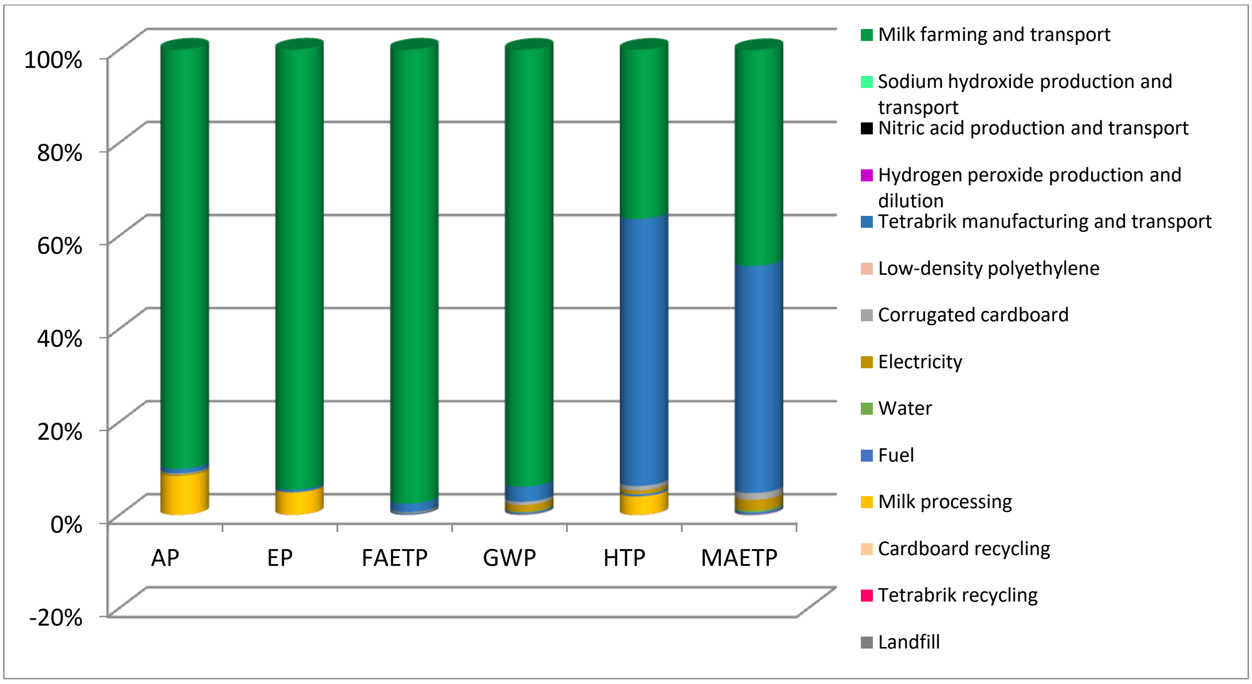

Figure 8. Spanish system with Milk farm and transport stage included.

6.5 ANNEX 5: PORTUGUESE SYSTEM INCLUDING MILK FARM AND TRANSPORT STAGE

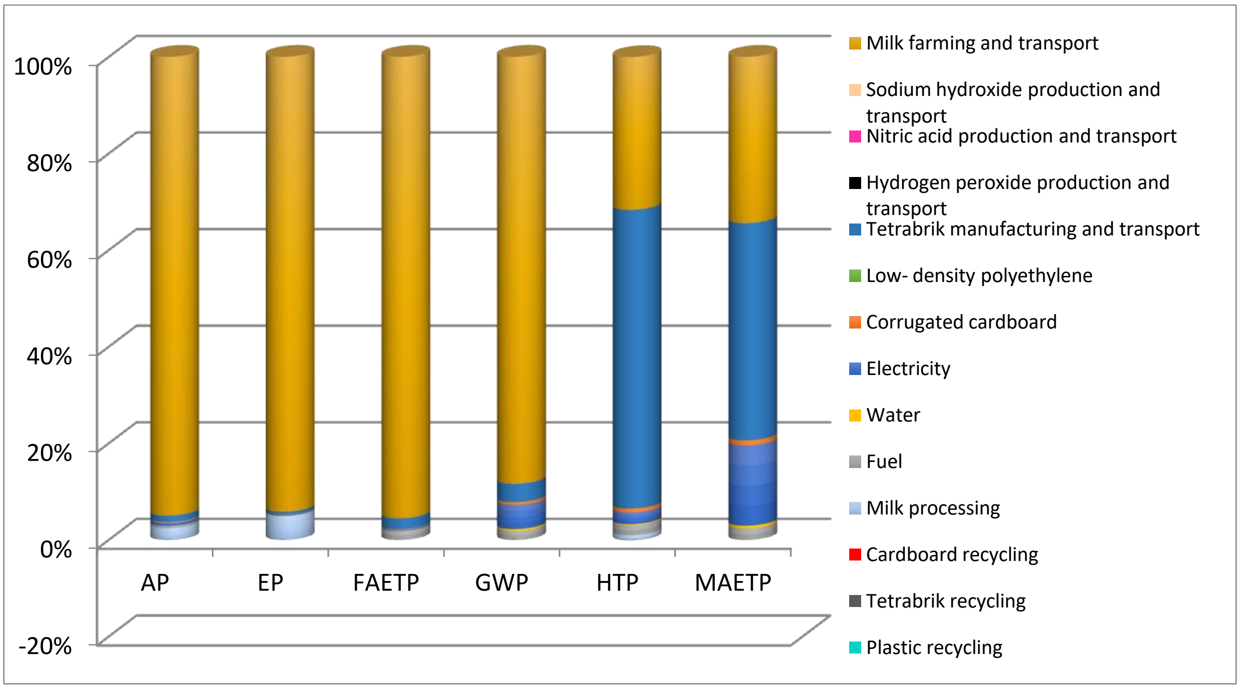

Figure 9. Portuguese system with Milk farm and transport stage included.

6.6 ANNEX 6: POTENTIAL ENVIRONMENTAL IMPACTS FROM PORTUGUESE MILK PRODUCTION

Table 15. Potential environmental impacts from Portuguese milk production (I)

Enviromental Impacts	Units	Total system	Milk farming and transport	NaOH production and transport	HNO_3 production and transport	H_2O_2 production and transport	Tetrabrick manufacturing and transport	Low-density polyethylene(LDPE)
Acidification Potential (AP)	[kg SO_2-Equiv.]	1,55E-02	1,48E-02	5,49E-07	4,20E-07	2,38E-07	2,02E-04	1,15E-06
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	7,54E-03	7,10E-03	1,25E-07	1,39E-07	5,75E-08	4,51E-05	7,21E-08
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3,17E-02	3,03E-02	7,81E-07	6,47E-07	3,94E-07	7,18E-04	1,59E-07
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	9,26E-01	8,16E-01	2,01E-04	1,81E-04	7,41E-05	3,50E-02	3,08E-04
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	9,81E-02	3,12E-02	7,37E-06	5,05E-06	3,00E-06	6,09E-02	1,90E-06
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6,61E+01	2,28E+01	8,40E-03	2,17E-03	1,10E-03	2,98E+01	1,51E-02

Table 16. Potential environmental impacts from Portuguese milk production (II)

Enviromental Impacts	Units	Corrugated cardboard	Electricity	Water	Fuel	Milk processing	Cardboard recycling	Tetrabrick recycling	Plastic recycling
Acidification Potential (AP)	[kg SO_2-Equiv.]	3,11E-05	9,58E-05	5,75E-06	6,62E-05	3,74E-04	-7,17E-09	-2,69E-06	-3,14E-09
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	5,26E-06	1,23E-05	1,68E-06	4,86E-06	3,67E-04	-1,24E-09	-1,26E-07	4,54E-10
Freshwater Aquatic Ecotoxicity Potential (FAETP)	[kg DCB-Equiv.]	3,79E-05	7,10E-05	1,55E-05	5,65E-04		-1,13E-08	-4,51E-06	-2,21E-08
Global Waming Potential (GWP)	[kg CO_2-Equiv.]	5,24E-03	4,61E-02	3,88E-03	1,58E-02	2,75E-04	-3,72E-07	4,95E-04	-6,44E-07
Human Toxicity Potential (HTP)	[kg DCB-Equiv.]	7,93E-04	2,38E-03	2,23E-04	2,07E-03	8,95E-04	1,52E-08	-6,37E-05	-7,93E-08
Marine Aquatic Ecotoxicity Potential (MAETP)	[kg DCB-Equiv.]	6,85E-01	1,10E+01	3,83E-01	1,55E+00		-1,28E-04	-7,21E-03	-6,83E-06