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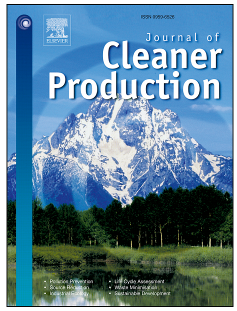

Water and carbon footprint of selected dairy products: A case study in Catalonia

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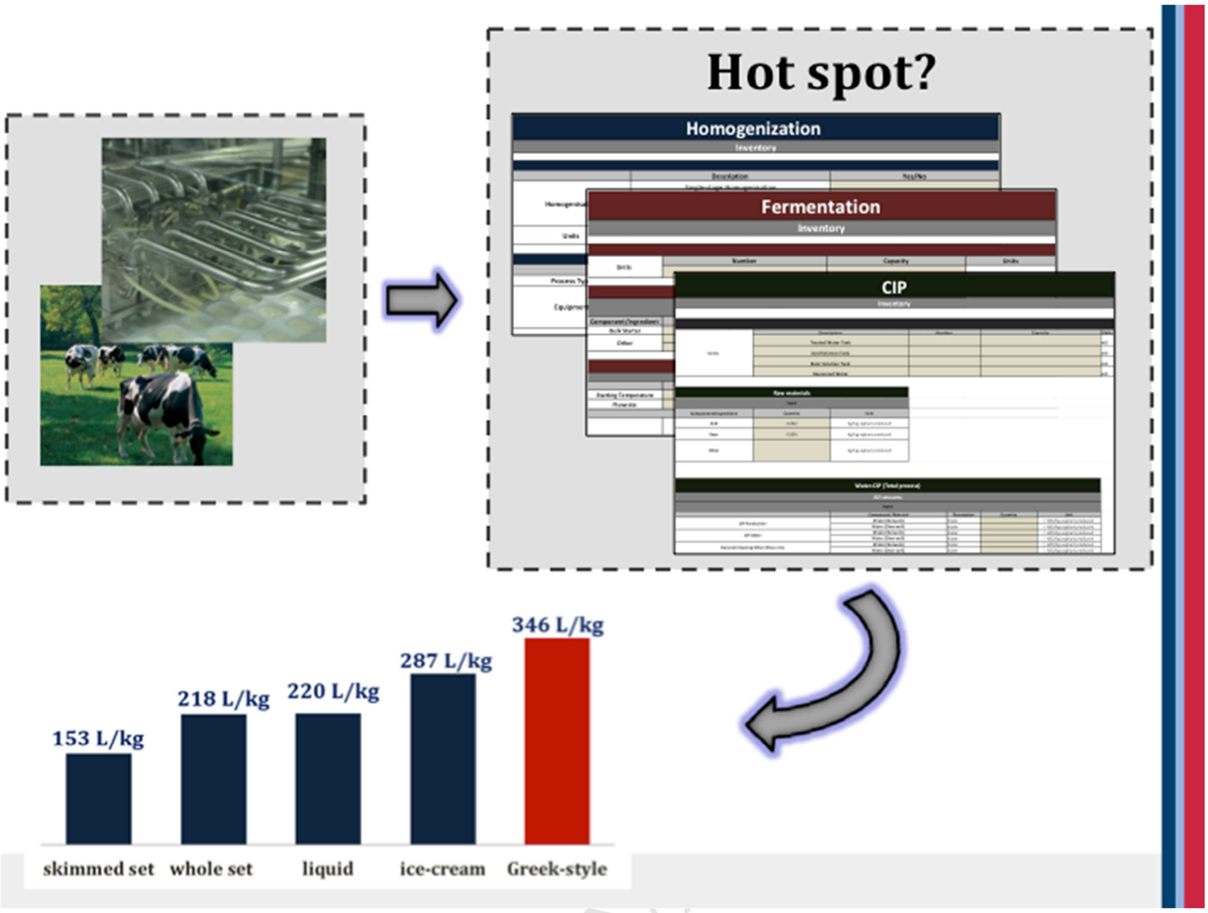
Hot spot?
Homogenization
Inventory
Fermentation
Inventory
CIP
Inventory
153 L/kg
218 L/kg
220 L/kg
287 L/kg
346 L/kg
skimmed set
whole set
liquid
ice-cream
Greek-style

Title: Water and carbon footprint of selected dairy products: A case study in Catalonia

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Abstract

This study assesses the LCA-based Water Footprint (WF) and Carbon Footprint (CF) of various types of yoghurts in the Spanish dairy plant of La Fageda. Primary data have been used to allocate impacts to the core processing stages. . The total amount of water consumption and greenhouse gas emissions for the production of 1 kg of yoghurt in La Fageda plant are 204 L H_2O and 1.94 kg CO_{2eq} respectively. The results indicated that raw milk and milk-based ingredients are the main contributors to all impact categories examined; their contribution to CO_{2eq} ranged from 80 to 96%. Energy consumption and packaging materials have significant contribution to freshwater ecotoxicity, acidification and global warming potential (GWP) impact categories ranging from 30 to 99% when raw milk is excluded from the analysis. In terms of the direct impacts of the plant, Cleaning in Place (CIP) and cleaning operations are responsible for 70% of the water requirements, while refrigerators, pasteurisation and packaging account for 70% of the energy consumption in the facility. The water and carbon footprint varies depending on the production process and the region. The sensitivity analysis illustrates that high precipitation and application of different techniques for raw milk production increases the contribution of the direct impacts of the plant from 2% to 15% in terms of water use.

Keywords: dairy industry, yogurt production process, water footprint, carbon footprint, LCA

Abbreviations	
AR_c	Fraction of cream,
BAT	Best Available Techniques
CF	Carbon Footprint
CIP	Clean-in-place
F_c	g fat content in cream/100g of skimmed milk produced
F&B	Food and Beverage
F_{sm}	g fat content in 100 g skimmed milk
GHG	Greenhouse Gas
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
M_c	Production (%) of cream/kg skimmed milk
P_c	g of protein content in cream per 100g of skimmed milk produced
P_{sm}	g protein in 100 g of skimmed milk
PCR	Product Category Rules
WF	Water footprint
WFN	Water Footprint Network
WTA	Withdrawal to availability
WULCA	Water use in life cycle assessment (working group)
WWTP	Wastewater treatment plant
Impact Categories	
WU	Water Use (L H_2O)
WC	Water Consumption (L $H_2O_{eq)}$
WS	Water Scarcity (L $H_2O_{eq)}$
FETP	Freshwater eutrophication potential (kg $P_{eq)}$
FEP	Freshwater ecotoxicity (1,4-Db_{eq})
AP	Acidification potential (kg $PO4^{3-}{}_{eq}$)
HH	Disability adjusted life years (DALY)
GWP	Global warming potential (kg CO_{2eq})
Yoghurt Types	
SNF	Set natural full yoghurt
SFL	Set flavoured full yoghurt
SKN	Skimmed natural yoghurt
SKFL	Skimmed flavoured yoghurt
GN	Greek-style natural yoghurt
GFL	Greek-style flavoured yoghurt
LN	Liquid natural yoghurt
LF	Liquid flavoured yoghurt
IN	Ice-cream natural yoghurt
IFL	Ice-cream flavoured yoghurt

1. Introduction

The food industry is a major consumer of water; it is ranked third for water consumption and wastewater discharge after the chemical and refinery industries (Olmez and Kretzschmar, 2009). According to Falkenmark (2008), fresh water availability is expected to be one of the most significant constraints towards future food production. Given that the food sector is also responsible for 30% of the Greenhouse Gas (GHG) emissions deriving from human activities (Garnett, 2011), mitigating actions must be considered in order to secure sustainability of food systems (Smith et al., 2013; Hallström et al., 2014; West et al., 2014). Dairy products are an irreplaceable aspect of human diet and one of the largest and most important sub-sectors of the Food industry in Europe (Wijnands et al., 2007). However, their production is associated with severe environmental impacts including GHG emissions and water and energy consumption (Milani et al., 2011). In 2007, the dairy sector globally contributed by 4% to the GHG emissions (FAO, 2010). According to the Commission Directorate (2006), the average direct use of water for yoghurt manufacturing, ranges from 0.8 to 25 L/kg processed milk. The application of Best Available Techniques (Prasad and Pagan, 2006) can lower water use to 0.1 L/L milk.

The establishment of target – standardized environmental indicators is a key element for the assessment and mitigation of the environmental impacts and the unsustainable freshwater utilisation from the food sector (Fang et al., 2014). Two main approaches have been reported in recent literature for the determination of the water footprint (WF) of a product (McGlade et al., 2012). The first approach was developed by the Water Footprint Network (WFN) (Hoekstra et al., 2011) following a volumetric concept. It focuses on the identification of the water-related hotspots of a product's life cycle (Manzardo et al., 2014). The second one was introduced by the Life Cycle Assessment (LCA) community (Kounina et al., 2013) and focuses on the assessment of environmental indicators (i.e. eutrophication, ecotoxicity, human toxicity and water scarcity). The LCA based WF has been extensively used for the assessment of different alternatives towards the minimisation of product environmental impacts (Feng et al., 2014). However, the most widely accepted LCA methods disregard water-based impacts and water use (Canals et al., 2009).

The application of different WF approaches can be confusing, resulting in different outcome even when the same data are used (Danielsson et al., 2015). Ridoutt et al. (2009) mentions that volumetric methods, such as the WFN methodology (Hoekstra et al., 2011) are often misleading, since they do not consider the environmental impacts of water use. Zonderland-Thomassen and Ledgard, (2012) propose to cosider additional impacts related to water degradation and depletion A response to the 'gap' is given by the UNEP-SETAC WULCA project (Boulay et al., 2014) and recent ISO (BS ISO 14046, 2014), aiming to set up a standardisation tool and guide towards a consistent assessment of the

water-related environmental impacts locally, regionally and globally. The ISO follows an LCA-based approach.
Another popular eco-indicator, specifically focused on the reduction of GHGs is the Carbon Footprint (CF), which is defined as the total GHG emissions of a product's whole life cycle (BS ISO 14047, 2008) (Pandey et al., 2011). ISO/TS 14067 (2013) develops standards and guidelines for the standardisation of the carbon footprint methodology.

The majority of research studies examine the environmental impacts of the dairy sector following the LCA methodology (Flysjö et al., 2011a). Among them, a significant number of studies focus on the comparison of organic and conventional farming activities (Cederberg and Mattsson, 2000), considering site specific case studies (Castanheira et al., 2010), milk supply chain (Fantin et al., 2012) and on other milk based products, such as cheese, whey (Kim et al., 2013) and yoghurt (González-García et al., 2013). The farm stage has been again the centre of interest in several standalone studies on carbon footprint. For example, Flysjö et al., (2011b) examined the allocation methodologies for multi-output farming systems, whereas a recent study performed by de Léis et al., (2015) compared different farming production systems. Regarding the carbon footprint of dairy products, milk has mainly been examined (Flysjö et al., 2014). Vergé et al., (2013) assessed various dairy products in Canada and concluded that the carbon footprint depends on the energy requirements of the processing stages. The majority of the environmental studies in the dairy sector have identified that climate change (GWP) is the main impact category that is connected to the dairy sector; particularly with the farm stage and feed production. On the other hand, current research regarding the water footprint of dairy products has almost exclusively focused on the farm stage. Recently, the WF for the production of conventional and organic milk of Brazilian dairy farming was assessed (Palhares and Pezzopane, 2015), following the WFN methodology (Hoekstra et al., 2011). The authors concluded that the volumetric water degradation measured by the grey water footprint is not a distinctive indicator of water pollution. A combination of different methods for WF assessment for dairy farming in New Zealand has been applied in the work of Zonderland-Thomassen and Ledgard (2012). The authors demonstrated that freshwater availability, depletion and degradation are essential components in order to assess the comprehensive WF profile of dairy farming. The LCA-based WF is becoming an increasingly popular concept. Following the ISO 14046 Standards (2014), Jing et al. (2014) assessed the water availability footprint of dairy systems in Northeast China. In contrast to similar studies following the WFN methodology, the findings of their impact-oriented analysis, show that dairy products can be produced without contributing significantly to the water scarcity of the region. De Boer et al. (2013) evaluated the impacts related with freshwater use in Dutch dairy farms and compared them with the respective ones related to broccoli production in Spain. The authors found that standalone water use volumetric assessments are not sufficient to characterise the impacts from water use.

The assessment of dairy products WF throughout their whole supply is limited mainly due to lack of primary data. This limitation has been revealed for the LCA-based water footprint studies, assessing the water-related environmental impacts of products. Only few environmental studies deal with fermented milk products (González-García et al., 2013; White et al., 2008), such as yoghurt, whereas the impacts of yoghurt production on water resources and on greenhouse gas emissions have not yet been thoroughly examined. Even in the LCA focused studies of milk products, processing is considered as ‘a black box’ (González-García et al., 2013); this means that materials and energy flows have not yet been allocated to specific processes. The allocation of impacts to production processes is the first step for the improvement of the environmental profile of the industrial sector and the establishment of environmental policy (Kouchaki-Penchah et al., 2016a). Additionally, the impacts from life-cycle water use have not been properly addressed in LCA studies. A recent review on LCA studies for milk production published by Maldini et al., (2016) showed that out of 29 studies considered, only 2 addressed impacts from freshwater eutrophication and 4 from freshwater ecotoxicity, while the hotspots for water use have not yet been sufficiently examined. The quantification and evaluation of the WF of dairy products following the ISO and LCA methodology remains a gap in current literature (Tillotson et al., 2014).

The main objective of this study is to quantify the water and carbon footprint of a yoghurt processing plant and to assess the water and carbon related environmental impacts. The degradative and consumptive water use of the dairy plant is assessed, providing an analysis of the whole spectrum of the water-related environmental impacts in compliance with the LCA-based ISO 14046. Therefore, the water and carbon hotspots are identified following a ‘cradle to gate’ approach in order to propose measures for the mitigation of targeted environmental impacts. The selection of yoghurt is based both on the nutritive significance of the product for the human diet and on the lack of environmental studies, concerning yoghurt manufacturing.

2. Materials and Methods

2.1 Dairy plant

Real data from a yoghurt manufacturing plant are used in order to perform a complete assessment of the impacts of different types of yoghurts on freshwater resources deprivation and depletion taking into consideration both ecosystems and human health on a product and process level. La Fageda is the second largest yoghurt producer in Catalonia. The dairy industry is located in La Garrotxa, in the middle of the Volcanic Natural Park Zone. The company produces various dairy products, managing the whole supply chain from agricultural land and feed production up to the milk processing and distribution. Core processing stages include production, packaging and storage of yoghurts, dairy desserts, ice-creams and marmalades. The yoghurt types examined in this work include: the set type fermented and cooled in the package, the stirred type fermented in tanks and cooled before packaging, the drinking type, where the coagulum is liquidated before packaging and the frozen type fermented in tanks and refrigerated like ice cream.

The case study of La Fageda focuses on cultured milk products and on set, Greek-style, liquid and ice-cream yoghurt that the company produces. The milk is produced, processed into the final product, packaged onsite and then distributed to several areas in Catalonia. In 2014, the company produced approximately 6,274 t of fermented milk products and 7,851 t of dairy products in total.

2.2 LCA-based water and carbon footprint assessment

2.2.1 Functional unit

Product Category Rules (PCR) setting standards towards environmental impact assessment for yoghurt were identified and followed. According to yoghurt's valid PCR (EPD, 2014) the selected functional unit is 1 kg of yoghurt produced in the plant.

2.2.2 System boundaries and processing stages

The LCA 'cradle to gate' approach was adopted (Finnveden et al., 2009) in order to calculate the water and carbon footprint of selected dairy products taking into consideration the upstream and the core processes of the dairy plant (Fig. 1) as proposed by yoghurt's PCR (EPD, 2014). Given that the study focused on the environmental profile of the diary plant the downstream processes were out of the scope of the study. The upstream processes include raw milk, other auxiliary products and packaging materials production. The core processes mainly refer to the yoghurt production stages including the waste management scheme of the company.

Fig. 2 shows a simplified flowchart of milk processing (core processes) in the targeted dairy plant. The raw milk is produced on site in La Fageda dairy farm and it is received through pipes in the processing plant. About 15% of the raw milk undergoes a separation process, where skimmed milk (less than 1.5% fat) is separated from the cream (40% fat content). The unseparated whole milk (4% fat) is used for the production of whole set yoghurts and skimmed milk for the production of skimmed yoghurts, while whole milk is mixed with cream in the Greek yoghurt production line. Then all streams are mixed with additives including flavours, sweeteners and dry powder milk to increase yoghurt consistency.

Following the mixing the homogenisation process takes place at high pressure at temperature (65°C) to stabilise the mixture and prevent the fat suspension. Pasteurisation is a heat treatment process at 95°C that destroys the microorganisms in the milk and denatures whey proteins improving the yoghurt's texture. In order to reduce energy consumption, the heated milk that exits pasteurisation is recirculated back to the system to pre-heat raw milk and enhance homogenisation. After recirculation, the milk mixture is cooled at 10°C using ice water. Then, the milk is heated again at 45°C with steam before the addition of bulk starter that enhances the fermentation process. As illustrated in Fig. 2, the fermentation process differs depending on the type of yoghurt. All products are preserved in refrigerators until distribution. The electricity network provides the energy required for the processing machines in la Fageda.

Cleaning operations in La Fageda are divided into automatic cleaning in place for the tanks, pipes and packaging machines, cleaning in place for the pasteurizer and manual cleaning operations. Cleaning in place is an automatic process, where rinsing water and detergent solutions are circulated through tanks, pipes and process lines. Other processes that are indirectly connected with yoghurt manufacturing include the treatment of the well water that is abstracted and purified in order to comply with the required water quality standards and then used in the processing stages and the wastewater treatment plant at La Fageda premises. Both aforementioned processes are considered as 'black box' for the analysis and only total input and output materials and energy are taken into consideration.

2.2.3 Assumptions

Avoided impacts regarding the recycling of the produced waste in the plant are taken into consideration for the impact categories of the life-cycle of yoghurt. Environmental credits from recycled materials, mainly packaging waste in the plant, are attributed to the waste management process. Data for the final disposal of waste and the type of treatment were supplied by the company. In addition, the cut-off rule has been applied according to the ISO 14044 and ISO 14047 standards (2006). Thus, materials and processes that account for less than 1% to the impact categories (i.e. impacts related to the infrastructure of the dairy plant) are not considered.

Given that the plant manufactures dairy products that are not examined in this study, only 50% of the impacts related to the office operations (i.e. electricity consumption) are included in the assessment. Due to the lack of available information, the transportation of materials from their place of production to Spain was excluded from the analysis.

2.2.4 Allocation of burdens

Each yoghurt type in La Fageda is a unique product in the production stage thus, no burden allocation has been applied. The majority of the production lines are independent of other lines (i.e. iced yoghurts follow different production line from stirred yoghurts) enabling the individual calculation of electricity and water consumption for each product. However, when a machine is used for the production of more than one yoghurt group, electricity and direct water consumption have been mass allocated within each group. Heating requirements (woodchips, propane) and auxiliary products that are used for more than one product groups (i.e. chemicals) as well as water treatment and water related emissions have been also mass allocated.

Additionally, in La Fageda, part of the raw milk is separated into cream and skimmed milk. Skimmed milk is used for the production of skimmed yoghurts, while cream is used in Greek and iced yoghurts. Mass of protein and fat allocation is considered in order to reflect the physical relationships between the mass of protein and fat of the partitioning of co-products in the same production line as proposed by yoghurt's PCR (EPD, 2014). Consequently, 53% of the impacts of raw milk and of energy requirements for separation are allocated to skimmed milk for set yoghurt and 47% to cream for Greek yoghurt (Equation 1).

$$AR_c = \frac{(F_c + P_c) \times M_c(\%)}{(F_c + P_c) \times M_c(\%) + (F_{sm} + P_{sm}) \times 100(\%)} \tag{1}$$

Where AR_c is the fraction of cream, F_c (g) is the fat content in cream per 100g of skimmed milk produced, P_c (g) is the protein content in cream per 100g of skimmed milk produced, M_c (%) is the production of cream per 1 kg skimmed milk produced and F_{sm} and P_{sm} (g) are the fat and protein content of 100 g of skimmed milk, respectively.

2.3 Water footprint assessment

2.3.1 Impact assessment methodology

The impact assessment methods for the water footprint were selected to cover impacts associated with quantitative and degradative concerns, as required by ISO 14046. Therefore, the water comprehensive footprint profile used in this study consists of 6 midpoint impact category indicators divided in (i) water availability indicators (water use, water consumption, water scarcity) and water degradation indicators (freshwater eutrophication, freshwater acidification and freshwater ecotoxicity). In addition, one endpoint impact category indicator (Human Health water scarcity) has been applied.

Methods associated with quantitative water includes (i) water use (expressed in m^3 of water) defined as any water withdrawal, water release or other human activity within the drainage basin, (ii) water consumption (expressed in m^3 of water) defined as water removed, but not returned to the same drainage basin due to evaporation, transpiration, integration to a product or release into a different drainage basin and (iii) water scarcity (expressed in m^3_{eq} of water) which was modelled according to the method proposed by Pfister et al. (2009). The annual water stress index (WSI) developed from Pfister et al. (2009), was based on a withdrawal-to-availability ratio, and was used as a characterisation factor. The Spanish average WSI value of 0.7147 m^3_{eq}/m^3 was applied to processes that occurred throughout Spain (e.g., electricity, milk production, etc.) or in unknown locations.

Methods associated with water degradation were chosen in order to cover the most common impact pathways. A detailed description of these methods can be found in the literature (SimaPro, 2016).

Briefly, freshwater eutrophication is modelled based on the ReCiPe methodology (Goedkoop et al. 2012) and expressed as kilogram P_{eq}. Freshwater acidification is characterized with the IMPACT 2002+ methodology (Jolliet et al. 2003) and expressed as kilogram SO_{2eq}. Freshwater ecotoxicity is also modelled based on the ReCiPe methodology (Goedkoop et al. 2012) and expressed as Kilogram 1,4-DB_{eq}.

At the endpoint, water availability impact assessment methods model the impact pathways from user deprivation (agriculture, domestic, and/or fisheries) to human health in disability-adjusted life year (DALY) and was calculated from methodology proposed by Pfister et al. 2009.

2.3.2 Water consumption calculation methodology

Different approaches for the calculation of water consumption have been applied for (i) raw milk, milk related products and other ingredients, (ii) other secondary flow (energy, packaging, transport, etc.) and (iii) direct water consumption.

- Blue water consumption for milk, milk related products and other ingredients were calculated based on the country's specific data reported by Mekonnen and Hoekstra (2010a, 2010b).
- Blue water consumption of all the other secondary flows was calculated using water balances in Ecoinvent 3.1 following the methodology proposed by Pfister et al. (2015). Briefly, net freshwater consumption of the secondary flows was calculated by deducting water outputs to freshwater bodies from freshwater inputs.
- Direct blue water consumption was modelled using the consumption factors proposed by Flury et al. (2013) expressing the fraction of water consumed in relation to the water used in the production process. Consumptions factors of 0.05 for cooling water, 0,1 for the other production processes (e.g. cleaning water) and 1 for water embodied in products were used.

2.4 *Carbon footprint determination*

ISO/TS 14067 (2013) aims to develop standards and guidelines for the standardisation of the carbon footprint methodology. It is also known as Global Warming Potential (GWP) and includes the assessment of all GHG emissions throughout a product's supply chain and their transformation into CO_2-equivalents based on their global warming potential (Röös et al., 2013). The transformation into a common unit enables the calculation and the weighting of a product's life cycle emissions that contribute to the greenhouse gas effect (Weidema et al., 2008).

The impact category of the Global Warming potential assesses emissions contributing to the Greenhouse effect and thus to global warming. It was extracted from Recipe methodology for a time horizon of 100 years in kg CO_{2eq}. In the Recipe methodology, the GHG emissions attributable to climate change were modelled based on a simplified version of the Fund model (Tol, 2002). The latter is one of the best available models and it is based on highly acknowledged studies (Goedkoop et al., 2009). The Carbon Footprint of the final product consists of the aggregated CO_2 equivalents emitted in the atmosphere through the whole life cycle of yoghurt production.

2.5 Global inventory

2.5.1 Primary Data

The challenges for the development of the inventory have been emphasised by several researchers (Finnveden et al., 2009). Processing is often considered as a black box (González-García et al., 2013) in LCA studies of milk products, mainly due to the limited availability of reviewed data. Meticulous consideration is required when selecting proxy data for the inputs and outputs of the production processes since differences in the technology and regulations can significantly affect the results (Kouchaki-Penchah et al., 2016b). The development of the life-cycle inventory was based on primary data obtained through visits in the factory and data provided by process engineers and operators. The data collection period lasted one year, from mid 2014 to mid 2015. Real data for products composition, auxiliary materials, energy and water consumption, solid waste and wastewater management and transport distances were obtained for this period. The average global inventory collected for the yoghurt processing plant is illustrated in Table 1, where all ingredients are summed up and average amounts are used per kg of yoghurt produced. However, in order to assess the impact categories of different yoghurt groups (i.e. set natural yoghurts) differentiated data for the specific amounts of raw ingredients, packaging materials, energy and water requirements have been provided by the dairy facility (Table 2). The average transportation distances for the raw ingredients (i.e. 40 km), the packaging materials (i.e. 8km) and the waste management scheme (i.e. 67 km) were selected based on the location of the suppliers and used in all the dairy products studied in this work.

2.5.2 Secondary data

The material and energy inventories in Table 1 and Table 2 include also background data for all the upstream processes. In the current study, secondary data of processes regarding raw milk, ingredients, different types of energy, packaging materials, waste treatment techniques and transportation were obtained from the highly acknowledged Ecoinvent 3.1 database. The only exception is skimmed milk powder, which was modelled assuming skimmed milk as the main ingredient, while, processing electricity and heat requirements were defined according to the study of van Zeist et al. (2012). Also, as stated in section 2.3.2, the amount of blue water used and consumed for raw milk and ingredients/additives production were derived from Mekonnen and Hoekstra (2010a, 2010b) due to limited availability of regional data concerning agricultural and milk ingredients.

3. Results and Discussion

3.1 Water and carbon footprint of yogurt's production process

Analysis of the different yoghurt types processed in La Fageda, indicated significant differences in the impact categories for each yoghurt type. Table 3 shows the environmental results for the impact categories that were assessed (WU: water use, WC: water consumption, WS: Water Scarcity, FETP: freshwater eutrophication potential, FEP: freshwater ecotoxicity potential, AP: acidification potential, HH: human health, GWP: global warming potential), in relation to the functional unit (1kg of yoghurt at dairy plant gate) for the examined yoghurt types. In most cases the differences are related to the different concentrations of additives in each yoghurt type and the different packaging materials used. The product that has the lowest water-related environmental impacts and GHG emissions is the liquid natural yoghurt, while the most environmental intensive product is the Greek-style yoghurt and the ice-cream yoghurt (Table 3). This is mainly because liquid natural yoghurt does not contain milk powder, cream or fruit additives that are major contributors to the water profile of the final products. The average total water consumed for the production of 1 kg of fermented product in a Spanish dairy plant is 203.7 L H_2O_{eq}.Given that in the case of La Fageda, more than 99% of water consumption is sourced from indirect water inputs it is important to consider both direct and 'virtual water' consumption of dairy products; indirect water inputs, correspond to an average Spanish case. The direct contribution of La Fageda processing techniques includes the energy and water consumption in the core processes and ranges from 0.2% (representing WS for Greek natural yoghurt) to 7.2% (representing WU for skimmed natural yoghurt) for the majority of the impact categories, as shown in Table 3.

The embodied water in raw milk is responsible for up to 90-95% of the total water consumption in the final products. For example, 95% of the total water consumption in liquid natural yoghurts is sourced solely from milk. The same pattern has been observed by several authors (Hoekstra et al., 2011; Zonderland-Thomassen and Ledgard, 2012; Palhares and Pezzopane, 2015). Raw milk and cream are the major contributors of the majority of impact categories for all types of examined yoghurts (on average 86% WS, 87% FEP, 82% FETP). Raw milk and cream are responsible for 91% and 81% of the water consumption of Greek-style and ice-cream yoghurt respectively. In addition, raw milk, which is the main ingredient of yoghurt, accounts on average for 63% of total GHG emissions of liquid yoghurt's supply chain, which increases for set yoghurt; 73% contribution was noticed. Similarly, 1 kg of Greek-style yoghurt and ice-cream, raw milk and cream are responsible for 81% and 64% of the total GHG emissions.

3.2 Identification and assessment of yogurt processing hotspots

Even though the majority of the results identify the farming stage as the most important environmental hotspot, it is important to assess the impacts of the processing stages of yoghurt and propose actions for the improvement of their environmental profile. Until now, most studies have focused on the farm stage of dairy products which has resulted in the significant reduction of the environmental impact of milk production in many areas (Zonderland-Thomassen and Ledgard, 2012; Jing et al., 2014; Palhares and Pezzopane, 2015). In the UK for example, the water embodied in 1 kg of milk is 24L, which is significantly lower than the respective one for the case of Spain, where 1kg of milk is equivalent to 198L H_2O consumed. This happens because the Spanish dairy farms are irrigated due to low annual precipitation (Lecina et al., 2010). The relative contributions to the impact categories of the subsystems, excluding inputs of raw milk and consequently cream, are shown in Fig. 3. Raw ingredients and especially milk powder dominate in almost all impact categories (i.e. WC: 58-89%, FETP: 48-85%, FEP: 24-67%, AP: 17-58%). The absence of milk powder in liquid yoghurts is responsible for the differences in their water profile, where the impacts of the raw ingredients in all impact categories are negligible.

Additionally, the packaging materials are identified as 'hotspot' in the majority of the categories. Approximately 10.4-11 L of H_2O are abstracted from freshwater resources for the packaging of 1kg of cupped yoghurt respectively (20%-38% relative contribution) and 2.8-3 L H_2O is not returned to the same catchment (8%-15% relative contribution to the water consumption). The environmental impacts of packaging materials are also strongly connected to water quality aspects that are a hotspot especially for liquid yoghurts; eutrophication (89%) and ecotoxicity (63%). The environmental impacts of packaging in yoghurt manufacturing have also been identified as an environmental hotspot in other research works (González-García et al., 2013). This is mainly sourced from the polystyrene used for the packaging of Greek and set yoghurt and the glass used for liquid yoghurt.

Another important contributor to the environmental impacts is the energy requirements that are responsible for 16-35% of the Freshwater Ecotoxicity and 10-29% of Global Warming potential . In Spain 69% of the electricity mix consists of carbon-free sources (del Río González, 2008); the latter indicates that higher contribution to GHGs emissions is expected for coal-dependant countries. Avoided impacts due to the waste management scheme applied in the plant, and the recycling of the plastic, glass and carton waste, range from 0.02% for the water scarcity impact category to 0.7% for the global warming potential.

3.3 Direct yoghurt processing impacts

Direct water use and degradation, along with the energy requirements are mainly responsible for the environmental impacts of yoghurt processing. Even though the magnitude of water-related environmental impacts of yoghurt is mainly affected by the indirect water flows (Fig. 3), direct water consumption in the plant also plays an important role. Dairy plants are characterized by high-energy demand due to the intensive and extensive range of heating and cooling processes. Fig. 4 presents a breakdown of water, and electricity use as well as GWP in the plant for the production of 1kg of Greek-style yoghurt.

Direct water use accounts for 3.5 L of water abstracted from the local well and used for the production 1 kg of Greek-style yoghurt in La Fageda plant. Ice-cream production requires the highest direct water use volume, which is equal to 5.76 L of water. As shown in Fig. 4, out of 3.5 L H_2O used for the production of 1kg of Greek-style yoghurt, ~86% is directly connected to the processing stages. CIP and cleaning operations are the main contributors for direct water use consuming 2.4 L H_2O per kg of yoghurt, while 0.33 L H_2O and 0.23 L H_2O are required for the production of 1kg of yoghurt, due to cooling and heating respectively. Satisfactory results are obtained in the plant in terms water management and consumption. This is due to the water recirculation system of the CIP and milk recirculation instead of steam or cooling water, which is used during pasteurisation-homogenisation. According to the European Commission Directorate (2006) water consumption for the processing of fermented milk products, varies from 0.8 to 25 L/kg of processed milk. The estimated value of 3.5 L H_2O_{eq}/ kg yoghurt is below the average amount of 3.8 L H_2O_{eq}/ kg yoghurt that is published by Envirowise (undated).

The average electricity requirements for the production of 1kg of fermented products in La Fageda are 0.15 kWh. A biomass and a propane gas boiler are also used, consuming on average 0.21kWh and 0.07 kWh respectively for the production of 1 kg of fermented products. The benchmark value that has been reported for the European dairy sector is 0.04-0.69kWh per kg of liquid milk processed (1.08 kg of fermented product equivalent on average) from the electricity network and 0.05-0.46kWh from fuels (Commission Directorate, 2006). In accordance with the literature findings (Rad and Lewis, 2014), pasteurisation is one of the most energy intensive steps (22% contribution). Moreover, cold tunnels, refrigerators and packaging result in high electricity consumption (26% and 22% respectively). When this work was carried out, several important modifications to the facility were being implemented; due to these modifications cold rooms were not properly insulated and doors remained open for hours intensifying the energy use. All yoghurts types, present a similar profile in terms of electricity distribution. The application of biomass boiler in the plant is an efficient strategy to reduce GHG emissions of the processing stages by reducing the dependency on the national electricity grid.

Given that CF of the core processes in La Fageda is highly dependent on the energy consumption (electricity, fuels) of each process, the CF profile is similar to the profile of the electricity consumption. Overall, 0.1 kg CO_{2eq} are emitted per kg of Greek flavoured yoghurt produced. Again, the most important hotspots are the refrigerators (25%), the pasteurisation (22%) and the packaging (22%). A study published by Thoma et al., (2008) on the GHGs emissions from milk production in the United States, followed the IPCC methodology and calculated 0.076 kg CO_{2eq}/kg milk at the factory gate.

3.4 Packaging and ingredients

Further examination of the contribution of each packaging material in the cupped Greek-style yoghurt shows that polystyrene cups constitute a ‘hotspot’ for almost all impact categories (Fig. 5a). The average cup weight in La Fageda is approximately 4g; thus the production of 1kg of Greek-style yoghurt requires 5.8L H_2O (51% relative contribution of all packaging materials) and carries an ‘embodied’ water load of 2.1L H_2O_{eq} (69% relative contribution). Polystyrene is another major contributor for human health impacts (77%). Additionally, it is estimated that out of 0.27kg CO_{2eq} life cycle emissions of packaging 1kg cupped yoghurt, 53% are sourced from polystyrene based cups.
The packaging of liquid yoghurt consists of glass bottles, aluminium based metal caps and labels made of polyethylene-based packaging film. The GHGs emissions originating from the manufacturing of bottled glasses are relatively high (0.38 kg CO_{2eq} per kg of yoghurt). However, glass is a packaging material readily recyclable, theoretically indefinitely, in all markets with high recycling rates in Europe (70% in 2013 as reported by the European Container Glass Federation statistics; FEVE 2015). Hence, glass bottles are not considered ‘environmental hotspots’ in the packaging family.
Even though the main focus of the current work is not on the raw milk production and milk based products, it is important to identify the allocation of the impacts associated with yoghurt’s raw ingredients (Fig. 5b). It was found that milk, cream and milk powder are a hot spot of Greek-style yoghurt’s ingredients with indirect water load of 330.2L H_2O/kg yoghurt, accounting for 99% of the water consumption of the total raw ingredients. The highest contribution of non-dairy ingredients in terms of water consumption was 5.7% for set yoghurt.

3.5 The importance of the location - Sensitivity Analysis

The assessment of the impact categories for the target yoghurt processing plant in Spain revealed that raw milk and milk-based raw materials are the main contributors to environmental impacts related to degradative and quantitative water use and GHG emissions (Fig. 6); this is in line with the findings of González-García et al. (2013) and is mainly attributed to the farm stage of milk production. All the milk-based and agricultural products in Spain exhibit relatively high impacts concerning water use, consumption and scarcity; especially when considering that Spain is a country that has one of the lowest available water per capita among the European countries and it is considered as a water-stressed area (European Environmental Agency – EEA, 2008).
However, the annual accumulated precipitation in Spain varies from 150-2500mm, which significantly affects the water availability across the country (De Castro et al., 2005). Thus, it is important to consider real data, on a watershed lever, for the WF assessment of the upstream processes of dairy products and particularly for raw milk production. Garrotxa, where the targeted dairy plant is located, is characterised by humid Mediterranean climate, with average precipitation of 1000mm uniformly

distributed during the year (Isamat et al., 2008). As a result, cattle feeding and raw milk production in La Fageda relies much more on precipitation, rather than irrigation and the actual water use and consumption of raw milk production is expected to be less than the theoretical one used in this work that takes into account an average value for Spain.

Hence, it is important to examine the effect of water availability of the plant in the final water profile of yoghurts. A sensitivity analysis was performed considering an identical dairy facility located in the UK with a reported average yearly precipitation <1000mm (ranging from <600 to 3000 mm). The results of this new scenario (Scenario 2) were compared against the respective ones obtained for the baseline scenario, where the dairy plant is located in Spain. The characterisation factors of the impact categories for Scenario 2 were UK-based (e.g. WSI = 0.395 m^3_{eq}/m^3). Additionally, the differences in the water profile of dairy products that are produced in water abundant and water scarce regions with different electricity mixes was examined. The total water consumption for the production of 1kg of flavoured Greek-style yoghurt in an average UK dairy plant (Scenario 2), with the same ingredient sources, processing techniques, energy requirements and waste management schemes as in an average Spanish plant are 67.7 L H_2O_{eq} instead of 356.1 L H_2O_{eq} (Scenario 1). In the specific case of La Fageda, where the annual precipitation is closer to the average value of UK, total water consumption similar to this second scenario could be expected.

As shown in Fig. 6, high precipitation (Scenario 2) and different techniques of raw milk production can increase the relative contribution of the direct impacts of the plant from 2% to 15% in terms of water use, from 0.2% to 1.6% in terms of water consumption and from 0.2% to 1.2% in terms of water scarcity impact category, even when raw milk is included in the analysis. Consequently, the contribution of the raw ingredients in Greek-style yoghurt reduces the total water use from 93% to 62% in the Spanish dairy plant for the production of 1 kg of product. As a result, the contribution of the energy use and packaging materials to the total water use for the production of 1kg of Greek-style yoghurt increases from 2% and 3% (Spanish scenario) to 14% and 15% (UK scenario) respectively. The same applies for the total water consumption, where the contribution of the packaging materials increases from 0.9% to 6.5% in scenario 2. Finally, the same trend is observed for the Water Scarcity Index, where in scenario 2 the contribution of the packaging materials increases from 0.6% to 8%.

3.6 Measures for the reduction of the environmental impact

The total volume of water abstracted from the local well in La Fageda is 3.5 L H_2O per kg of yoghurt that is equivalent to 21,950 m^3 annually. This is mainly used for cleaning operations, as well as, for the cooling and heating requirements of the plant. The facility operates a wastewater treatment plant (WWTP), where the wastewater is treated and returned to the same catchment; thus, the total direct water consumption during the production of 1kg of yoghurt is 0.3 L H_2O, which translates to 2000 m^3 of water consumed on an annual basis. Even though the water consumption is low compared to available benchmarks (Envirowise, undated), the reduction of water consumption in the plant is essential; this is mainly due to costs associated with the treatment of the raw well water and wastewater.

The good performance of La Fageda in terms of water use is mainly due to the installed CIP system, which is programmed to recycle the final rinse water following a pre-rinse water cycle. In addition, the system recirculates the streams that contain cleaning agents, resulting in the generation of small amounts of wastewater in every cleaning cycle, as proposed by the 'Best Available Techniques - BAT' (Korsström and Lampi, 2008; Prasad and Pagan, 2006). During pasteurisation, the pasteurised hot milk is used for the pre-heating of the incoming milk and vice versa, achieving water and energy savings in the facility. A potential measure to further reduce the water requirements is to reuse specific waste streams; directly or after suitable pre-treatments. For example, the cooling processing water can be re-used for cleaning purposes, especially for the cleaning of the milk tank; s , several dairy companies, such as Arla Foods, are already using this minimisation technique. Concerning La Fageda plant, the application of this measure can result in water savings up to 0.33L H_2O_{eq} per kg of yoghurt; this amount is equivalent to 9% of the total water use.

Additionally, there are several techniques that can be applied for the reduction of wastewater and milk loss; thus, reducing wastewater treatment related costs and 'virtual' water losses. Typically, milk losses in manual systems can be up to 2% of the total volume being processed (Singh et al., 2014). In La Fageda this translates into 125t of milk loss annually, which is equivalent to 27,875 m^3 of virtual water loss in the drain. The estimation has been done by considering the water that is included in the final product. Technologies that spot the product-water transition points can significantly contribute to the reduction of milk losses in wastewater. At the beginning of the production process in the plant, the remaining water in pipes is pushed by milk ending to WWTP. This remaining water in the pipes though, is followed by a 'mixing zone' consisting of both water and product loss. The opposite occurs during the CIP, where the milk remaining in the pipes is pushed with water. In La Fageda, these transition points are visually identified, which results in significant product losses. Systems for automation and control, such as conductivity transmitters and optical sensors can be installed in existing pipelines with minor modifications. The latter can reduce the biochemical oxygen demand (BOD) in the generated wastewater by 30% and the product loss by 50% (Korsström and Lampi, 2008). In parallel, the use of the aforementioned equipment enables the collection of the product water mixtures, which can be further processed. Recommendations for further processing include the drying of milk and cream water mixtures into powder, whereas mixtures containing fermented products can be used as animal feed after being concentrated in ultrafiltration units. According to the European Commission Directorate (2006), recovery of products can also be achieved through the installation of pigging systems, especially for the cream pasteurisation line and the remaining water in the pipes after cleaning operations. The ‘pigs’ can be fitted in the pipe and when pushed (by water, compressed air or even the product), they empty the pipe removing the wall-deposits.

The packaging stage has gathered increasing interest in the past years, while several strategies towards the reduction of its environmental impact focus on the weight of packaging material and the selection of recyclable and renewable materials (Prasad and Pagan, 2006). The main ‘hotspot’ in terms of packaging was identified in set and Greek yoghurt in La Fageda; polystyrene cups and aluminium lidding is used. The use of polystyrene cups increases the environmental impacts of the final product (e.g. 0.14kg CO_{2eq} are emitted per kg of cupped yoghurt produced). The application of innovative technologies in yoghurt packaging materials can reduce the environmental impacts related to packaging in the dairy sector. For instance, bioplastics have already been introduced in yoghurt packaging (Essel, 2012). This initiative reduced the product’s packaging carbon footprint by 25% achieving certification from both the International Sustainability & Carbon Certification (ISCC) Association and the Institute for Agriculture and Trade Policy (IATP).

4. Conclusions

The current work assesses the Water and Carbon Footprint of yoghurt following a ‘cradle to factory gate’ approach. Production of 1 kg of yogurt at a Spanish dairy plant requires 204 L of water consumption and emits 1.94 kg CO_{2eq}. Raw milk and milk ingredients are the main hotspots in the analysis, contributing more than 80% to all impact categories. Focusing on the core processes of the dairy plant, energy consumption and especially refrigerators, pasteurisation and packaging significantly contribute in freshwater ecotoxicity, acidification and GWP impact categories. On average, 3.5 L of direct water are used in the core processes for the production of 1 kg of yoghurt, 70% of which are connected to the cleaning requirements. The use of characterisation factors for water availability at a national level for the upstream processing of yoghurt manufacturing can lead to under or overestimation of the contribution of the dairy plant to the total environmental profile of dairy products. Characterisation factors on a watershed level are essential and should be a key activity of future works. The findings of this work revealed that the yoghurt's environmental profile can be enhanced through the reduction of product losses and waste generation in the processing stages. However, there is still limited information on the virtual water losses related to the waste generated from the food industry. The developed method can be transferred to other dairy plants, allowing the application of water and carbon footprints as well as LCA in the yogurt’s production process.

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Table 1. Global average inventory for the production of 1 kg of yoghurt in La Fageda

Input from technosphere		**Input from environment**	
Materials		Water	3.5 L
Raw milk (from dairy farm)	0.89 kg		
Milk powder	0.02 kg	**Output to technosphere**	
Additives		**Yoghurts**	
Sugar	0.05 kg	Set yoghurt	0.88 kg
Strawberry concentrate	1.2E-03 kg	Greek-style yoghurt	0.06 kg
Lemon concentrate	9.6E-04 kg	Liquid yoghurt	0.06 kg
Banana concentrate	9.0E-04 kg	Ice-cream yoghurt	0.005 kg
Cleaning agents		**Energy**	
Nitric acid	2.1E-03 kg	Electricity (Dairy factory)	0.15 kWh
Sodium hydroxide	4.2E-03 kg		
		Transport	
Packaging materials		Truck 3.5–16 t (additives factory—input)	40 km
Polystyrene cups	0.03 kg	Truck 3.5–16 t (packaging—input)	8 km
Ice-cream cups	3.7E-04 kg	Truck 3.5–16 t (dairy factory—waste)	67.3 km
Cardboard	0.02 kg		
Glass Bottle	0.02 kg	**Waste to Treatment**	
Bottle labels	9.8E-05 kg	Plastics to recycling	1.0E-02 kg
Metal caps for bottles	2.9E-04 kg	Cardboard to recycling	4.6E-03 kg
Seals for bottles	4.0E-05 kg	Glass to recycling	9.8E-03 kg
Lids for yoghurt cups	2.8E-03 kg	Municipal waste undifferentiated	1.1E-02 kg
Cartons	0.02 kg		
		Water emissions (after treatment)	
Fuels		COD	75 mg O_2/L
Propane gas	0.008 kg	Phosphorous	0.007 mg/L
Biomass	0.09 kg	NKT	28 mg/L

Table 2. Specific inventory of ingredients, additives, packaging materials and energy and water use for the production of 1 kg of each specific selecected product in La Fageda. SNF: set natural full, SFL: set full flavoured, SKN: skimmed natural, SKFL: skimmed flavoured, GN: Greek-style natural, GFL: Greek-style flavoured, LN: liquid natural, LF: liquid flavoured, IN: ice-cream natural, IF: ice-cream flavoured

	NSF (kg/kg yoghurt)	**SFL** (kg/kg yoghurt)	**SKN** (kg/kg yoghurt)	**SKFL** (kg/kg yoghurt)	**GN** (kg/kg yoghurt)	**GFL** (kg/kg yoghurt)	**LN** (kg/kg yoghurt)	**LFL** (kg/kg yoghurt)	**IN** (kg/kg yoghurt)	**IFL** (kg/kg yoghurt)
Ingredients										
Raw milk (from dairy farm)	0.97	0.87	-	-	0.72	0.76	0.9	0.9	0.18	0.12
Skimmed milk (after separation)	-	-	0.93	0.93	-	-	-	-	-	-
Milk powder	0.004	0.026	0.03	0.03	0.004	0.026	-	0.002	0.02	0.02
Cream	-	-	-	-	0.185	0.185	-	-	0.11	0.11
Set natural yoghurt	-	-	-	-	-	-	-	-	0.5	0.47
Additives*										
Sugar	-	0.086	-	-	-	0.08	0.1	0.1	0.13	0.11
Strawberry concentrate	-	0.002	-	-	-	0.002	-	0.05	-	0.05
Lemon concentrate	-	0.002	-	0.006	-	-	-	0.05	-	0.005
Banana concentrate	-	0.002	-	-	-	-	-	-	-	-
Packaging materials										
Polystyrene cups	0.037	0.037	0.037	0.037	0.04	0.04	-	-	-	-
Cardboard	0.038	0.038	0.038	0.038	0.038	0.038	-	-	0.058	0.058
Lids for yoghurt cups	0.003	0.003	0.003	0.003	0.003	0.003	-	-	-	-
Cartons	0.035	0.035	0.035	0.035	0.034	0.034	0.17	0.17	0.022	0.022
Glass bottle	-	-	-	-	-	-	0.36	0.36	-	-
Bottle labels	-	-	-	-	-	-	0.002	0.002	-	-
Metal cups for bottles	-	-	-	-	-	-	0.005	0.005	-	-
Seals for bottles	-	-	-	-	-	-	0.0007	0.0007	-	-
Container	-	-	-	-	-	-			0.027	0.027
Ice-cream cups	-	-	-	-	-	-			0.007	0.007
Energy										
Electricity (Dairy factory)	0.15	0.13	0.14	0.14	0.14	0.15	0.13	0.13	0.14	0.15

Fuels										
Propane gas	0.009	0.008	0.009	0.009	0.009	0.009	0.008	0.08	0.009	0.009
Biomass	0.1	0.09	0.09	0.09	0.1	0.1	0.09	0.09	0.1	0.1
Input from environment										
Water	3.6	3.2	3.4	3.4	3.3	3.5	3.5	3.5	5.8	5

* Apart from sugar, only one additive is included as ingredient in each type of dairy product (e.g. SFL lemon yoghurt only have sugar and lemon concentrate as additives)

Table 3. WF profile of 1kg final product in La Fageda. T: Total Impact Assessment, D: % contribution of La Fageda processing plant, SNF: set natural full, SFL: set full flavoured, SKN: skimmed natural, SKFL: skimmed flavoured, GN: Greek-style natural, GFL: Greek-style flavoured, LN: liquid natural, LF: liquid flavoured, IN: ice-cream natural, IF: ice-cream flavoured

Impact Category		WU L H_2O	WC L H_2O_{eq}	WS L H_2O_{eq}	FETP kg P_{eq}	FEP 1,4-DB_{eq}	AP kg SO_{2eq}	HH DALY	GWP kg CO_{2eq}
SNF	**T**	218	199	142	2.47E-03	0.10	0.017	5.23E-09	1.89
	D	5.1%	0.4%	0.3%	0.7%	3.2%	1.2%	3.1%	5.0%
SFL	**T**	234	214	152	2.52E-03	0.10	0.018	1.61E-08	1.98
	D	4.7%	0.3%	0.3%	0.7%	3.1%	1.1%	1.0%	4.8%
SKN	**T**	153	137	97	1.71E-03	0.07	0.018	4.19E-09	1.41
	D	7.2%	0.5%	0.4%	1.1%	4.5%	1.1%	3.9%	6.7%
SKFL	**T**	162	146	103	1.71E-03	0.07	0.018	9.52E-09	1.42
	D	6.8%	0.5%	0.4%	1.1%	4.5%	1.1%	1.7%	6.6%
GN	**T**	346	326	232	4.02E-03	0.15	0.028	7.49E-09	2.92
	D	3.5%	0.2%	0.2%	0.5%	2.2%	0.7%	2.4%	3.5%
GFL	**T**	**356**	**334**	**239**	**4.11E-03**	**0.16**	0.028	**7.72E-09**	**2.98**
	D	3.4%	0.2%	0.2%	0.5%	2.2%	0.7%	2.3%	3.5%
LN	**T**	**220**	**187**	**133**	**2.38E-03**	**0.09**	0.029	**1.41E-08**	**2.22**
	D	4.8%	0.4%	0.3%	0.7%	3.1%	0.7%	1.1%	4.0%
LF	**T**	222	190	135	2.38E-03	0.09	0.022	1.50E-08	2.23
	D	4.7%	0.4%	0.3%	0.7%	3.1%	0.9%	1.0%	4.0%
IN	**T**	287	252	178	3.16E-03	0.12	0.029408	1.72E-08	2.65
	D	5.4%	0.4%	0.4%	0.7%	3.0%	1.3%	1.1%	4.1%
IFL	**T**	**307**	**273**	**190**	**3.12E-03**	**0.12**	0.029648	**2.23E-08**	**2.67**
	D	5.0%	0.4%	0.3%	0.7%	3.1%	1.2%	0.9%	4.0%
Average		223	204	145	2.46E-03	0.10	0.018	1.10E-08	1.94

Figure Captions

Figure 1. Supply chain of yoghurt-system boundaries

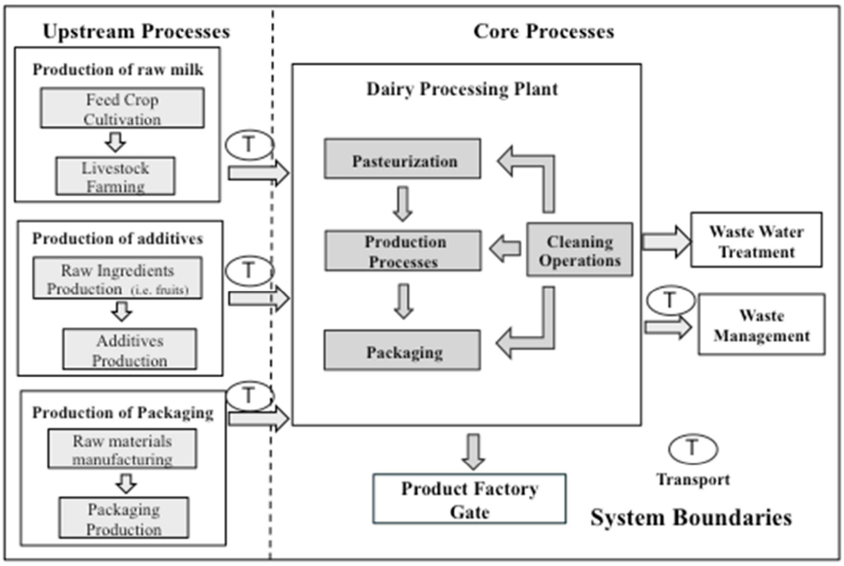
Figure 2. Flow chart of the processing stages of yoghurt products in La Fageda

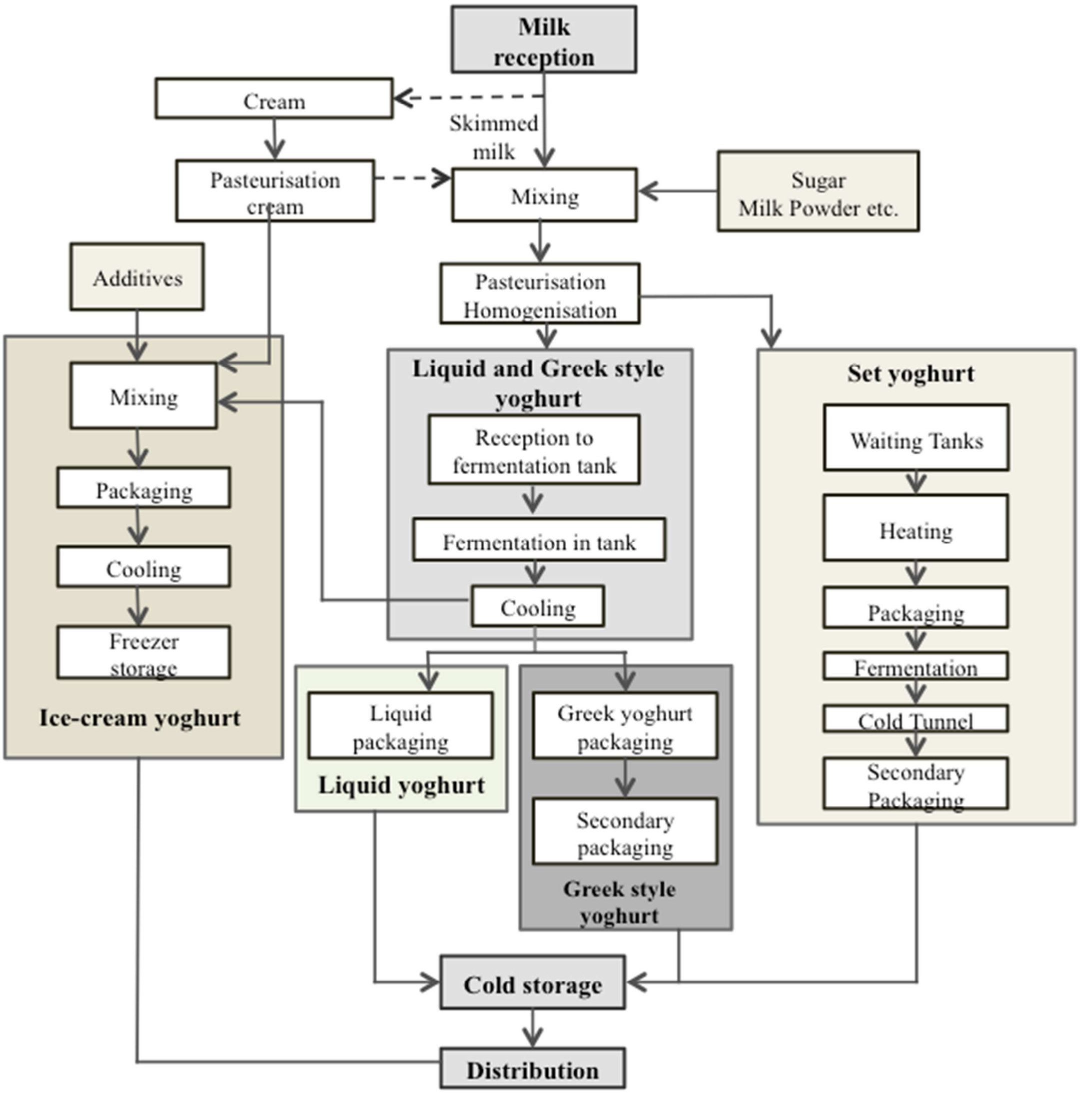
Figure 3. Relative contributions to the impact categories of the subsystems excluding raw milk inputs for all the examined fermented products. (a) Water use, (b) water consumption, (c) Water Scarcity Index, (d) freshwater eutrophication, (e) freshwater ecotoxicity, (f) aquatic acidification, (g) human health, (h) GWP: global warming potential

Figure 4. Distribution of (a) water use (a) and (b) electricity consumption per processing stage of Greek-style yoghurt

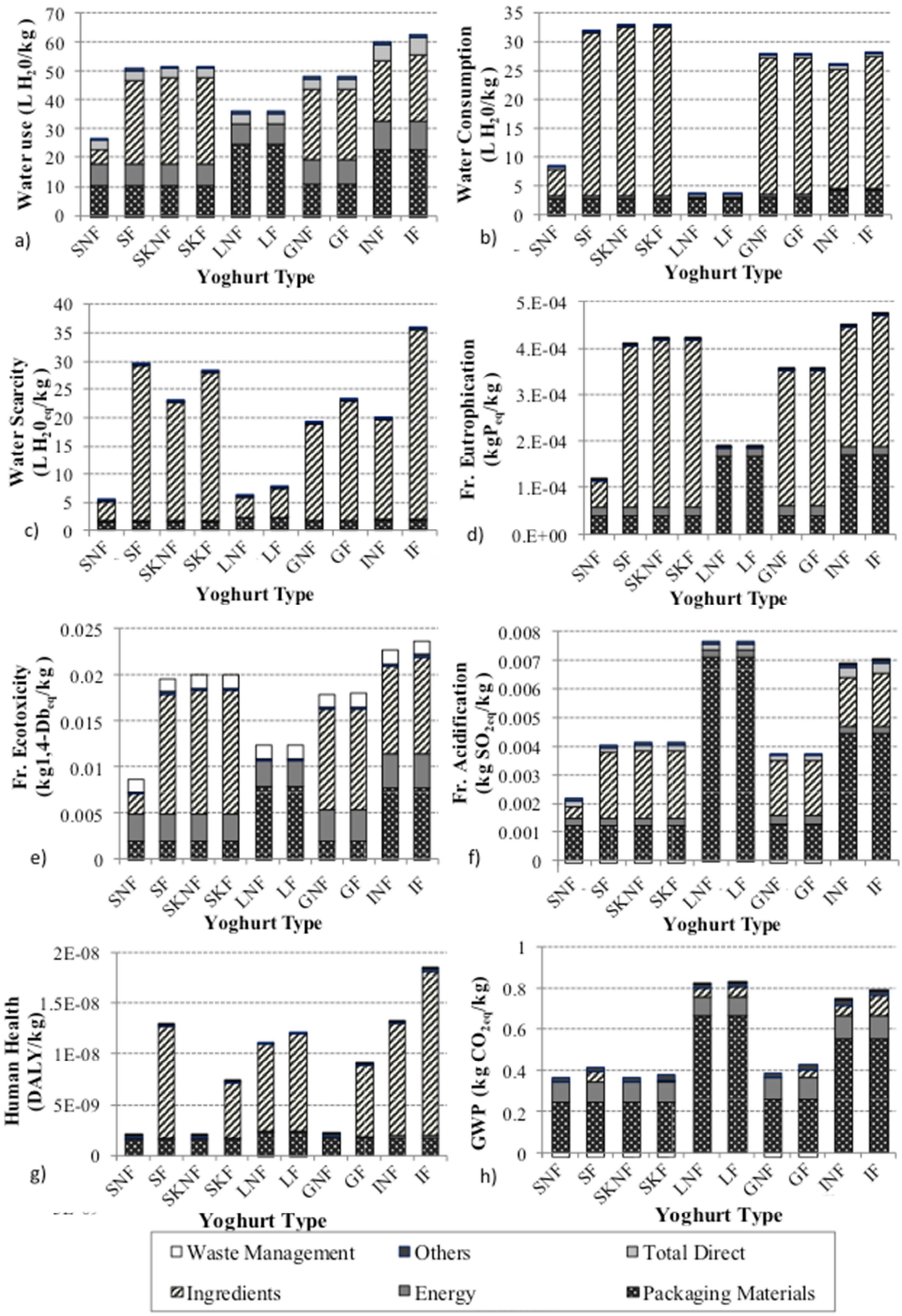
Figure 5. Relative contributions of (a) the ingredients and (b) of packaging materials of for Greek-style flavored yoghurts

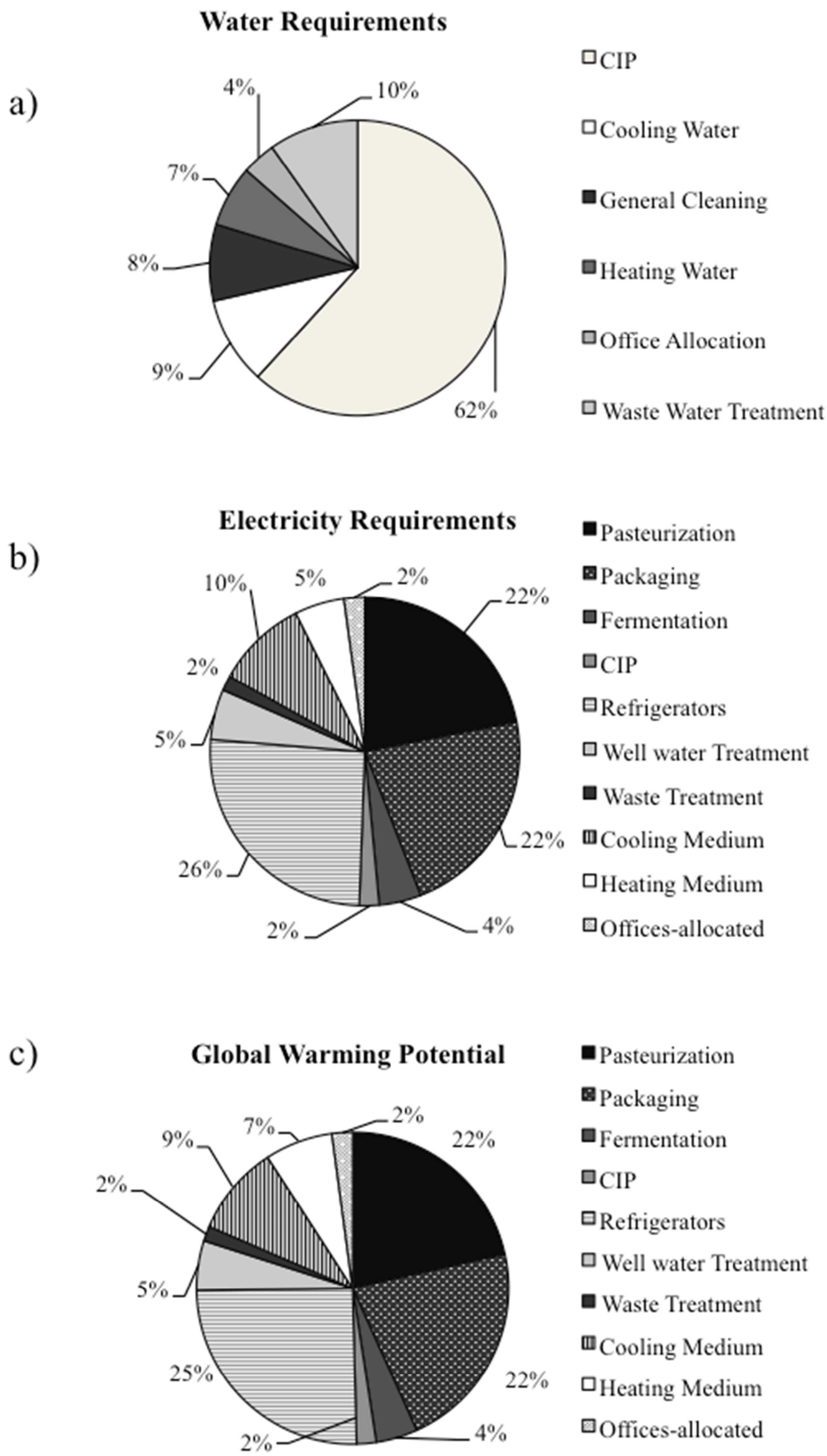
Figure 6. (%) (a) Water use, (b) water consumption and (c) water scarcity for a dairy plant located in Spain

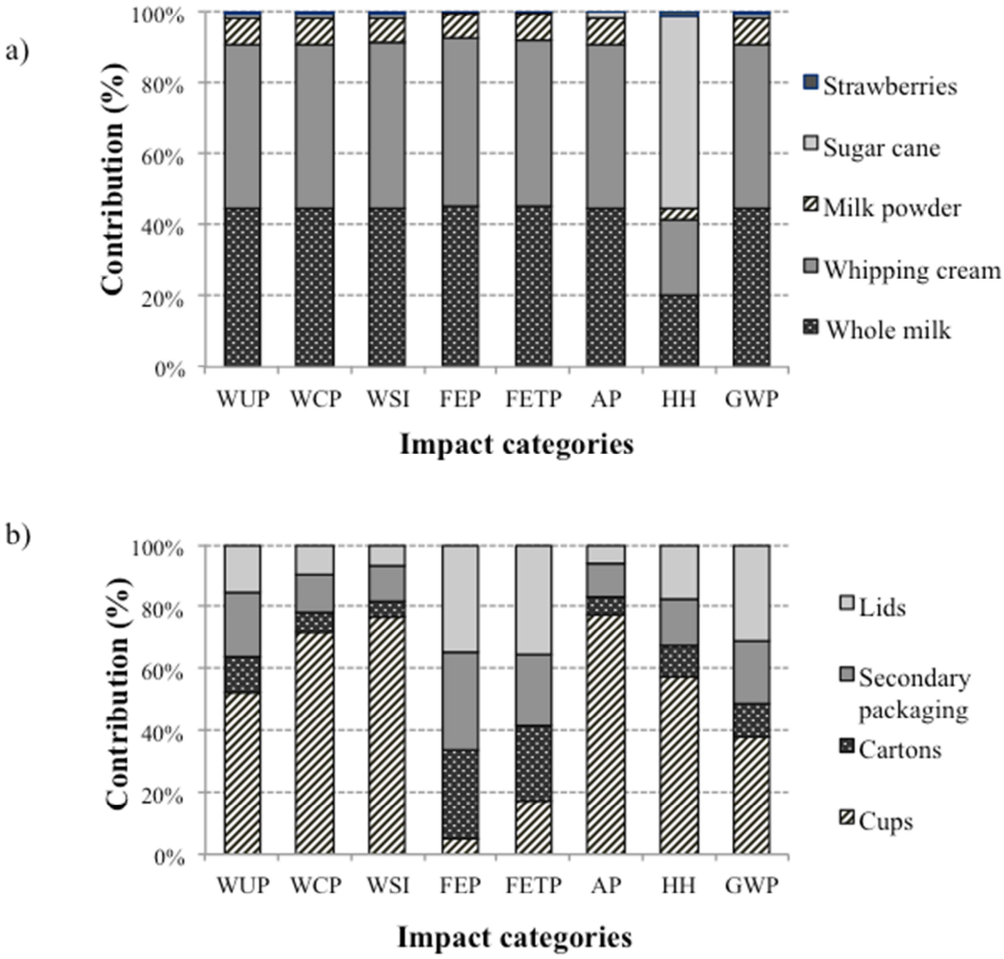

Upstream Processes
Core Processes
Production of raw milk
Feed Crop Cultivation
Livestock Farming
Production of additives
Raw Ingredients Production (i.e. fruits)
Additives Production
Production of Packaging
Raw materials manufacturing
Packaging Production
Dairy Processing Plant
Pasteurization
Production Processes
Packaging
Cleaning Operations
Waste Water Treatment
Waste Management
T
Product Factory Gate
Transport
System Boundaries

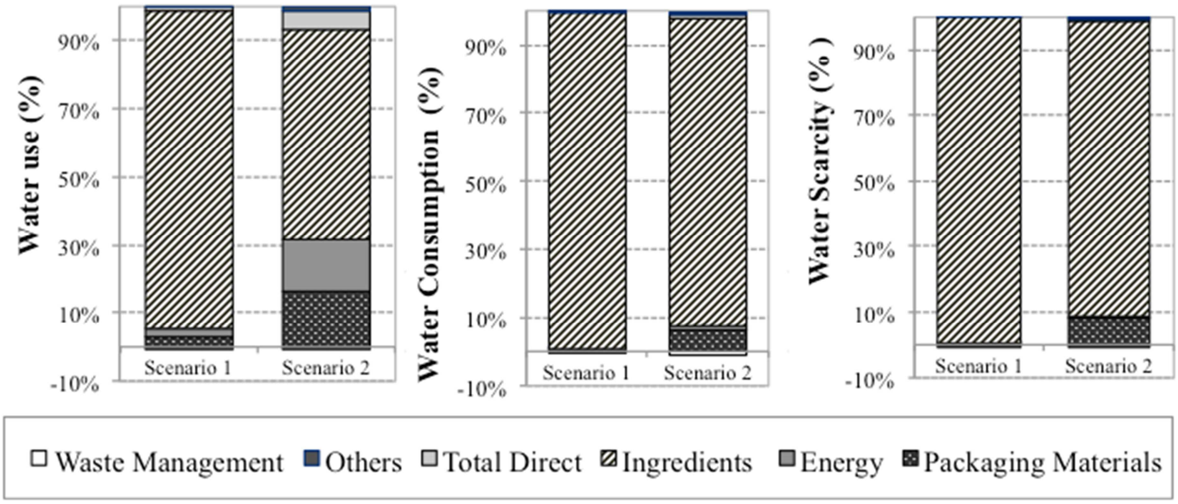


Milk reception
Cream
Skimmed milk
Pasteurisation cream
Mixing
Sugar
Milk Powder etc.
Additives
Pasteurisation
Homogenisation
Mixing
Packaging
Cooling
Freezer storage
Ice-cream yoghurt
Liquid and Greek style yoghurt
Reception to fermentation tank
Fermentation in tank
Cooling
Set yoghurt
Waiting Tanks
Heating
Packaging
Fermentation
Cold Tunnel
Secondary Packaging
Liquid packaging
Liquid yoghurt
Greek yoghurt packaging
Secondary packaging
Greek style yoghurt
Cold storage
Distribution


a)
Water use (L H$_2$0/kg)
b)
Water Consumption (L H$_2$0/kg)
c)
Water Scarcity (L H$_2$0$_{eq}$/kg)
d)
Fr. Eutrophication (kgP$_{eq}$/kg)
e)
Fr. Ecotoxicity (kg1,4-Db$_{eq}$/kg)
f)
Fr. Acidification (kg SO$_{2eq}$/kg)
g)
Human Health (DALY/kg)
h)
GWP (kg CO$_{2eq}$/kg)
SNF
SF
SKNF
SKF
LNF
LF
GNF
GF
INF
IF
Yoghurt Type
Waste Management
Others
Total Direct
Ingredients
Energy
Packaging Materials


a)
Water Requirements
62%
9%
8%
7%
4%
10%
CIP
Cooling Water
General Cleaning
Heating Water
Office Allocation
Waste Water Treatment
b)
Electricity Requirements
22%
22%
4%
2%
26%
5%
2%
10%
5%
2%
Pasteurization
Packaging
Fermentation
CIP
Refrigerators
Well water Treatment
Waste Treatment
Cooling Medium
Heating Medium
Offices-allocated
c)
Global Warming Potential
22%
22%
4%
2%
25%
5%
2%
9%
7%
2%
Pasteurization
Packaging
Fermentation
CIP
Refrigerators
Well water Treatment
Waste Treatment
Cooling Medium
Heating Medium
Offices-allocated


a)
Contribution (%)
100%
80%
60%
40%
20%
0%
WUP
WCP
WSI
FEP
FETP
AP
HH
GWP
Impact categories
Strawberries
Sugar cane
Milk powder
Whipping cream
Whole milk
b)
Contribution (%)
100%
80%
60%
40%
20%
0%
WUP
WCP
WSI
FEP
FETP
AP
HH
GWP
Impact categories
Lids
Secondary packaging
Cartons
Cups



Water use (%)
90%
70%
50%
30%
10%
-10%
Scenario 1
Scenario 2
Water Consumption (%)
90%
70%
50%
30%
10%
-10%
Scenario 1
Scenario 2
Water Scarcity (%)
90%
70%
50%
30%
10%
-10%
Scenario 1
Scenario 2
Waste Management
Others
Total Direct
Ingredients
Energy
Packaging Materials

Highlights

- Assessment of Water and Carbon Footprint of various types of yoghurts has been carried out
- Hot-spots and environmental burdens associated to processing stages are identified
- Raw milk and milk-based ingredients are the main contributors to all impact categories