ENVIRONMENTAL IMPACT OF CHEESE PRODUCTION: A CASE STUDY OF A SMALL-SCALE FACTORY IN SOUTHERN EUROPE AND GLOBAL OVERVIEW OF CARBON FOOTPRINT

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ABSTRACT

The environmental performance of a small-scale cheese factory sited in a NW Spanish region has been analysed by Life Cycle Assessment (LCA) as representative of numerous cheese traditional factories that are scattered through the European Union, especially in the southern countries. Inventory data were directly obtained from this facility corresponding to one-year operation, and the main subsystems involved in cheese production were included, i.e. raw materials, water, electricity, energy, cleaning products, packaging materials, transports, solid and liquid wastes and gas emissions. Results indicated that the environmental impacts derived from cheese making were mainly originated from raw milk production and the natural land transformation was the most affected of the considered categories. On the contrary, the manufacturing of packaging material and other non-dairy ingredients barely influenced on the total impact. Additionally, an average carbon footprint of the cheeses produced in the analysed facility has also been calculated, resulting milk production and pellet boiler emissions the most contributing subsystems. Furthermore, it was notable the positive environmental effect that entailed the direct use of whey as animal feed, which was considered in this study as avoided fodder. Finally, a revision of published works regarding the environmental performance of cheese production worldwide was provided and compared to results found in the present work. According to the analysed data, it is clear that the content of fat and dry extract are determinant factors for the carbon footprint of cheeses, whereas the cheesemaking scale and the geographical area have a very low effect.

Keywords: LCA, traditional, cheese, environmental impact, carbon footprint, Spain.

1. INTRODUCTION

The food sector is one of the most important manufacturing and economic sectors in Europe, however, it is also an important source of environmental impacts (González-García, 2013a). Certainly, the food and beverages sector is responsible for 20-30% of the household environmental impacts in Europe (van Middelaar et al., 2011; Palmieri et al., 2017). The types of foods with the greatest burdens are meat products (beef, pork and poultry) and dairy products (cheese, milk and butter) (Notarnicola et al., 2017). Dairy products constitute a significant source of daily nutrients for human consumption, and are highly recommended as part of a healthy and balanced diet. Nevertheless, their production has been associated with a great environmental impact (Palmieri et al., 2017). Within dairy products, nowadays cheese is experiencing an increasing demand and is the most consumed dairy product after drinking milk (González-García, 2013b; Röös et al., 2016; FAO, 2017). Concretely, the per-capita apparent consumption of cheese represents about 3% of the overall basket in the European Union (Notarnicola et al., 2017). Since fresh milk is a highly perishable product with high transport cost associated, it is commonly processed in the region where it is produced (González-García, 2013a). In Europe, after local fresh-milk requirements have been met, cheese has traditionally been considered the preferred outlet for milk, being the European Union the largest producer of cheese in the world (Finnegan et al., 2017). In addition, every year, approximately 10 million tons of cheese are consumed in the EU. This means that, on average, each European yearly eats about 14 kilos and it is expected that cheese consumption per capita in the European Union will increase to 16 kg by 2025 (Statista, 2018).

Current patterns of food production and consumption are increasingly considered to be unsustainable in several ways. Lifecycle thinking and assessment, and their analytical power in assessing supply chains, have been recommended as reference methodologies for assessing the impacts derived from food production (Notarnicola et al., 2017). In fact, it has been demonstrated that life cycle assessment (LCA) is a convenient method for quantifying resource use and emissions in a wide range of primary and industrial sectors (Calderón et al., 2010; Laca et al., 2011; Iglesias et al., 2012; Vázquez-Rowe et al., 2012; Calderón et al., 2018; Abín et al., 2018). Particularly, this environmental methodology has been widely applied for the evaluation of the environmental performance of different agro-food products, such as, fish, eggs and meat, paying special attention to the dairy sector (González-García et al., 2013a). In addition, lately carbon footprint has been used as a global measure of the production performance of different foodstuffs regarding the different domains of sustainability. Therefore, carbon footprint is a very effective tool from a communication point of view, although, as reported by Casolani et al. (2016), it is only part of the whole.

The first LCA studies focused on cheese production appeared in 2000 and, since then to now, the number of them has been increasing. However, several authors claim that there is still a lack of information regarding different aspects of the environmental performance of cheese factories (Finnegan et al., 2017). In this context, it should be remark that very little information about the production of small-scale artisanal cheese has been reported. Indeed, to the best of our knowledge, only a few works has been published regarding this issue. Specifically, Vagnoni et al. (2017) analysed the production of Sardinian sheep milk cheese at industrial and semi-artisanal scale in Italy and found that the scale has no effect on GHG emissions in the studied case. In Brazil, Santos et al. (2017) analysed a small-sized dairy industry and Nigri et al. (2014) assessed the artisanal manufacturing processes of “Minas” cheese. The former author concluded that the artisanal production of “Minas” cheese exerted lower environmental impacts than the industrial process and highlighted the need of further studies on the analysis of the environmental impact of cheese production at different scales.

Moreover, a considerable amount of cheese is produced in Europe, on both artisanal and factory scale, especially in southern Europe (Fox et al., 2017). Concretely, the quantity of artisan cheese producer has grown significantly (Bouma et al., 2014; Maye et al., 2016). Since 2012, FACE (Farmhouse and Artisan Cheese & Dairy Producers European Network) has been working to represent and defend the interests of European farmhouse and artisan cheesemakers. Actually, many cheese producers in Europe, are organized in small, family-owned and operated cheese factories. Spain occupies the seventh position in EU-28 in terms of the volume of cheese produced (EUROSTAT, 2015). There are few dairy multinational companies that account for the main production of industrial cheeses, however, in terms of the number of dairy factories, more than 85% have less than ten workers in Spain. Approximately, 70% of Spanish raw milk is produced in the North of Spain and, concretely Asturias is one of the regions with most tradition in manufacturing cheese, producing more than one hundred varieties, many of them included in the Protected Designation of Origin (PDO) (MAPAMA, 2017).

Cheese has been reported as one of the dairy products with higher environmental impacts and, although the dairy sector has been thoroughly analysed from a LCA perspective, and, as commented above, few environmental information is available about the manufacturing of artisanal cheeses. Indeed, still today, there is a lack of data regarding the environmental impacts associated with small- or large-scale cheese production. In addition, this is difficult to establish predictions since, it is expected that, on one hand, a larger scale entails saving on resources and, on the other hand, a smaller scale with less mechanised processes involves less requirements of energy (Iglesias et al., 2012; Santos et al. 2017). Consequently, the objective of this work has been to analyse the environmental performances of a small-scale cheese factory, which has been selected as representative of traditional cheese production in southern Europe. This factory is located in a Spanish region (Asturias), where the artisanal production of cheese has a strong traditional character. With this work it is expected to increase the knowledge about the environmental performance of small sized artisanal factories in southern Europe. Particularly, the results obtained here have been analysed and compared to other LCA-studies found in literature with the main aim to determine the possible effects of scale and degree of mechanisation, as well as cheese composition and geographical area, on the impacts derived from cheese production. Besides, the identification of the subsystems with major environmental impacts in the specific factory here analysed would permit to establish improvement actions, which could be extrapolated to other artisanal cheese factories with similar size and organization.

2. MATERIALS AND METHODS

2.1 LCA

2.1.1 Objectives and functional unit definition

LCA methodology was employed with the aim to determine the environmental impact of a small-scale cheese factory sited in southern Europe. The functional unit chosen was 4770 kg of cheese, which is the amount of cheese produced in 2016.

2.1.2 System description and boundaries

The environmental assessment was carried out considering a "cradle to retail stores" perspective including the production of the main raw material and the management of wastes. The small factory selected as a case study for this work is located in northern Spain (Piloña, Asturias) and it produces mainly two different types of artisanal cheeses: "Franxón" Cheese (around 70% of production) and PDO "Casín" Cheese (approximately 30% of production). "Franxón" is a white mould cheese (similar to Camembert), which is made from pasteurized cow milk and matured for 15-20 days. "Casín" is a hard cheese obtained from raw cow milk and matured during 2 months, its texture is crumbly and dry and it possesses a characteristic odour and strong taste. "Franxón" and "Casín" are commercialised as whole cheese with weights of 270 g and 250 g, respectively. They are wrapped in paper and, due to its soft texture, "Franxón" is also packaged inside a poplar wood box. Both types of chesses are sold within the same region where they are produced. A plan of the main facilities of the cheese factory is shown in Figure 1.

2.1.3. Inventory analysis

Data were mainly collected through personal interviews with the owner of the cheese factory. Regarding the raw milk production, the main ingredient of cheese, data were obtained from a previous work where the environmental performance of a typical mid-sized farm (72 Holstein cows including heifers) sited in Asturias was analysed by LCA (Laca et al., 2018, unpublished results). The study included the whole life cycle involved in the production of the raw milk, i.e., farming of meadow grass silage and maize, transportation and production of raw materials (animal feed, cleaning products, bedding materials and drugs), consumption of energy and water, cow emissions (CO_2, CH_4 and NH_3) and management of manure, purines and wastewater. Manure and purines were applied to the farming land and wastewaters were used to irrigate the fields and the crops of the farm. Emissions derived from this activity were calculated considering that 30% of nitrogen was emitted as ammonia. Cattle were fed fodder concentrate, alfalfa, hay, maize silage, meadow grass silage and pasture. The transportation of food materials that were bought was considered. Heifers born in the farm were employed for replacement, whereas bull calves and old and low-producing cows were sold for meat (considered as by-product). A summary of this system is shown in the upper part of Figure 2.

At the cheese factory, minority ingredients, i.e., salt and $CaCl_2$, employed to produce the cheese were also considered. However, other ingredients that amounted less than 0.02% of total, i.e., starters and rennet, were not included in this work.

In relation to packaging materials, three different compounds were taken into account: paper, plastic bags (low density polyethylene) and poplar wood boxes.

Heat energy was obtained from a biomass pellet boiler. The emissions of this boiler were included in the study considering that the calorific value of biomass pellets is approximately 4200 kcal/kg and that this kind of boilers usually have 90% of efficiency. The production of consumed pellets was also included as an input in the system. The other source of energy employed in the facility was electricity.

Regarding cleaning products, it only was taken into account the impact derived from producing the plastic containers and the active compounds included in the composition of the commercial products. The impacts derived from producing other materials, such as cellulose rolls gloves were also considered.

The main waste originated from the cheesemaking process is whey. However, this whey is employed to feed pigs bred in a nearby farm. Hence, this waste was included in the inventory as pig fodder avoided. The correspondence between the whey used to feed the pigs and the avoided fodder was calculated on basis of their protein concentrations (9 g/L and 90 g/kg, respectively), so that 10 L of whey corresponded to 1 kg of avoided fodder.

The manufactured cheeses were transported to the retail stores by workers of the cheese factory employing a delivery van, whereas milk was transported by the suppliers and whey was transported by the owner of the pig farm.

It was assumed that all consumed tap water was managed as wastewater and sent to an urban wastewater treatment plant. Packaging of raw materials were separately recycled, whereas organic wastes were disposed in a landfill as municipal solid wastes.

Inventory data of cheese factory has been organized into the subsystems shown in Figure 2 and it is detailed in Table 1.

2.1.4 Impact assessment

Impact assessment of both phases, milk farming and cheese production, was performed with the LCA software package SimaPro v8, using the ReCiPe Midpoint (H) V1.12 / Europe Recipe H method. This method includes 18 impact category indicators (climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion) to reach wide impact category coverage and follows the latest recommendations of the LCA community (Heinonen et al., 2016). The advantages of this method include (i) the broadest set of midpoint impact categories and (ii) the use of impact mechanisms that have global scope (Santos et al., 2017).

2.2 Carbon Footprint

The carbon footprint (CF) of the cheeses was calculated employing the Greenhouse Gas Protocol V1.01 / CO2 eq (kg) again by means of the LCA software package SimaPro v8. The system boundaries and inventory analysis are described in sections 2.1.2 and 2.1.3. This method was selected because it is the method employed by the Spanish Ministry of Agriculture and Fishing, Food and Environment for CF calculations of industrial facilities (MAPAMA, 2017). Three different scopes are considered: scope 1 that includes all direct GHG emissions, scope 2 that includes GHG indirect emissions from purchased electricity and scope 3 that includes all the indirect emissions not considered by scope 2.

3. RESULTS AND DISCUSSION

3.1. LCA assessment

As can be seen in Figure 3, results obtained with the ReCiPe method revealed the production of raw milk as the factor with the highest environmental loads in all categories considered. Specifically, the milk subsystem is responsible of more than 75% of damaging impact for 8 of the 18 categories evaluated (climate change, terrestrial acidification, freshwater eutrophication, marine eutrophication, particulate matter formation, terrestrial ecotoxicity, urban land occupation and natural land transformation). In addition, this subsystem is almost the unique contributor to terrestrial ecotoxicy and natural transformation meaning more than 99% of the damaging impact in these categories.

The subsystems related with consumption of energy showed also a great influence on the categories considered. In fact, electricity contributes more than 40% to freshwater ecotoxicity, marine ecotoxicity and ionising radiation categories. Regarding this last category, it should be kept in mind that the use of radioactive material within nuclear reactors to generate electricity also generates additional ionising radiation and, nowadays, in Spain, nuclear energy is the second source of electricity (MINETUR, 2017). With concerns to in situ heat energy production, the boiler emissions were responsible for more than 10% of the impact in 8 of the categories considered (human toxicity, photochemical oxidant formation, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, and metal depletion). Additionally, transport exerted a noticeable influence on ozone depletion category (57%) and it meant more than 10% of impact in human toxicity, photochemical oxidant formation and fossil depletion categories. Other meaningful subsystems that can be observed in Figure 3, were the use of tap water on water depletion category (35%) and the production of the pellets that contributed to the impact of agricultural land occupation and urban land occupation categories in 7% and 5%, respectively.

It is also worth to notice the favourable effect of the subsystem wastes on water depletion category (31%) due to the recycling of plastic containers and to the management of wastewater that, once treated, is returned to the environment. Moreover, the use of whey to feed pigs exerted a beneficial effect on all the studied categories because of the consideration of this whey as fodder avoided. Specifically, this beneficial effect means 41% (with respect to the harmful impact) on urban land occupation, 21% on natural land transformation, 21% on terrestrial ecotoxicity and 15% on human toxicity. González-García et al. (2013b) analysed the environmental impact of a traditional Galician cheese production and pointed out that when whey was valorised, reductions of up to 15% were achieved in the harmful impacts.

Despite to the fact that different methodological choices are employed by different authors, it should be highlighted that, results obtained in this work are in general in agreement with results obtained in previous studies. Hence, in all the works summarised in Table 2, raw milk production resulted to be the main contributor to the environmental impact derived from cheese production. González-García et al. (2013a) and González-García et al. (2013b) reported that contribution of raw milk production to environmental impacts of cheese elaboration was within the range 63-91%, whereas Santos et al. (2016) found that in a small-sized industry in Brazil the contribution of the production of the cheese at the dairy was lower than 29% and raw milk contributed 70-98% to the impact categories. In the present work these values were between 21 and 99%, depending on the impact category considered. Therefore, reducing the impact of milk production is the key parameter to decrease the ecological impact of cheese manufacture.

The normalization phase allows comparing all environmental impacts using the same scale. According to the obtained outcomes, the most significant category, which showed the maximum deviation from the reference average, was natural land transformation. As above commented, the raw milk subsystem is responsible for almost all the harmful impact in this category, whereas the avoided product exerted a favourable effect. Marine eutrophication, terrestrial ecotoxicity, freshwater ecotoxicity and marine ecotoxicity were also notable categories considering normalization results. Marine eutrophication and terrestrial ecotoxicity impacts were determined again by milk production, whereas, in addition to the milk subsystem, electricity exerted an important effect on freshwater and marine ecotoxicities.

Finally, it should be remarked that, according with a previous study (Laca et al., 2018, unpublished results), cow feed was responsible of nearly all the impact generated by milk production. Specifically, the impact in natural land transformation can be almost totally attributed to fodder production, mainly to the use of soybean as ingredient. It is clear that soybean cultivation is linked to serious environmental problems. This agrees with results reported in literature regarding the use of soy in animal feeding, since soy production is described as responsible of land use change and rainforest depletion, especially in South America (Leguizamón, 2014; Cesari et al., 2017; Thrane et al., 2017). Moreover, soy used in Europe are partly or wholly produced overseas, concretely, soy is imported mainly from Brazil and Argentina, in which land may have been converted from forest (Leinonen et al., 2012).

3.2. Carbon footprint

An average value of 10.2 kg CO_2 eq per kg of cheese was obtained from Green House Gas Protocol for the studied factory (calculated by considering all the CO_2 categories shown in Figure 4). It should be remark that this value includes 1, 2 and 3 scopes. In detail, scope 1 (including only the emissions from the boiler and from the transport of the manufactured cheeses) meant 3.1 kg CO_2 eq kg^{-1} cheese, whereas scope 1+2 (including also electricity) signified 4.6 kg CO_2 eq kg^{-1} cheese. The remaining 25% was due to indirect activities such as the production of raw materials.

The production of raw milk meant more than 70% of fossil CO_2 eq emissions (mainly due to cow food production), whereas electricity contributed approximately 17% to the total. Besides, the most part of biogenic CO_2 eq was also originated by raw milk production (58%) (mainly due to cow emissions), followed by pellet boiler emissions (42%), and, again, milk is responsible for almost 100% of CO_2 eq derived from land transformation. It should be highlighted the reduction in fossil CO_2 emissions achieved by the fodder avoided by the use of whey for pig feeding. However, this beneficial effect was almost balanced by the reduction in CO_2 uptake, since the use of whey for animal feeding avoids the raise of crops to be employed for livestock feeding. On the contrary, the production of raw milk contributed favourably to this category, which compensate biogenic emission of CO_2 eq.

3.3. Global overview and measures for environmental improvement

It is evident that the specific characteristics of each process to produce a particular type of cheese are determinants for the derived environmental impacts. As can be seen in Table 2, the carbon footprint (CF) value resulting from the present study (10.2 kg CO_2 eq kg^{-1}) were within the range of values reported in literature for cow cheeses (4.2-16.9 kg CO_2 eq kg^{-1}). Moreover, it should be highlighted that this CF value was almost the same as that estimated by González-García et al. (2013b) for “San Simón da Costa” (a traditional Galician cheese, Spain) and it is also in the range reported for Cheddar in USA and Denmark (8.6-16.2 kg CO_2 eq per kg) (Capper and Cady, 2012; Kim et al., 2013; Kristensen et al., 2015). All these cheeses (“Franxón”, “Casín”, “San Simón da Costa” and Cheddar) are considered as full-fat cheeses, i.e., their fat content (on a dry matter basis) is above or equal to 45% and less than 60%, according to the Codex General Standard for Cheese (FAO, 2017). Additionally, Finnegan et al. (2017), who reviewed several LCA studies focused on the environmental impacts of different cheese types (fresh, mature and semi-hard) in the USA, Canada and Europe, concluded that fresh cheeses imply less environmental impact than semi-hard cheeses. Thus, it is obvious that environmental impacts vary in terms of cheese moisture and fat content, which is closely linked to the type of cheese, as it was reported by Djekic et al. (2014).

The effect of several factors on the CF values reported in Table 2 are analysed in Figure 5 (only CF values corresponding to facilities where cheese was the main product were included). According to that above mentioned, a clear relation between carbon footprint and cheese composition can be observed, since CF value raises as the content of fat (FAT) and dry extract (DE) increases (see Figure 5A and Figure 5B, respectively). Furthermore, the CF values and the fat content of cheese can be related with a very good fitting by a lineal equation, obtaining the next empirical expression:

$$CF = 0.2983xFAT+1.55 \quad (R^2=0.9488) \quad \text{(Eq. 1)}$$

In a similar manner, the CF and the dry extract content data can be correlated by means of a polynomial equation, also with a considerably good fitting, obtaining the next empirical expression:

$$CF = 0.0109xDE^2-0.850xDE+23.5 \quad (R^2=0.9332) \quad \text{(Eq. 2)}$$

In addition to the fact that the data fitting was better, the content of fat on dry basis is a more sensitive parameter than the dry matter content, thus, Eq. 1 is a better option to estimate the CF of cheeses from its fat content.

In Figure 5C, a slight trend could be observed indicating lower CF values for bigger factories. However, it was impossible to find an equation that related CF and facility size thorough the amount of milk processed per year. Concerning this matter, there are very few works that analyse the effect of the scale on the impact derived from cheese production. In this context, Vagnoni et al. (2017) compared the production of Sardinian sheep milk cheese at industrial scale and manufactured on-farm with a semi-artisanal system and found that the CF of 1 kg of each cheese were similar, with an average value of 17 kg CO_2 eq per kg of cheese.

Regarding the effect of geographical area, it can be seen in Figure 5D that the average values of CF were similar in all cases, around 10 kg CO_2 eq per kg of cheese. The widest range of CF values was found for USA-Canada, whereas in Northern and Southern Europe the variability was more similar.

When sheep milk is employed instead of cow milk, the CF of the cheese is notably higher. Certainly, Vagnoni et al. (2017) obtained an average value of 17 kg CO_2 eq/kg cheese for Italian "Pecorino" cheese. This is due to the fact that the CF of raw sheep milk is quite higher (2.0-5.2 kg CO_2 eq/kg milk) than the CF of raw cow milk (0.6-2.1 kg CO_2 eq/kg milk), mainly due to the lower milk yield of sheep (Flysjö et al., 2011; Weiss and Leip, 2012; Del Prado et al., 2013; Batalla et al., 2015).

It is evident that the main actions to reduce environment impacts of cheese production should be focused on decreasing the impact of raw milk production. Therefore, the development of an adequate cattle feed formulation is a key aspect to lessen the milk production impact. For this purpose, different improvement actions could be carried out. For example, it has been previously reported the convenience of increasing pasture grazing and producing the crops employed for cattle feeding in the same farm that produces the milk. Concerning this matter, and according to O´Brien et al. (2015), increasing the length of the grazing season helps to reduce the carbon footprint enhancing at the same time the economic performance. Certainly, Weiss and Leip (2012) suggested that high productivity, low dependency of imported feed products and a high share of pasture in the animal feed diet are three main factors to decrease derived environmental impacts. In the particular case studied here, the cheese factory was located in the green zone of Spain, which has a mild and humid climate. These climatic conditions are suitable to favour the local production of forages and pasture, thus, the actions described above are viable measurements that could be carried out to improve the environmental performance not only of the analysed factory, but also of those dairies placed on the green Europe.

The cow breed is also an important factor to be considered with regards to the impact of milk production, concretely the production of milk from Jersey cows has been found to have lower environmental impacts compared to Holstein milk production (Capper and Cady, 2011; Kristensen et al., 2015). Besides, it should be highlighted that the sold of surplus calves and culled cows for meat production exerts a beneficial effect on the environmental impacts and contributes noticeably to the reduction of the carbon footprint value (on behalf of considering the meat as avoided product) (Hospido et al., 2003; Iribarren et al., 2011; Laca et al., 2018, unpublished results).

Additionally, some actions could be taken at the cheese factory to improve the environmental performance of cheesemaking. In this regard, the Reference Document on Best Available Techniques (BREF) in the food, drink and milk industries summarises the principal BAT (Best Available Techniques) for dairies and specific BAT for producing cheese (EIPPCB, 2017). Some of the techniques recommended specifically for this sector are the use of ultrafiltration, the reduction of fat and cheese fines in whey, the minimisation and re-use of the whey produced and the recovery of heat from warm streams. In the factory analysed in this work, the whey is already delivered for re-use, however, it can be considered the possibility of using ultrafiltration to treat the whey before being discharged in order to increase the cheese yield. Certainly, the yield of this cheesemaking factory is 0.107 kg of cheese per L of milk, which means 91% of the theoretical maximum. Therefore, it can be expected that the recovery of casein fines, whey proteins and fat particles from the whey and they addition to the cheese drought could increase the yield in almost 10%. Additionally, increments in yield of about 8% by using ultrafiltration have been reported for hard cheeses (Pal, 2003). Taking into account that the implementation of an ultrafiltration system would allow an 8% increase in cheese yield, the reduction of the impact would be between 1.2 and 7.3%, depending on the considered category. With respect to the energy, a saving measure that could be taken is the use of the heat from the pasteurised milk to preheat the raw milk. However, even with an optimistic prevision that considered a 30% saving in the thermal energy (pellet boiler), the impact reduction would be between zero and 8.5%. A measure that could reduce significantly the impacts would be the replacement of the pellet boiler for a solar panel system. In addition to the elimination of the impacts derived from the subsystems “Pellets” and “Boiler emissions”, a 24% decrease in electricity consumption could be achieved (assuming saving of electricity similar to those that can be achieved in family homes). The results of this alternative scenario are shown in Figure 6. It is noticeable that the use of a solar panel system would exert a beneficial effect on all the impacts categories considered, with reductions lower than 1% for natural land transformation and terrestrial ecotoxicity and even around 30% for other categories, such as agricultural and urban land occupations, freshwater and marine ecotoxicities, metal depletion and ionising radiation.

Another aspect that must be considered to understand the magnitude of the impacts derived from cheese making is the existence of multi-product systems, i.e., those facilities where not only cheese is produced, but also food-grade whey powder. In this scenario, the allocation of environmental burdens on both products (cheese and dry whey co-product) usually decreases the environmental impacts associated with the cheese production (González-García et al., 2013a).

4. CONCLUSIONS

An artisanal small-scale cheese factory in Southern Europe has been environmentally assessed. The inventory data corresponding to the year 2016 have been thoroughly collected, an LCA analysis has been carried out and, in addition, the carbon footprint has also been calculated. The global warming potential (10.2 kg CO_2 eq) resulting from the production of 1 kg of cheese in this geographical area was within the range of values reported for other full-fat cheeses (8.6-16.2 kg CO_2 eq per kg). An analysis of published works carried out showed that the composition of cheese, i.e. fat and dry extract contents, is determinant for the CF value, and mathematical expressions were proposed for estimated the CF just by knowing one of these parameters.

In addition, LCA results showed that, raw milk was the most relevant source of environmental impacts in all the categories under assessment. Concretely, the natural land transformation was the most notably affected of the studied categories. In particular, the production of food for cow feeding in the farm was the most impacting factor derived from milk production and therefore associated to cheese production. Electricity consumption at the cheese factory and boiler emissions also showed notable influence on the impact of some of the analysed categories, i.e., freshwater ecotoxicity, marine ecotoxicity and ionising radiation.

Hence, and according to carbon footprint calculation and also LCA results, raw food would be the main subsystem to take into account in order to lessen the environmental impact of this factory. Thereof, the only action that can be carried out at the cheese factory with respect to decrease the impact related with milk production would be to select milk suppliers with more environmental-friendly farms. Nevertheless, some aspects can be modified in the industrial phase to reduce environmental impacts of cheese factory such as yield improving and reducing energy consumption. In addition, in the system analysed, the carbon footprint is reduced in 1.7 kg CO_2 eq kg^{-1} cheese on behalf of the use of whey to feed pigs. Thus, the employment of whey from small-sized factories as animal feed has been proved to be an interesting way to balance in some extent the harmful impacts derived from cheese production.

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REFERENCES

Abín, R., Laca, A., Laca, A., Díaz, M., 2018. Environmental assessment of intensive egg production: A Spanish case study. J. Clean. Prod. 179, 160-168.

Batalla, I., Knudsen, M.T., Mogensen, L., del Hierro, O., Pinto, M., Hermansen, J.E., 2015. Carbon footprint of milk from sheep farming systems in Northern Spain including soil carbon sequestration in grass lands. J. Clean. Prod. 104, 121-129.

Bava, L., Bacenetti, J., Gislon, G., Pellegrino, L., D'Incecco, P., Sandrucci, A., Tamburini, A., Fiala, M., Zucali, M., 2018. Impact assessment of traditional food manufacturing: The case of Grana Padano cheese. Sci. Total Environ. 626, 1200-1209.

Bouma, A., Durham, C.A., Meunier-Goddik, L., 2014. Start-up and operating costs for artisan cheese companies. J. Dairy Sci. 97, 3964-3972.

Calderón, L.A., Iglesias, L., Laca, A., Herrero, M., Díaz, M., 2010. The utility of Life Cycle Assessment in the ready meal food industry. Resour. Conserv. Recycl. 54, 1196-1207.

Calderón, L.A., Iglesias, L., Laca, A., Herrero, M., Díaz, M., 2018. Environmental impact of a traditional cooked dish at four different manufacturing scales: from ready meal industry and catering company to traditional restaurant and homemade. Int. J. Life Cycle Assess. (in press).

Capper, J.L., Cady, R.A., 2012. A comparison of the environmental impact of Jersey compared with Holstein milk for cheese production. J. Dairy Sci. 95, 165-176.

Casolani, N., Pattara, C., Liberatore, L., 2016. Water and Carbon footprint perspective in Italian durum wheat production. Land Use Policy 58, 394-402.

Cesari, V., Zucali, M., Sandrucci, A., Tamburini, A., Bava, L., Toschi, I., 2017. Environmental impact assessment of an Italian vertically integrated broiler system through a Life Cycle approach. J. Clean. Prod. 143, 904-911.

Clune, S., Crossin, E., Verghese, K., 2017. Systematic review of greenhouse gas emissions for different fresh food categories. J. Clean. Prod. 140, 766-783.

Dalla Riva, A., Burek, J., Kim, D., Thoma, G., Cassandro, M., De Marchi, M., 2014. Environmental life cycle assessment of Italian mozzarella cheese: Hotspots and improvement opportunities. J. Dairy Sci. 100, 7933-7952.

Del Prado, A., Mas, K., Pardo, G., Gallejones, P., 2013. Modelling the interactions between C and N farm balances and GHG emissions from confinement dairy farms in northern Spain. Sci. Total Environ. 465, 156-165.

Djekic, I., Miocinovic, J., Tomasevic, I., Smigic, N., Tomic, N., 2014. Environmental life-cycle assessment of various dairy products. J. Clean. Prod. 68, 64-72.

European IPPC Bureau (EIPPCB), 2006. Reference Document on Best Available Techniques in the Food, Drink and Milk Industries: http://eippcb.jrc.ec.europa.eu/reference/BREF/fdm_bref_0806.pdf (accessed 10 January 2018).

Eurostat-European Commission, 2015: http://ec.europa.eu/eurostat (accessed 17 January 2018).

FAO, 2017. Food and Agriculture Organization of the United Nations: www.fao.org/ (accessed 17 January 2018).

Finnegan, W, Yan, M., Holden, N.M., Goggins, J., 2017. A review of environmental life cycle assessment studies examining cheese production. Int. J. Life Cycle Assess. (in press).

Flysjö, A., Henriksson, M., Cederberg, C., Ledgard, S., Englund, J.E., 2011. The impact of various parameters on the carbon footprint of milk production in New Zealand and Sweden. Agric. Syst. 104, 459-469.

Fox, P.F., McSweeney, P.L.H., Cogan, T.M., Guinee, T.P., 2017. Overview of Cheese Manufacture, in: Fox, P.F., McSweeney, P.L.H., Cogan, T.M., Guinee, T.P., (Eds.), Fundamentals of Cheese Science. Springer, New York, pp. 11-25.

González-García, S., Castanheira, E.G., Dias, A.C., Arroja, L., 2013a. Environmental performance of a Portuguese mature cheese-making dairy mill. J. Clean. Prod. 41, 65-73.

González-García, S., Hospido, A. Moreira, M.T., Feijoo, G., Arroja, L., 2013b. Environmental Life Cycle Assessment of a Galician cheese: San Simon da Costa. J. Clean. Prod. 52, 253-262.

Heinonen, J., Säynäjoki, A., Junnonen, J.M., Pöyry, A., Junnila, S., 2016. Pre-use phase LCA of a multi-story residential building: Can greenhouse gas emissions be used as a more general environmental performance indicator? Build. Environ. 95, 116-125.

Hospido, A., Moreira, M.T., Feijoo, G., 2003. Simplified life cycle assessment of galician milk production. Int. Dairy J. 13, 783-796.

Iglesias, L., Laca, A., Herrero, M., Díaz, M., 2012. A life cycle assessment comparison between centralized and decentralized biodiesel production from raw sunflower oil and waste cooking oils. J. Clean, Prod, 37, 162-171.

Iribarren, D., Hospido, A., Moreira, M.T., Feijoo, G., 2011. Benchmarking environmental and operational parameters through eco-efficiency criteria for dairy farms. Sci. Total Environ. 409, 1786-1798.

Kim, D., Thoma, G., Nutter, D., Milani, F., Ulrich, R., Norris, G., 2013. Life cycle assessment of cheese and whey production in the USA. Int. J. Life Cycle Assess. 18, 1019-1035.

Kristensen, T., Søegaard, K., Eriksen, J., Mogensen, L., 2015. Carbon footprint of cheese produced on milk from Holstein and Jersey cows fed hay differing in herb content. J. Clean. Prod. 101, 229-237.

Laca, A., Herrero, M., Díaz, M., 2011. Process Considerations. Life Cycle Assessment in Biotechnology, in: Moo-Young, M. (Ed.), Comprehensive Biotechnology, Elsevier, Oxford, pp. 839-851.

Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I., 2012. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: egg production systems. Poult. Sci. 91, 26-40.

Leguizamón, A., 2014. Modifying Argentina: GM soy and socio-environmental change. Geoforum 53, 149-160.

Maye, D., Kirwan, J., Schmitt, E., Keech, D., Barjolle, D., 2016. PDO as a mechanism for reterritorialisation and agri-food governance: A comparative analysis of cheese products in the UK and Switzerland. Agriculture 6, 54.

Milani, F.X., Nutter, D., Thoma, G., 2011. Invited review: Environmental impacts of dairy processing and products: a review. J. Dairy Sci. 94, 4243-4254.

MAPAMA, 2017: Ministry of Agriculture, Fishing, Food and Environment (Spain): http://www.mapama.gob.es/es/. (accessed 9 January 2018).

MINETUR, 2017: Ministry of Energy, Tourism and Digital Schedule (Spain): http://www.minetur.gob.es/ (accessed 9 January 2018).

Nielsen, P.H., Høier, E., 2009. Environmental assessment of yield improvements obtained by the use of the enzyme phospholipase in mozzarella cheese production. Int. J. Life Cycle Assess. 14, 137-143.

Nigri, E.M., Barros, A.C., Rocha, S.D.F., Filho, E.R., 2014. Assessing environmental impacts using a comparative LCA of industrial and artisanal production processes: “Minas Cheese” case. J. Food Sci. Technol., Campinas, 34, 522-531.

Notarnicola, B., Tassielli, G., Renzulli, P.A., Castellani, V., Sala, S., 2017. Environmental impacts of food consumption in Europe. J. Clean. Prod. 140, 753-765.

O’Brien, D., Hennessy, T., Moran, B., Shalloo, L., 2015. Relating the carbon footprint of milk from Irish dairy farms to economic performance. J. Dairy Sci. 98, 7394-7407.

Pal, 2003. Membrane techniques - Applications of ultrafiltration, in: Caballero, B., Trugo, L., Finglas, P.M. (Eds.), Encyclopedia of Food Sciences and Nutrition, Academic Press, Elsevier, Cambridge, pp. 3842-3848.

Palmieri, N., Forleo, M.B., Salimei, E., 2017. Environmental impacts of a dairy cheese chain including whey feeding: An Italian case study. J. Clean. Prod. 140, 881-889.

Röös, E., Patel, M., Spångberg, J., 2016. Producing oat drink or cow's milk on a Swedish farm - Environmental impacts considering the service of grazing, the opportunity cost of land and the demand for beef and protein. Agric. Syst. 142, 23-32.

Santos, H.C.M., Jr., Maranduba, H.L., de Almeida Neto, J.A., Rodrigues, L.B., 2017. Life cycle assessment of cheese production process in a small-sized dairy industry in Brazil. Environ. Sci. Pollut. Res. 24, 3470-3482.

Sheane, R., Lewis, K., Hall, P., Holmes-Ling, P., Kerr, A., Stewart, K., Webb, D. Identifying opportunities to reduce the carbon footprint associated with the Scottish dairy supply chain – Main report. Edinburgh: Scottish Government, 2011.

Statista, 2018: https://www.statista.com/. (accessed 15 March 2018).

Thrane, M., Paulsen, P.V., Orcutt, M.W., Krieger, T.M., 2017. Soy protein: impacts, production, and applications, in: Nadathur, S. Wanasundara, J.P.D., Scanlin, L. (Eds.), Sustainable Protein Sources. Academic Press, London, pp. 23-45.

Vagnoni, E., Franca, A., Porqueddu, C., Duce, P., 2017. Environmental profile of Sardinian sheep milk cheese supply chain: A comparison between two contrasting dairy systems. J. Clean. Prod. 165, 1078-1089.

Van Middelaar, C.E., Berentsen, P.B.M., Dolman, M.A., de Boer, I.J.M., 2011. Eco-efficiency in the production chain of Dutch semi-hard cheese. Livest. Sci. 139, 91-99.

Vázquez-Rowe, I., Hospido, A., Moreira, M.T., Feijoo, G., 2012. Best practices in life cycle assessment implementation in fisheries. Improving and broadening environmental assessment for seafood production systems. Trends Food Sci. Technol. 28, 116-131.

Vergé X.P.C., Maxime, D., Dyer, J.A., Desjardins, R.L., Arcand, Y., Vanderzaag, A., 2013. Carbon footprint of Canadian dairy products: Calculations and issues. J. Dairy Sci. 96, 6091-6104.

Weiss, F., Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. Agric. Ecosyst. Environ. 149, 124-134.

FIGURE CAPTIONS

Figure 1. Scheme of the cheesemaking procedure.

Figure 2. System boundaries.

Figure 3. Characterization results obtained using ReCiPe Midpoint.

Figure 4. Carbon footprint per kg of cheese obtained using Greenhouse Gas Protocol.

Figure 5. Carbon footprint (CF) of cow milk cheeses reported in Table 2 vs. different factors: A) fat content, B) dry extract content, C) facility size and D) geographical area. Dotted lines denote lineal fitting in A), polynomial fitting in B) and dispersion area in C). ▲ corresponds to the CF obtained in the present work and □ corresponds to the average of different CF reported in other works for the same type of cheese. In D) the average values are shown and also the minimum and maximum values (in brackets it is indicated the number of CF values considered in each case).

Figure 6. Comparison between the environmental impacts derived from the production of cheese in the facility here analysed (dark bars) and those obtained for an alternative scenario that replaces the pellet boiler by a solar panel system (light bars).

Figure 1
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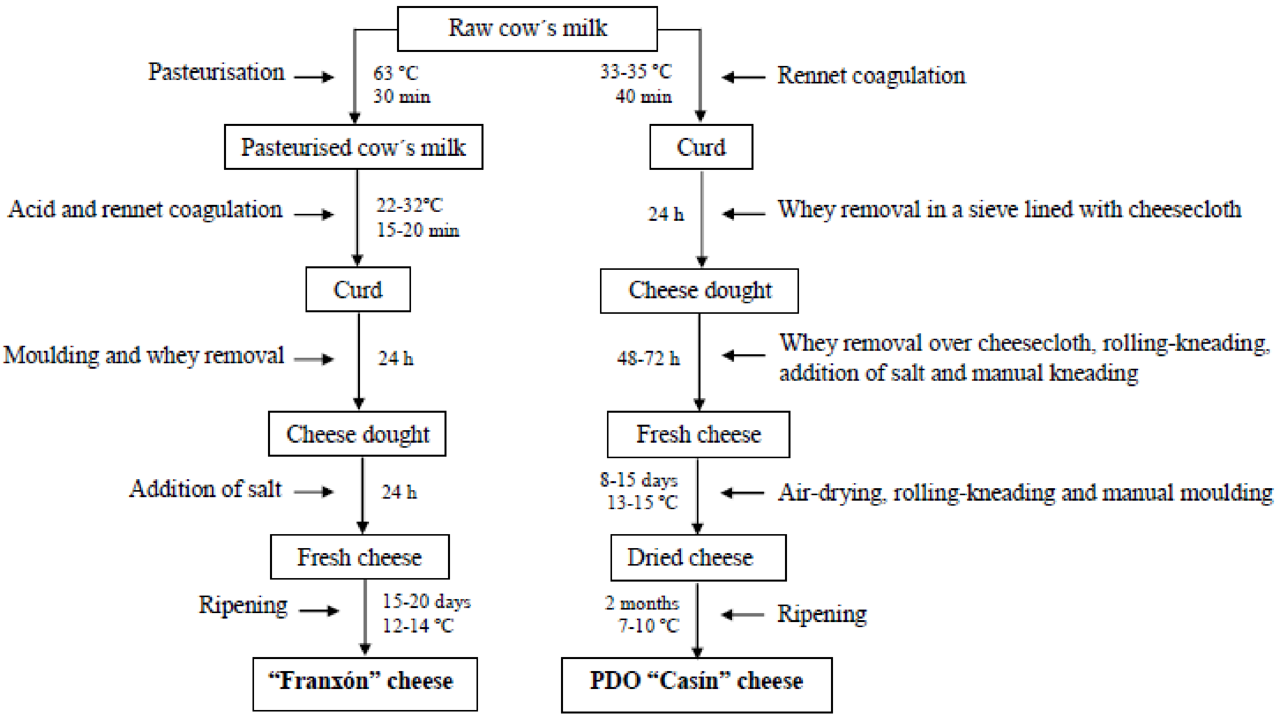

Figure 2

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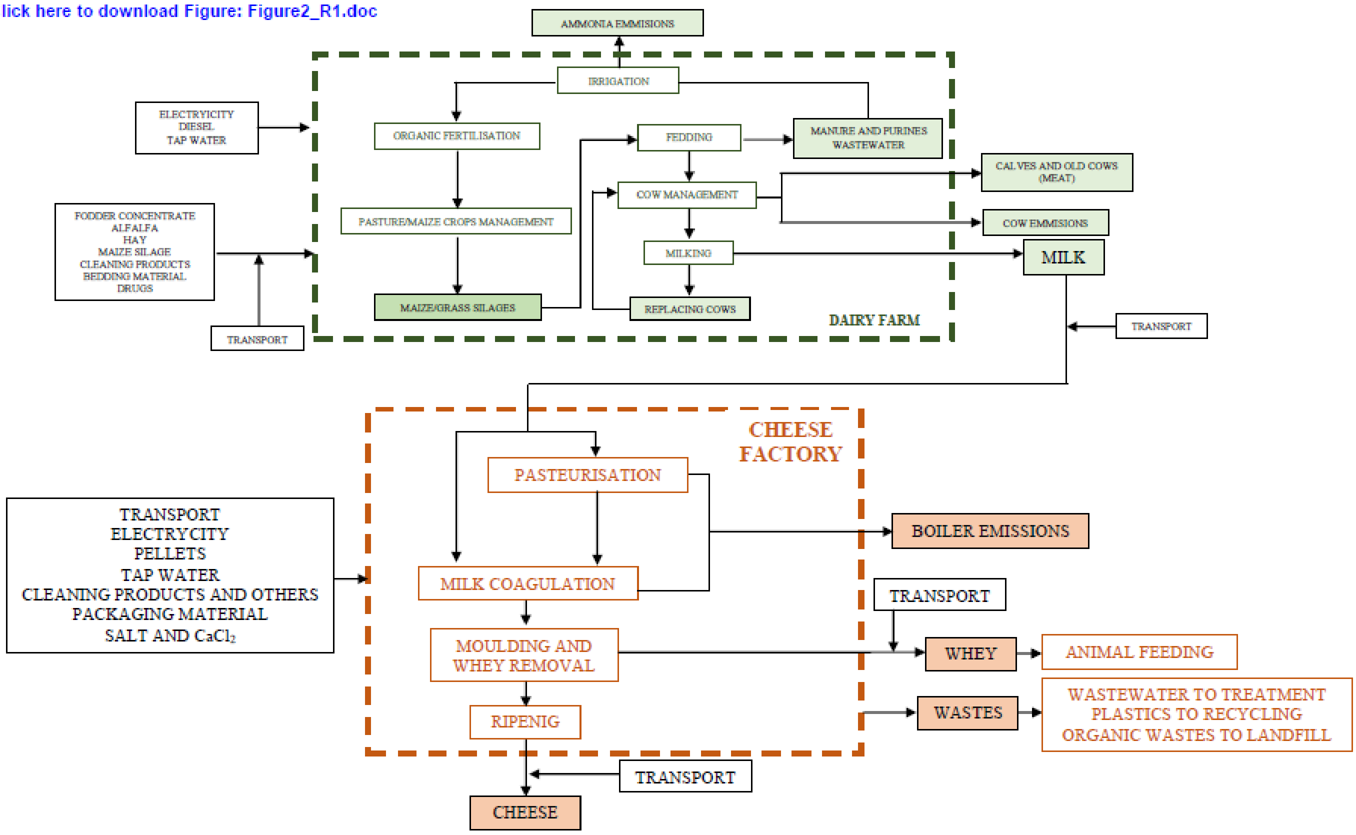

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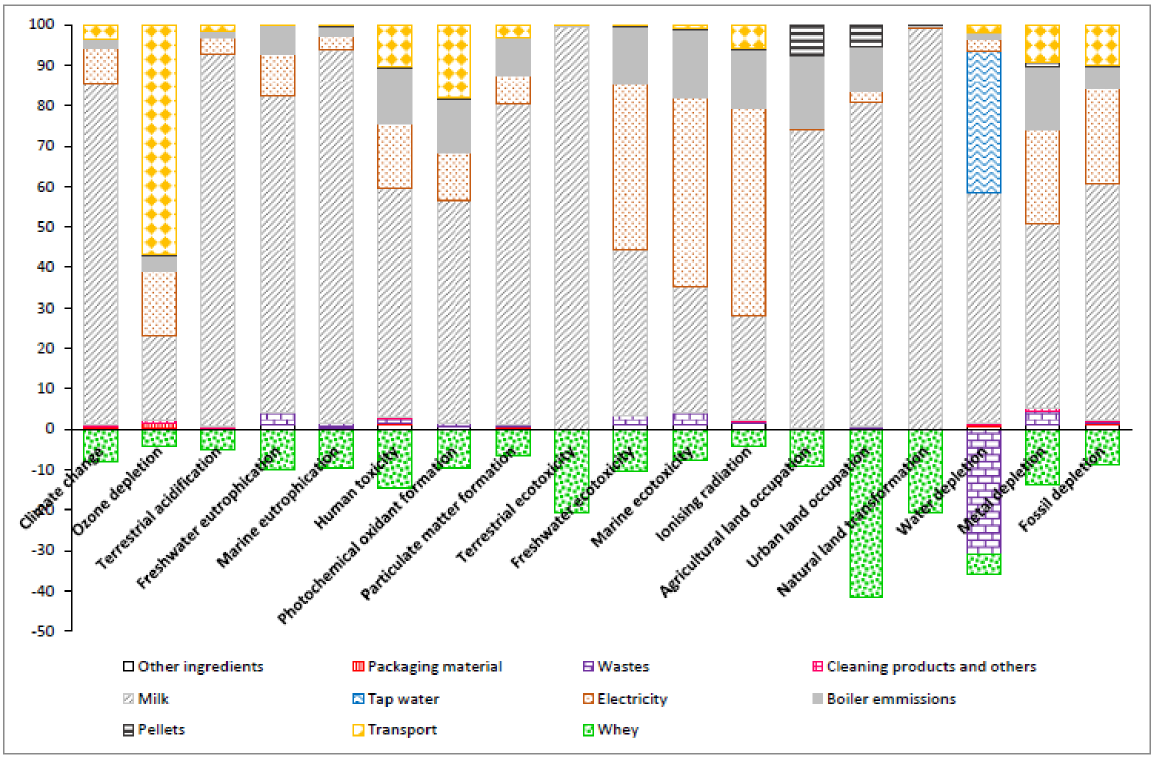

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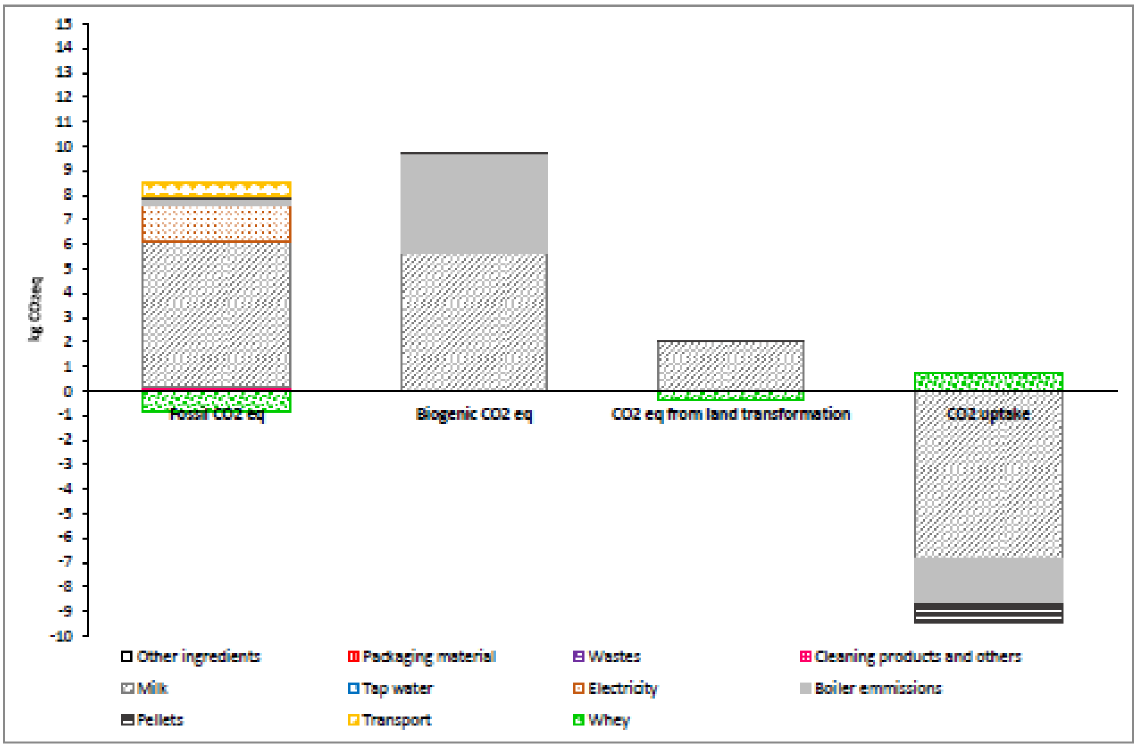

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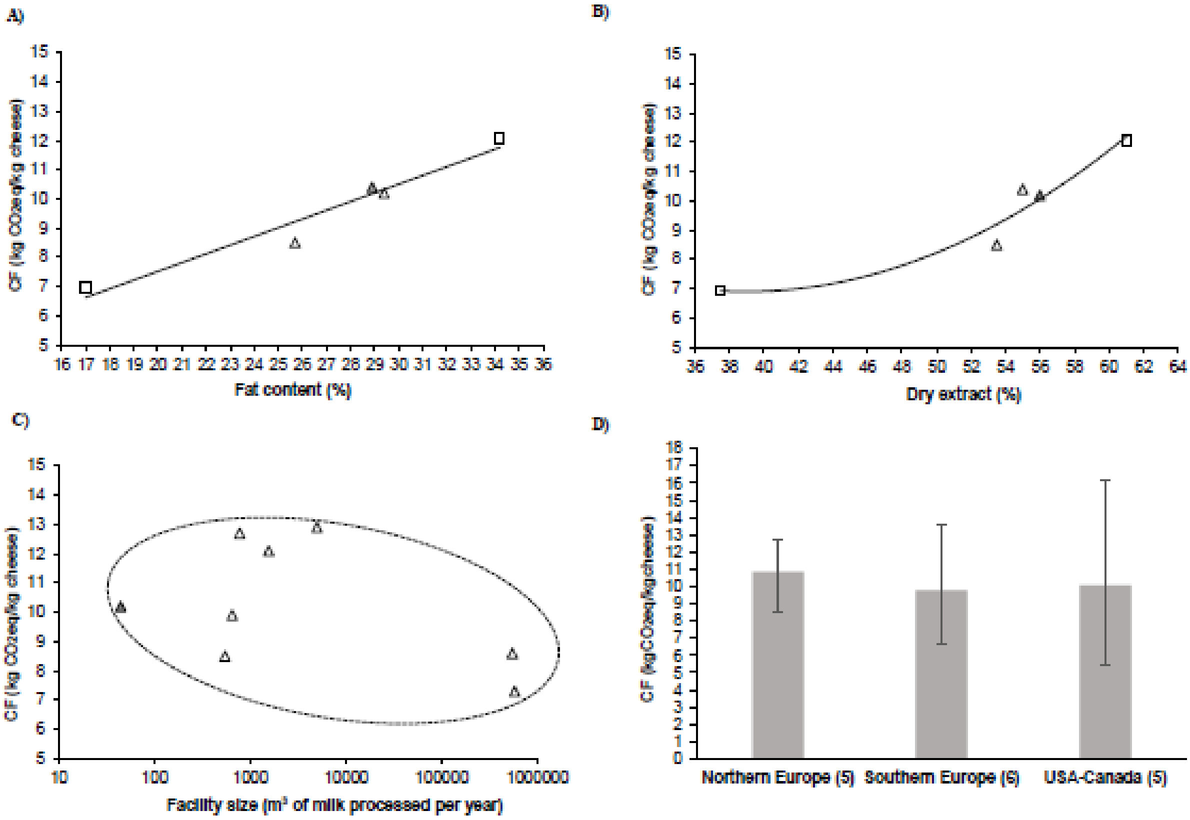

Figure 6
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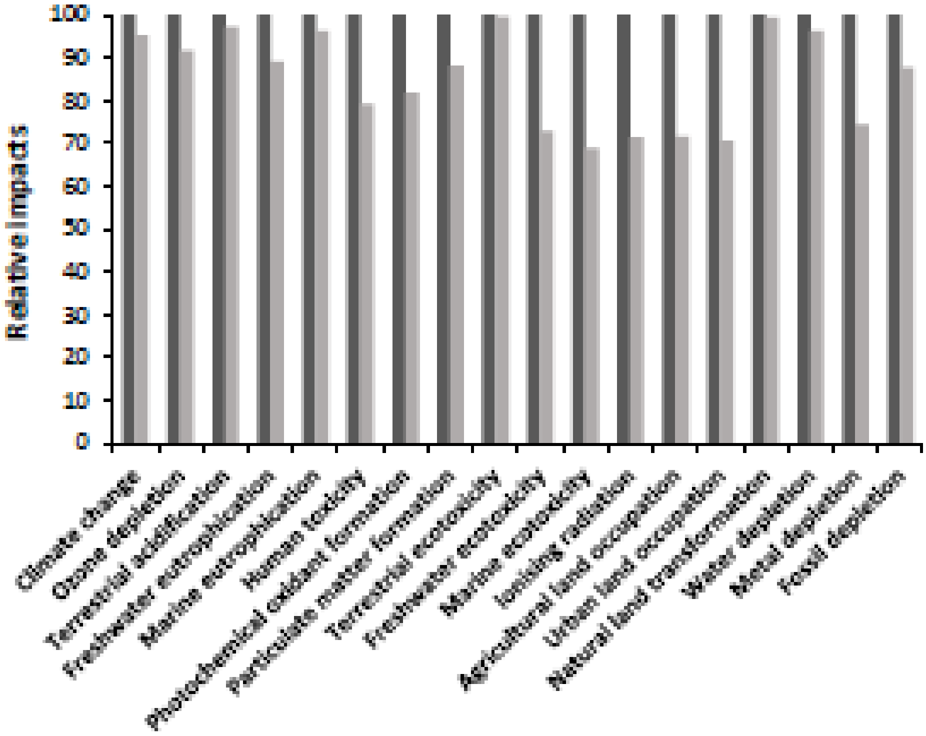

Table 1. Inventory data of the cheese factory, expressed per functional unit (FU = 4770 kg of cheese).

Inputs	
1. Milk (L)	44600
2. Tap water (L)	345000
3. Electricity (kWh)	13864
4. Pellets (kg)	6006
5. Packaging material (kg)	
a. Paper	27
b. Plastic bags (LDPE)	5.8
c. Poplar wood boxes	72
6. Cleaning products and others	
a. NaClO (kg)	28
b. NaOH (kg)	35
c. H_2O_2 (L)	4
d. Acetic acid (L)	1.5
e. H_3PO_4 (kg)	25
f. Plastic containers (PET) (kg)	8.3
g. Cellulose rolls (kg)	20
h. Nitrile gloves (kg)	2.7
7. Other ingredients (kg)	
a. Salt	65
b. $CaCl_2$	3.3
8. Transport by delivery van < 3.5 t (tkm)	
a. Milk	734.8
b. Whey	735.8
c. Manufactured cheeses	159.1
Outputs	
1. Cheese (kg)	4770
2. Boiler emissions (CO_2, SO_2, NO_x,…) (heat energy) (MJ)	146135
3. Wastes	
a. Wastewater (to treatment) (L)	345000
b. Plastics (PET) (to recycling) (kg)	8.3
c. Organic wastes (to landfill) (kg)	25
4. Whey (L) (avoided pig fodder: 3600 kg)	36000

Table 2. Summary of different works reported in the last ten years and focused on the study of the environmental impact derived from cheese production by means of LCA methodology.

Reference	Country	Research focus	Main conclusions	Carbon Footprint (kg CO_2eq/kg cheese)
This work	Spain	An artisanal small-sized cheese factory sited in southern Europe.	- Raw milk production is the main responsible of environmental impacts, hence improvement actions should be carried out mainly at the dairy farm. - The use of whey as animal feed is an important way to reduce the harmful impacts of cheese production.	10.2
Bava et al. (2018)	Italy	A factory that produces 3.6% of the total production of Grana Padano cheese.	- Milk production phase was the most important contribution to the environmental impact of cheese (93.5-99.6%), followed by milk production, milk transport and electricity use.	10.3-16.9
Clune et al. (2017)	Worldwide	Review of greenhouse gas emissions for different foods.	- Regarding carbon footprint values of dairy products, cheese is in second place.	5.3-16.4
Finnegan et al. (2017)	USA Canada EU	Review of several works, exploring the impact from the production of different cheese types (fresh, mature and semi-hard).	- Raw milk production was found to be the most significant contributor to the total impact. - Fresh cheese has less environmental impact than semi-hard cheeses.	-
Palmieri et al. (2017)	Italy	Environmental impacts of mozzarella cheese production.	- Raw milk production was the most impactful phase along the supply chain. - At the cheese factory, recycling the whey may have environmental benefits.	-
Santos et al. (2017)	Brazil	LCA of cheese production process in a small-sized dairy industry.	- Most of the environmental impacts of cheese life cycle are not from the dairy industry but in the production of raw milk. - Lesser content of fat in cheese implies lower impacts in six categories.	-
Vagnoni et al. (2017)	Italy	Comparison of the production of Sardinian sheep milk cheese at semi-artisanal and industrial scale.	- The GHG emissions of the two systems were similar. - The main difference between the two system environmental performances were founded for human- and eco-toxicity and eutrophication impacts.	17
Kristensen et al. (2015)	Denmark	Comparison of CF of cheddar cheese type produced with milk from Holstein and Jersey cows.	- The carbon footprint was lowest for milk from the Jersey cows than that from the two Holstein cows.	12.1 and 12.7 (Holstein) 9.9 (Jersey)
Dalla Riva et al. (2014)	Italy	Analyse the differences between mozzarella produced from raw milk (high-moisture) and produced from curd (low-moisture)	- Animal feed production and raw milk production were hot spots for almost all impact categories. - From a farm gate-to-grave perspective, ecotoxicity and freshwater and marine eutrophication are the categories more affected. environmentally sustainable than low-moisture mozzarella.	6.66 (high-moisture mozzarella)
Djekic et al. (2014)	Serbia	Environmental LCA of various dairy products.	- The largest contributor to the environmental profile is the raw milk production at dairy farms. - Contributions of the dairy processing plants are mainly due to energy requirement and inputs of goods at the dairy gate.	6.7-9.5
Nigri et al. (2014)	Brazil	Evaluate the environmental impacts of the artisanal and the industrial manufacturing processes of "Minas cheese".	- The milk production stage exerts the greater environmental impacts. - The artisanal production exerted lower environmental impacts. - There is a need of further research to determine the impact of production scale on the environment.	-
Gonzalez-Garcia et al. (2013a)	Portugal	Environmental impacts of mature cheese production in an international cheese-making dairy factory.	- The dairy farm-related activities are important sources of environmental impacts. - From cheese-making, the most important contributions are mainly due to the energy requirements in the production processes.	7.5
Gonzalez-Garcia et al. (2013b)	Spain	Environmental impact of a traditional Galician cheese production.	- The farm activities are the most relevant source of environmental impacts. - The use of whey as by-product reduced in 1 kg CO_2eq/kg milk the carbon footprint.	10.4
Kim et al. (2013)	USA	Environmental impacts of cheddar and mozzarella production	- Raw milk production is the major contributor to nearly all impact categories. - On-farm mitigation efforts around enteric methane, manure management, phosphorus and nitrogen runoff and pesticides used can significantly reduce impacts.	8.6 (Cheddar) 7.3 (Mozzarella)
Vergé et al. (2013)	Canada	Estimate the CF of the main dairy products from farm to the exit gate of processing plants.	- The on-farm contributions were estimated to be about 90% of total GHG emissions.	4.2-5.7
Capper & Cady (2012)	USA	Compare the environmental impact of Jersey and Holstein milk for Cheddar cheese production.	- Jersey milk consumed fewer natural resources for cheese production than Holstein milk. - Producing cheese from Jersey milk has a lower environmental impact compared to Holstein milk.	16.2 (Holstein) 12.9 (Jersey)
Milani et al. (2011)	Worldwide	Summary of the environmental impacts of dairy processing and products.	- The production of cheese and whey products implies the emission of high levels of GHG and consume high quantities of water that need a suitable treatment. - The production of milk at the farm level is responsible for the majority of environmental impacts.	5.9
van Middelaar et al. (2011)	The Netherlands	Evaluate the eco-efficiency in the production chain of Dutch semi-hard cheese.	- Reducing the impact of milk production is the key parameter to decrease the ecological impact of cheese manufacture. - Stages after farm gate can reduce their impact by minimizing the use of fossil energy and the losses of milk and cheese.	8.5
Sheane et al. (2011)	Scotland	Identify the opportunities to reduce GHG emissions associated with dairy supply chains without producing economic drawbacks.	- Strategies should be focus at nitrogen management, packaging redesign, more efficient distribution and chilling processes. - Most dairy farms are not big enough to address the investment alone, so collaboration through the supply chain and between competitors will be required.	11.1
Nielsen & Høier (2009)	Denmark	Environmental assessment of yield improvements obtained by the use of the enzyme phospholipase in mozzarella cheese production.	- Use of phospholipase is a means of reducing environmental impact of mozzarella production. - Use of phospholipase reduces the potential contribution to global warming by about 0.22 kg CO_2eq/kg cheese.	-