Impact assessment of traditional food manufacturing: the case of Grana Padano cheese

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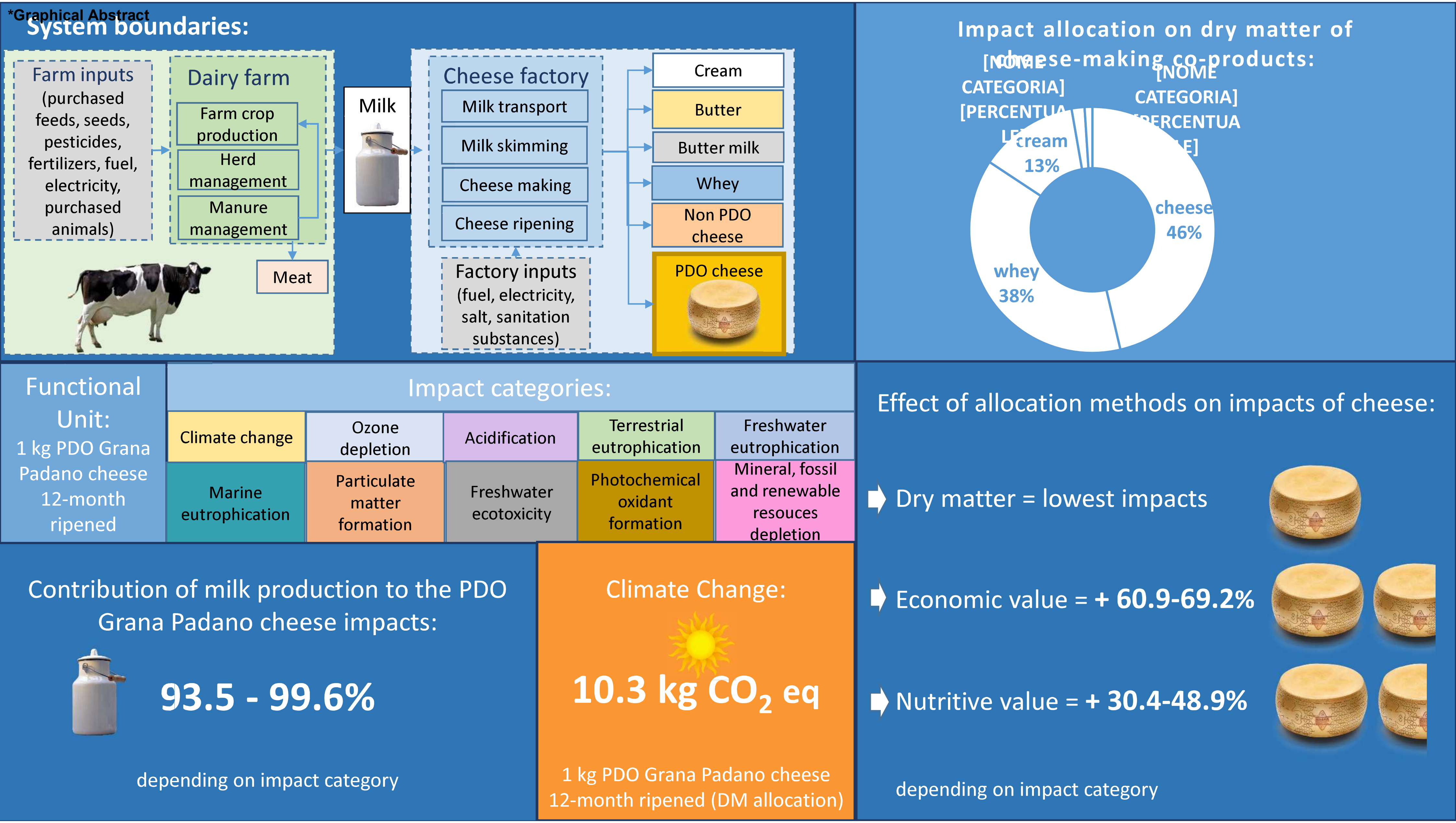
*Graphical Abstract



Highlights

- Environmental impact of Grana Padano cheese was evaluated using LCA.
- Data were collected through personal interviews at cheese factory and 5 dairy farms.
- Allocation factors choice is crucial to determine cheese environmental load.
- Environmental impacts of co-products: butter, whey and cream, were also evaluated.
- Milk production at farm loaded more than 93.5% of environmental impact of cheese.

*Revised manuscript with no changes marked (double-spaced and continuously LINE and PAGE numbered)
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Abstract

The dairy sector is recognised as one of the most impacting agricultural activities. In Italy approximately 24% of cow's milk is destined to Grana Padano, a Protected Designation of Origin long ripening cheese. The Grana Padano production has increased by 10% in the last decade and approximately reached 183,000 t in 2015. Around 38% of this production is exported to Germany, US, France and to the rest of the world. This study evaluated the environmental impact of production of Grana Padano, through a "cradle to cheese factory gate" Life Cycle Assessment. The study involved an Italian cheese factory that produces about 3.6% of the total production of Grana Padano cheese and a group of 5 dairy farms, chosen among the farms that sold all milk produced to the cheese factory. The functional unit was 1 kg of Grana Padano cheese 12-month ripened. Environmental impacts of co-products: whey, cream, butter and buttermilk were also evaluated. Two sensitivity analyses were conducted: the first one had the aim to explore the effect of different allocation methods based on dry matter content, economic or nutritive value of cheese, respectively; the second one considered the variation of the impacts of milk production and its effect on cheese environmental impact.

Milk production phase gave the most important contribution to the environmental impact of cheese, with a percentage of 93.5-99.6% depending on the impact category. Excluding milk production from the system boundary, milk transport and use of electricity were the main responsible of the environmental impact of cheese-making process. The climate change impact for the production of 1 kg Grana Padano was 10.3 kg of CO_2 eq, using a dry matter allocation method, while 16.9 and 15.2 kg of CO_2 eq adopting economic and nutritive value allocation methods, respectively.

Keywords: LCA, milk, cheese, allocation, Grana Padano

1. Introduction

The future of the dairy sector has to face both the need of reducing environmental impact and the increasing demand of animal food products. Dairy products have covered an important role in the human diet for nearly 8000 years and are part of the official nutritional recommendations in many countries worldwide. Milk products provide a set of key nutrients; in fact, they contribute approximately 52-65% of the dietary reference intake of calcium and 20-28 % of the protein requirement, depending on the type of product and the age of the consumer (Rozenberg et al., 2016). In Italy, approximately 24% of cow's milk is destined to Grana Padano, a Protected Designation of Origin (PDO) cheese, that alone represents 38% of the Italian PDO cheese production, in terms of volume (Clal, 2016). Grana Padano (GP) is an extra-hard cheese with a long ripening period (from a minimum of 9 months up to 20 and more, depending on product category) produced in a defined area in Northern Italy (European Commission, 2011) using partly skimmed raw milk, calf rennet and natural whey cultures of thermophilic lactic acid bacteria as a starter (Santarelli et al, 2013). The GP production has increased by 10% in the last decade and approximately reached 183,000 t in 2015. Around 38% of this production is exported to Germany, US, France and to the rest of the world (Clal, 2016).

Life Cycle Assessment (LCA) is a generally accepted method for estimating the environmental impact of agricultural products on a global perspective (Bacenetti et al., 2015). Previous LCA studies in the dairy sector have focused primarily on environmental impact of milk production at farm gate, both gathering data from national agricultural databases (Yan et al., 2013; De Vries et al., 2015) or using primary data (Bava et al., 2014), whereas only a few studies dealt with the cheese industry. Recent studies have been conducted on the entire dairy chain in US: the first study (Kim et al., 2013) included into the LCA perspective the production of two type of cheeses (cheddar and mozzarella) and the valorization of co-products as whey (Carvalho et al., 2013; Carota et al., 2017); the second study (Capper and Cady, 2012) did a comparison of the environmental impact of cheese produced from Jersey or Holstein milk. In Australia (Flysjo et al., 2014) and European countries (Berlin 2002; Van Middelaar et al., 2011; Fornasari, 2013) some studies were made as well; although the analyses are referred to different kinds of cheeses, they confirmed that, in the environmental burden of cheese, milk production has always the greatest quota of impact. Despite the important role of GP in the Italian agrifood sector and its worldwide reputation, no previous studies were found on the evaluation of the environmental impact of this particular cheese or other similar hard cheeses.

The environmental impact of a hard and long ripened cheese such as GP is expected to be higher than the values obtained on other cheeses, above all due to the effect of the low cheese yield. In fact for the production of 1 kg of GP cheese approximately 13-14 kg of milk are needed (with a final cheese yield of about 7.7%). The low cheese yield is due to the particular production process, fixed by the product specifications that guarantee the traditional characteristics of GP; it includes partial skimming of milk, cutting and cooking (until 56°C) of the curd with high amount of whey drained off, and a long ripening period (on average 12 months), with further water loss. The cheese-making process is a typical multiple-output system where the allocation of environmental impact among products and co-products is needed (Fornasari, 2013). In fact, in addition to cheese, a variety of co-products such as cream, whey, butter and buttermilk are produced. Whereas allocation method is far from being established, it is possible to choose among different options: allocations based on economic value, mass, dry matter or nutrient density can greatly change the results of the analysis. The International Dairy Federation (IDF) considered the allocation issue and recently suggested (2015) to adopt an allocation based on dry matter content of the different products and co-products.

In extra-hard cheeses like GP the choice of the allocation method is more impactful on final results than in fresh cheeses due to the low cheese yield. For these reasons, the valorization of whey is essential to split the environmental impact of cheese production. The production of whey in Italy is estimated 9 Mt/year, half of which from hard cheeses (Clal, 2016).

The aim of this study was to evaluate the environmental impact of the production of PDO Grana Padano cheese through a “cradle to cheese factory gate” Life Cycle Assessment. The study involved a cheese factory that produces about 3.6% of the total production of PDO Grana Padano cheese and a representative group of 5 dairy farms. The described processes and operations represent a real case study. Two sensitivity analyses were conducted: the first one had the aim to explore the effect of different allocation methods based on dry matter content, economic or nutritive value of cheese, respectively; the second one considered the variability of the impacts of milk production and its effect on cheese environmental impact.

2. Materials and methods

2.1 System description

Raw milk for production of PDO Grana Padano cheese must be obtained from cows milked twice a day in dairy farms located in the production area defined in the Product Specification (European Commission, 2011). Cow feeding ration is based on fresh or preserved (as hay or silage) forages, and concentrates; the ratio between forage and concentrate, on dry matter (DM) basis, has to be lower than 1 in the daily ration. At least 50% DM of the whole daily ration must be produced within the defined production area. The milk must not be refrigerated below 8°C, neither at the farm nor during transportation to the cheese factory and, whether from a single milking session or from two mixed together, it must be partly skimmed by natural creaming (D'Incecco et al., 2015). Addition of lysozyme to milk is accepted up to a maximum of 25 g/t milk. The product cannot be labelled as PDO Grana Padano until it is nine months old and has passed the official quality control steps (Masotti et al., 2010; D'Incecco et al., 2016).
The production chain of PDO Grana Padano cheese is schematically reported in Fig. 1.

Figure 1 - around here

To perform the LCA analysis, the production process was divided in three subsystems:
1) **milk production**, this section includes all the operations that take place at the farm level such as crop cultivation for feed and forage production, animal feeding, manure management, milking and milk storage. In more details, for each crop, the whole sequence of field operations carried out from soil tillage to feed harvesting and storage have been considered. In addition, the environmental costs for extraction, production and transportation of purchased inputs as feed, seeds, fertilizers, fuels, etc. were considered. The main product of this subsystem is the milk with the co-products: meat from culled cows, sold and dead animals, animal slurry. The animal slurry is completely used to fertilize the fodder crops at farms;
2) **cheese-making**, this phase starts with the collection of the milk from the dairy farms and the transportation to the cheese factory and ends with the production of cheese. The cheese-making includes the operations described in figure 1.
The main product of this subsystem is the fresh cheese while whey, cream, butter and buttermilk are the co-products. Fresh cheese is moved to the ripening room while the co-products are sold.
3) **cheese ripening**, this step corresponds to the period during which the cheese is stored in the ripening room at a temperature in the range 15-22° C. During this period, which must last a minimum of 9 months,

the dry matter content of the cheese increases and the characteristic taste and structure develop. In this study, a 12-month ripening period was considered. The products of this step are: PDO Grana Padano cheese as wheels with two different quality levels (First and Second choice), and generic hard cheese grated which is the cheese that does not fully accomplish the specific quality and origin denomination.

2.2 Functional unit

The functional unit (FU) in a LCA study is defined as the quantified performance of a product system. In this study, two functional units were selected.

At farm gate, to evaluate the environmental impacts of milk production, the FU was 1 kg of Fat and Protein Corrected Milk (FPCM), as suggested by IDF (2015), while, at cheese factory gate, when also the cheese-making and ripening were included in the system boundaries, the FU was 1 kg of PDO Grana Padano cheese 12-month ripened without packaging because GP is generally sold as entire wheels.

2.3 System boundary

The environmental assessment was carried out considering a “cradle-to-cheese factory gate” perspective. Consequently, the system boundaries (Fig. 2) included feed production, slurry storage and spreading, as well as the cheese-making processes and ripening, while packaging, transport, distribution, consumption and end-of-life of the cheese were excluded from the assessment.

As crop production is concerned, this life cycle considered raw material extraction (e.g., fossil fuels and minerals), manufacture (fertilizers, seeds, pesticides and agricultural machines), use (diesel fuel consumption and engines exhaust gas emissions, tire abrasion emissions and fertilizer related emissions), maintenance and final disposal of machines, and supply of inputs to the farm (fertilizers, seeds and herbicides). The details about crop production are previously showed by Bacenetti et al. (2016). Concerning cheese-making and ripening the production of rennet and lysozyme was excluded from the evaluation considering the low amount consumed and the absence of information concerning their production process and capital goods (González-García et al., 2013b).

Figure 2 - around here

2.4 Inventory data collection

Primary data were directly collected by means of questionnaires and surveys in the dairy farms and in the cheese factory. For the estimation of environmental impact of milk production at dairy farm stage, a group of 5 farms was chosen among the 40 farms that sold all milk produced to the cheese factory. The farms were selected in agreement with the owner of cheese factory considering their representativeness in terms of cropping systems and ratio between on-farm produced and off-farm feed. The five farms were located at an average distance of 40 km from the cheese factory and were typical intensive farms of the Po plain (Northern Italy); they were characterized by high variability in terms of number of lactating cows (on average 268±333), milk production (2754±3528 t of fat and protein corrected milk per year), arable utilized land for annual crops (89.3±120.8 ha), permanent pasture destined to hay production (35.3±21.3 ha) and stocking density (3.0±0.7 livestock unit/ha). All farms produced and included maize silage into dairy cow ration, while 4 of them produced lucerne and grass hays, utilized as feed for animals. All the farms showed a high percentage of feed self-sufficiency, calculated as the percentage of the dry matter (DM) produced on farm on the total DM needed to feed animals (on average 75.6±16.9%). Dairy efficiency, expressed as the ratio between milk production and dry matter intake was also calculated resulting quite high (1.5±0.2%): The main data from the 5 dairy farms involved in the study are showed in table A1 (supplementary material).

The environmental impact of milk production was included in the estimation of PDO Grana Padano impact. It was supposed that each farm contributed to annually milk used in cheese factory proportionally to its annual milk production. All data concerning cheese making was collected directly at cheese factory and is showed in Table 1.

Table 1 - around here

Field emissions of nitrogen compounds into air, water and soil were assessed according to the model EFE-So (Estimation of Fertilisers Emissions-Software) based on Brentrup et al. (2000) and Schmidt Rivera et al. (2017). More in details, ammonia volatilization, emissions of dinitrogen oxide and nitrate leaching were assessed considering the characteristic of soil (texture, pH, CEC), climate (temperature, wind, precipitation) and the spreading technique (timing between spreading and soil incorporation, type of crop residues, type of machines). Phosphate emissions were calculated following Prahsun (2006) and Nemecek and Kägi (2007) considering two emissions sources: leaching to the ground water (0.07 kg $P \cdot ha^{-1} \cdot year^{-1}$) and run-off to surface water (0.175 kg $P \cdot ha^{-1} \cdot year^{-1}$). Fuel consumption for the different field operations was assessed considering the characteristics of tractors (engine power, mass, age and emissions stage) and equipment (working width, working depth) as well as soil conditions and working times (Lovarelli and Bacenetti, 2017).

Pesticide derived emissions into water, air and soil were estimated in accordance with Althaus et al. (2007) and Margni et al. (2002). According to these studies, 85% of the pesticide is released into the soil (10%, equal to 8.5% of the total, the run-off from the soil into the water), 10% is emitted into the air while 5% stays on the plant canopy.

The nutritive value, as chemical composition, of the rations of all the animal categories represented in the 5 farms were calculated using the program CPM (Cornell Penn Miner)-Dairy Rations Analyser v0.3.7. starting from the feed composition. In this way, it was also possible to estimate feeding ration digestibility for the calculation of methane emission from slurry. For methane emissions from livestock enteric fermentations, the equations proposed by Moraes et al. (2014) were used.

Animal nitrogen excretion, methane emissions from slurry storage before spreading and nitrous oxide (N_2O) emissions from slurry storages were estimated as proposed by the IPCC (2006) Tier 2 method; detailed information about emissions estimation was reported in Guerci et al. (2013) and Bacenetti et al. (2016). Ammonia (NH_3) and nitrogen oxide emissions (NO_X) that occur during animal housing and slurry storages were estimated following the method proposed by EEA (2009) on the basis of the total amount of nitrogen excreted by the animals.

Background data for the production of seeds, diesel fuel, fertilizers, pesticides, tractors and agricultural machines (equipment and self-propelled machines) as well as about transport were obtained from the Ecoinvent Database v.3 (Weidema et al., 2013).

2.5. Allocation

According to the ISO 14040, allocation should be avoided by applying a system expansion. Nevertheless, in attributional LCA the multifunctionality issue is usually solved by allocation based on physical or economic quantities. The co-products (butter, buttermilk, whey, etc.) arising during cheese making can be used for different purposes: for example, the whey can be used for biogas production, for animal feeding and for the production of whey protein concentrate (Bacenetti et al., 2018). Furthermore, in this study system expansion was not applicable due to the lack of detailed information concerning the specific mass consumptions and energy flows for each operation carried out during cheese making. Consequently, allocation was performed as in previous studies focused on cheese production (Berlin et al., 2002;

Gonzalez-Garcia et al., 2013a). At farm level, allocation between milk and meat was made according to IDF (2015), while at cheese factory level, different allocations were performed. More in details, among fresh cheese, whey, butter, cream and buttermilk, the environmental impact was allocated considering their dry matter content as suggested by IDF, (2015) (DM_All). Among the different cheese products (PDO cheese 1st quality, PDO cheese 2nd quality, non PDO grated cheese) an economic allocation based on market prices was carried out (Clal, 2017; cheese factory owner communication, 2017; Table 2).

Table 2 around here

2.6. Impact assessment

Within the Life Cycle Impact Assessment (LCIA), the following impact categories were considered for evaluation: climate change, ozone depletion, particulate matter formation, photochemical oxidant formation, terrestrial acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, mineral depletion and fossil depletion. The characterization factors considered were those from ILCD 2011 Midpoint V1.03.

2.7 Sensitivity analyses

Two sensitivity analyses were performed in order to test the robustness of the environmental impact results of 1 kg of PDO Grana Padano cheese 12-month ripened.

2.7.1 Sensitivity analysis based on different allocations

Previous studies (Flysjö et al., 2014; Helmes et al., 2016) found that allocation choice can significantly influence the impacts per kg of cheese product and, consequently, of co-products. Therefore, a sensitivity analysis was performed to compare the three different allocation methods: (i) dry matter content (suggested by IDF, 2015) (DM_All); ii) economic value (ECON_All) based on selling prices of different products, (iii) fat and protein content (suggested by EPD, 2014) (NUTR_All). Table 3 shows the allocation factors included in the sensitivity analysis.

Prices, dry matter content and nutritive value of the different products and co-products were obtained from different sources: national database of CREA (Centro di Ricerca per gli alimenti e la nutrizione, 2016); Mucchetti and Neviani (2006); Clal (2017); Salvadori dal Prato (2005); cheese factory owner communication (2017).

Table 3 around here

2.7.2 Sensitivity analysis based on different milk environmental impacts

A second sensitivity analysis was performed to investigate the variability of environmental impacts of cheese due to the variation of the environmental impact of milk production. To this purpose, the impact of PDO Grana Padano cheese has been assessed considering the milk produced in the farm 1 and farm 2 that was characterized by the highest (HIGH) and the lowest (LOW) environmental impact, respectively.

3. Results and discussion

In the following section, the results are presented and discussed focusing the attention on the contribution of the different subsystems (subchapter 3.1) as well as on the impact of the different by-products (subchapter 3.2). Lastly, the results of the sensitivity analyses carried out are reported.

3.1 Contribution of the different sub-systems

a) Milk production

Table 4 reports the average results of the environmental impact assessment of milk production in the farms included in the study, expressed per kg of FPCM; the detailed results are reported in Table A2 (supplementary material). Climate change per kg FPCM was higher (1.46 kg CO_2 eq) than the values previously found in the same area in Northern Italy (1.26 kg CO_2 eq; Bava et al., 2014) and in Irish commercial dairy farms (1.23 kg CO_2 eq; Yan et al., 2013). Climate change is highly influenced by Land Use Change (LUC), which is represented in this case by the CO_2 emission due to the cultivation of soybean on new fields in Brazilian area, at the expense of forest areas. The inclusion of LUC in the evaluations of this study increased climate change of milk production; other authors (Flysjö, et al., 2012; Guerci et al., 2014) reported that the contribution of commercial feed production to climate change of milk production can greatly increase with the inclusion of LUC emissions and the total impact can reach values more than three times higher compared to the estimates without LUC emissions.

In particular among the five farms considered in the analysis, the farm characterized by the higher milk production showed the highest impact for Climate Change (1.68 kg CO_2 eq/kg of FPCM) mainly due to LUC and the intensive utilization of the agricultural area for the production of maize silage.

Table 4 around here

For all impact categories, milk production was the most important contributor to the environmental impacts of cheese: its contribution ranged from 93.5% for freshwater eutrophication to 99.6% for terrestrial eutrophication. For climate change, milk production represented 95.6% of the total impact of cheese. As underlined by Berlin (2002), although cheese is a highly industrially processed dairy product, the activity that mainly contributes to its environmental impact is the milk production at farm due in particular to feed production and, above all, to gas emissions from animals and manure as methane and ammonia.

This result is in agreement with the conclusions of other studies from Kim et al. (2013) and Palmieri et al. (2017), on different kind of cheeses.

b) Cheese-making

Figure 3 shows contributions for the cheese-making subsystem alone (excluding milk production phase).

Milk transport from farms to cheese factory is one of the most important responsible of environmental impact of cheese-making. A rational organization of milk collection at the farms could be an interesting way to mitigate the impacts related to the transport.

The use of electricity is the second important contributor for all evaluated impact categories of the subsystem 2. Dalla Riva et al. (2016) found similar results: in their study, excluding raw milk production from the system boundary, electricity consumption, packaging and transport were the main environmental hotspots.

Flysjö et al. (2014) reported that, excluding milk production, the use of energy had the highest contribution on environmental impact of cheese production and other dairy products.

Figure 3 around here

c) Cheese ripening

As explained before, this phase includes the 12-month ripening and the production of grated cheese; from an environmental point of view, the natural gas utilized to maintain the required temperature and humidity of warehouse storage and the electricity to grate cheese were the main inputs.

The contribution of ripening phase to the environmental impact of GP production was negligible. The higher contribution was registered for the Freshwater eutrophication (1.61% of the freshwater eutrophication of total GP production) while the lowest contribution was related to the Terrestrial eutrophication (0.07%). The Climate change of ripening was 0.08 kg CO_2 eq/kg of GP, equal to 0.74% of total Climate change of cheese production.

3.2 Impact of the different co-products

Table 5 shows the environmental impact of production of butter, whey, buttermilk and cream for different impact categories using DM allocation.

Whey primarily consists of water (about 94%), lactose, minerals, proteins and fat; approximately 50% of the milk solids appear in the whey, in particular about 100% of the lactose and 20% of the protein (Smithers et al ., 2008).

Due to very low DM, environmental impacts of 1 kg of fresh whey resulted the lowest of all co-products when allocation is based on DM. The impact assessment of whey is strongly influenced by the allocation method; in the following paragraph this aspect will be investigated. The present results of whey environmental impact, in particular climate change, are consistent with other studies (van Middelaar et al., 2011; Helmes et al., 2016).

As underlined by Eymann et al. (2016), due to its high DM content, butter is the product with the highest climate change impact. Climate change for 1 kg of butter production (11.8 kg/CO_2 eq) is slightly lower than the value of 13 kg/CO_2 eq found by Eymann et al. (2016): the difference can be explained by the different impact of raw milk (1.46 kg CO_2 eq in this study vs 1.9 kg CO_2 eq in the study of Eymann et al., 2016). On the contrary Flysjö et al. (2014) reported a lower climate change impact for butter (8.1 kg CO_2 eq/kg), but it referred to a mixture that included butter and blend products with a 58% of fat.

Table 5 around here

3.3 Sensitivity analyses

3.3.1. Sensitivity analysis based on different allocation factors

In table 6 the effects of the different allocation approaches on environmental impact evaluation of 1 kg of PDO Grana Padano cheese (included all production phases) are showed.

For cheese production, considering DM allocation as the reference, most impact categories increased using economic allocation. The economic allocation is influenced by price fluctuations and, due to the low economic value of the co-products, assigns to cheese a higher share of the total impact. Climate change of cheese increased of approximately 65% using economic allocation instead of DM allocation ; on the other hand, climate change of butter, whey and cream decreased of about 21%, 87% and 25%, respectively. Results showed that the allocation methods ECON_All and NUTR_All (based on fat and protein content) gave similar impacts for cheese, generally higher than DM allocation. On the other hand, the application of a mass allocation can lead to wrong conclusions for the generation of great masses of co-products of very low economic and nutritional value (e.g. the mass of whey).

Table 6 - around here

3.3.2. Sensitivity analysis based on different milk environmental impacts

In table 7 the environmental impact for 1 kg of FPCM obtained in the HIGH and in the LOW impact dairy farms are reported. The two farms considerably differed in terms of herd size: 760 *vs* 140 lactating cows in the HIGH and in the LOW farm, respectively. The LOW farm destined half of the farm land to meadow hay production and did not buy forages from market, while in the HIGH farm 81% of arable land was sown with maize for silage. In the HIGH farm a large quantity of soybean meal was bought (about 1,000 t/year), taking behind an important load of environmental impact due to LUC; in the LOW farm soybean meal was not used. The variability of impacts of milk production between the two farms was very high: this suggests a potential for decreasing emissions of milk production through a proper combination of management choices and technical solutions already available.

Table 7 around here

Figure 4 shows the environmental impacts of 1 kg of GP considering all milk used for cheese making coming from the HIGH or the LOW farms (farm 1 and 2, respectively, in table A2 of the supplementary material).

Using the milk with the low impact (coming from the LOW farm) reduces the GP climate change by approximately 22% in comparison with the average value. On the contrary, in the hypothesis in which all the milk derives from the HIGH farm, the GP climate change increases by 5.7%. As milk production phase is the main environmental hotspot, the variation of the milk impact strongly affects the environmental performances of cheese. Moreover, the results of the sensitivity analysis show that some dairy farms can produce milk in a more sustainable way through the adoption of already existing good practices and this could have a high mitigation potential on the environmental impact of cheese production.

Figure 4 - around here

3.4 Mitigation strategies and relation between environmental impact and production disciplinary

A direct comparison between the results of the present study and the previous analyses of environmental impact of cheese production is difficult. In fact, although similar methodological choices were made (e.g., the functional unit selected is usually the mass of cheese and the multifunctionality issue is solved thanks to economic allocation), the production process of GP is considerably different from the other cheeses studied and, consequently, a huge difference in the environmental impacts occurs. Considering that the milk production is by far the main contributor to the environmental impact of cheese, among the different parameters characterizing the cheese making process, the cheese yield (kg of cheese per kg of milk) is the most important in the environmental perspective. As previously highlighted, cheese yield of GP is very low due to the peculiarities of the production process that are specified in the PDO guidelines with the aim to guarantee the traditional characteristics of the product. The environmental impact of GP, which is quite high in comparison to other cheeses, is strictly linked to its distinctive features.

Considering the importance of milk production phase in influencing the environmental impact of cheese the mitigation strategies should focus primarily on that phase. More in details, at farm level, the most promising solutions focus on slurry management during storage and field application. During field application, the emissions of ammonia and the related impacts (e.g., acidification) can be reduced using spreading techniques such as injection (Carozzi et al., 2014; Bacenetti et al., 2016b) and band spreading

(Misselbrook et al., 2002; Amon et al., 2006). The anaerobic digestion of slurry instead of their "conventional" storage in open tanks involves a double benefit of reducing the emissions of methane, dinitrogen monoxide and ammonia and producing electricity from renewable sources. Bacenetti et al. (2016a) highlighted that an impact reduction ranging from 20% to 30% can be achieved for climate change, acidification and eutrophication thanks to the anaerobic digestion of slurry in comparison with storage. With regard to the anaerobic digestion of manure similar results were reported by Battini et al. (2014) and Baldini et al. (2017).

Finally, concerning the PDO cheeses, a relation between the guidelines imposed by the production disciplinary and the environmental impact is hardly identifiable. Environmental benefits could arise from reduction of the transport distance of milk (thanks to the concentration of milk production and cheese making in a limited geographic area) or by a high use of manpower instead of electric machines. However, the use of small or not technologically updated devices for cheese making and the long ripening could involve an increase of the environmental load due to the higher energy consumption.

4 Conclusions

The results obtained from the study confirmed with evidence that the main environmental load in the cheese production is connected with the production of milk: for all impact categories considered, the contribution of milk production was between 93.5% to 99.6% of the total cheese environmental impacts. Starting from this conclusion, as highlighted by sensitivity analysis, the application of mitigation strategies at dairy farm level is the most important option to reduce the environmental impact of Grana Padano. Especially in the case of renowned and high-value products such as Grana Padano, cheese factories should make efforts to improve the environmental sustainability of milk production, through technical support, dissemination of good practices and economic incentives to the dairy farms.

The environmental impact of cheese-making and ripening phases was mainly determined by transport of milk from dairy farms to cheese factory and electricity use. A reduction of transport impact could be achieved through the organization of proper milk collection pathways.

The allocation method considerably affects the results especially in the case of cheese production due to the multiple co-products. A consensus on the allocation methods can give an important contribution to scientists and practitioners: policy makers and consumers ask for clear and comparable results on food product sustainability. In the case of cheese production, the allocation method based on dry matter content of the products seems to be the most suitable allowing to compare products with different dry matter contents (for example ripened cheese with fresh cheese). Moreover dry matter content is a parameter easy to obtain and related to the nutritive value of cheese.

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Table 1 - Main inventory data from cheese factory (2015)

Input		
Milk	t/year	86165
Rennet	t/year	3.21
Lysozime	t/year	1.83
Salt	t/year	120
Natural gas *	MWh	8655
Electricity *	MWh	4747
Cleaning detergent *	t/year	31.5
Output		
Cheese wheels	n/year	183443
Average wheel weight	kg/wheel	35.9
PDO GP cheese 1^{st} choice	t/year	5570
PDO GP cheese 2^{nd} choice	t/year	824
Non PDO GP cheese	t/year	198
Whey	t/year	61806
Cream	t/year	4385
Butter	t/year	205
Buttermilk	t/year	1104
Economic value		
PDO GP cheese 1^{st} quality	€/kg	7.30
PDO GP cheese 2^{nd} quality	€/kg	5.84
non PDO grated cheese	€/kg	8.18

* for cheesemaking and ripening

Table 2 - Economic allocation factors among the different cheese products

Products	**Allocation factors**
	%
PDO GP cheese 1^{st} quality	86.3
PDO GP cheese 2^{nd} quality	10.2
non PDO GP grated cheese	3.50

Table 3 - Production quality, market price and allocation factors of different products at cheesefactory

Formatted Table

	Unit	Fresh cheese	Whey	Cream	Butter	Buttermilk
Dry matter content[1]	%	61.0	6.0	29.0	82.0	9.0
Dry matter allocation factor (DM_All)	%	46.3	37.9	13.0	1.7	1.0
Market Price	€/kg	5.19[3]	0.04[3]	2.01[4]	3.34[4]	0.18[4]
Economic allocation factor (ECON_All)	%	76.2	4.84	17.3	1.34	0.39
Fat content[2]	%	27.0	0.6	22.0	83.4	0.6
Protein content[2]	%	29.7	0.75	2.60	0.80	3.20
Nutritive allocation factor (NUTR_All)	%	68.7	8.40	19.4	2.80	0.68

[1] Dry matter contentsts data from: fresh cheese and whey (personal communication); cream and buttermilk (Salvadori dal Prato, 2005); butter (CREA, 2016)
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[3] Data from cCheefactory owner communications
[43] Data from Clal (2017)

Table 4 - Environmental impact of 1 kg FPCM at farm level

Impact category	Unit	Mean	SD
Climate change	*kg CO_2 eq*	1.461	0.249
Ozone depletion	*g CFC-11 eq*	0.0001	0.0001
Particulate matter formation	*g PM2.5 eq*	0.687	0.221
Photochemical ozone oxidant formation	*kg NMVOC eq*	0.0026	0.0009
Terrestrial aAcidification	*molc H+ eq*	0.0237	0.0081
Terrestrial eutrophication	*molc N eq*	0.1024	0.0367
Freshwater eutrophication	*g P eq*	0.0933	0.0403
Marine eutrophication	*g N eq*	8.777	1.730
Freshwater ecotoxicity	*CTUe*	3.221	1.785
Mineral, fossil & ren resource depletion	*g Sb eq*	0.0081	0.0027

Table 5 - Environmental iImpacts potentials of 1 kg of different co-products (DM allocation)

Impact category	Unit	Whey	Butter	Buttermilk	Cream
Climate change	*kg CO_2 eq*	0.872	11.768	1.418	4.217
Ozone depletion	*g CFC-11 eq*	0.000080	0.001074	0.000129	0.000385
Particulate matter formation	*g PM2.5 eq*	0.483	6.513	0.785	2.334
Photochemical oxidantozone formation	*kg NMVOC eq*	0.002	0.026	0.003	0.009
Terrestrial aAcidification	*molc H+ eq*	0.016	0.219	0.026	0.078
Terrestrial eutrophication	*molc N eq*	0.070	0.948	0.114	0.340

Freshwater eutrophication	*g P eq*	0.069	0.931	0.112	0.334
Marine eutrophication	*g N eq*	5.402	72.88	8.780	26.12
Freshwater ecotoxicity	*CTUe*	2.486	33.54	4.040	12.02
Mineral, fossil & ren resource depletion	*g Sb eq*	0.006	0.074	0.009	0.027

Table 6 - Environmental impacts~~ potentials~~ of 1 kg of Grana Padano considering different allocation methods

Impact category	Unit	Allocation		
		DM_All	**ECON_All**	**NUTR_All**
Climate change	*kg CO_2 eq*	10.3	16.9	15.2
Ozone depletion	*g CFC-11 eq*	0.00094	0.00154	0.0014
Particulate matter formation	*g PM2.5 eq*	5.669	9.312	8.406
Photochemical oxidant ~~ozone~~ formation	*kg NMVOC eq*	0.023	0.037	0.03
Terrestrial a~~A~~cidification	*molc H+ eq*	0.190	0.312	0.28
Terrestrial eutrophication	*molc N eq*	0.823	1.353	1.22
Freshwater eutrophication	*g P eq*	0.820	1.341	1.21
Marine eutrophication	*g N eq*	63.25	104.0	93.87
Freshwater ecotoxicity	*CTUe*	29.20	48.0	43.3
Mineral, fossil & ren resource depletion	*g Sb eq*	0.065	0.11	0.096

Table 7 - Environmental impacts~~ potentials~~ of milk production (1 kg of FPCM) in the two farms with the highest and the lowest impacts.

Impact category	**Unit**	**HIGH**	**LOW**
Climate change	*kg CO_2 eq*	1.678	1.215
Ozone depletion	*g CFC-11 eq*	0.00018	0.00003
Particulate matter formation	*g PM2.5 eq*	1.053	0.657
Photochemical oxidant ~~ozone~~ formation	*kg NMVOC eq*	4.052	1.851
Terrestrial ~~A~~acidification	*molc H+ eq*	0.035	0.026
Terrestrial eutrophication	*molc N eq*	0.153	0.113
Freshwater eutrophication	*g P eq*	0.148	0.050
Marine eutrophication	*g N eq*	11.33	7.61
Freshwater ecotoxicity	*CTUe*	5.768	1.991
Mineral, fossil & ren resource depletion	*g Sb eq*	0.012	0.005

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Figure 1
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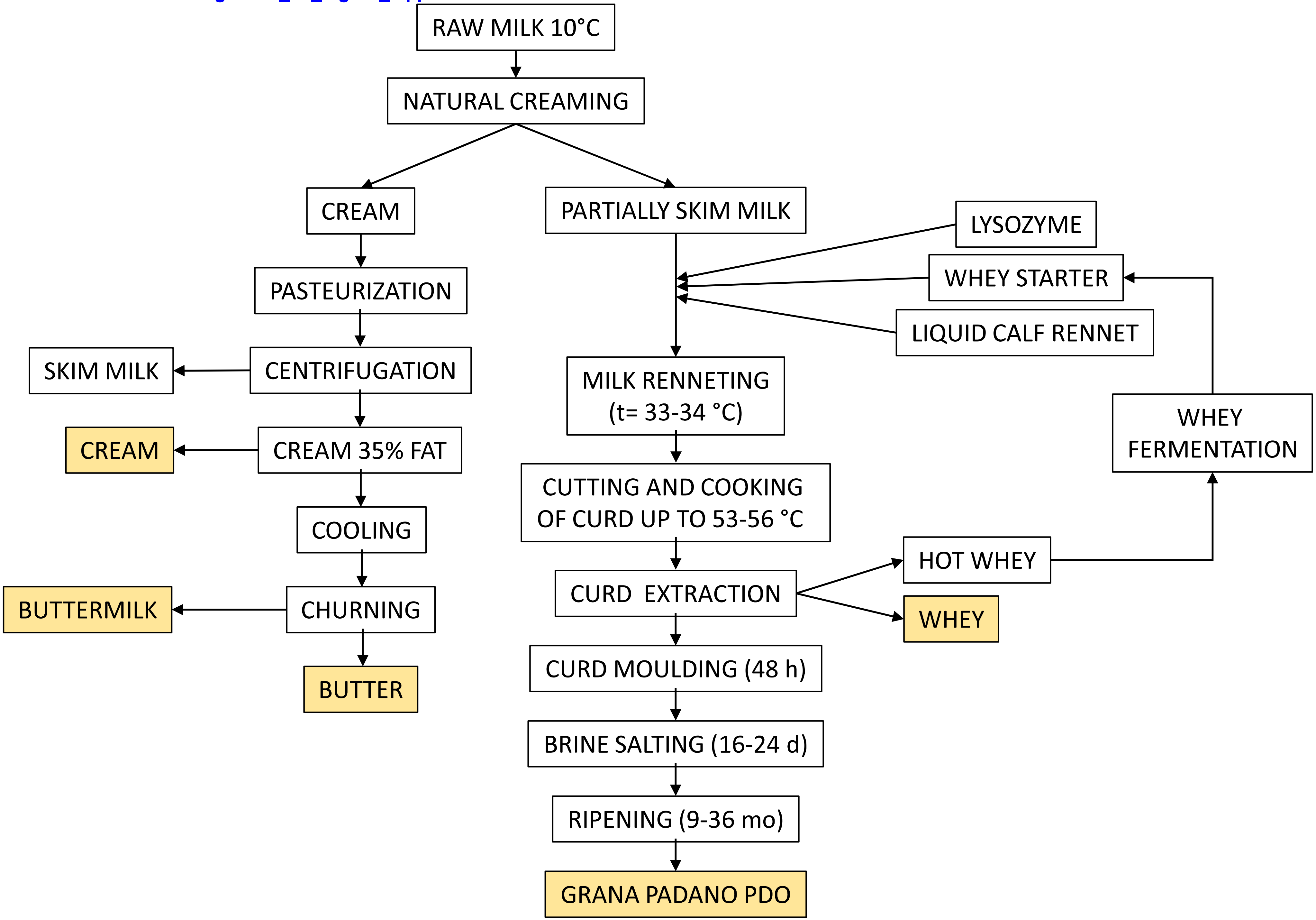

Figure 2

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