Horizon 2020

PROTECT

State-of-the art in energy use and sustainability of the dairy industry

Deliverable number: D5.1

*“This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement **No 813329**”*

Project Acronym: PROTECT

Project Full Title: Predictive modelling tools to evaluate the effects of climate change on food safety

Call: H2020-MSCA-ITN-2018
Topic: MSCA-ITN-2018
Type of Action: MSCA-ITN-ETN - European Training Network
Grant Number: 813329
Project URL: www.protect-itn.eu

Editor:	Serafim Bakalis– University of Nottingham
Deliverable nature:	Report (R)
Dissemination level:	Public (PU)
Contractual Delivery Date:	01/01/2020
Actual Delivery Date:	30/12/2019
Number of pages:	56
Keywords:	State of the art
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Contents

Abstract

ITN PROTECT will seek to understand the effect of climate change on the dairy chain and through scientific understanding develop a platform for the industry to assess possible interventions to mitigate the effects of climate change and propose a sustainable future for the dairy industry. The ITN started in April 2019 with the first ESRs appointed in October 2019. This document was a collaborative effort on the state of the art regarding the “energy and sustainability” in the dairy chain and will be further developed to turned into a publication in a conference and a peer reviewed journal publication.

The dairy sector represents a vibrant sector of the EU with profound influence both to the economy (12% of the total agricultural value) as well as the social fabric of EU. The sector supports a large number of farmers who produce 170 million tn of milk (95% cow) and been transformed to a wide range number of products. There is a rich ecosystem of organizations across the dairy value chain from small dairy farmers, to large multinational companies and cooperatives that allow nutritious products to reach consumers. The ongoing climate change will increase the pressures in the dairy chain. Current scenarios indicate that these will include different scenarios in the northern and southern. More specifically Northern countries will face strong wind and increasing rainfall, while southern increased temperatures and duration of heatwaves.

Milk is collected from farms daily and then sent to dairy plants that vary in size, from large industrial units to small local processing plants. The milk is processed in varying ways, packaged and then distributed. The distribution to the retail outlets is typically done through refrigerated chains, depending on the requirements of the products. The retail outlets vary in size from small grocery stores to large supermarkets (>1500 m^2). A significant proportion of dairy is wasted (> 30%) due to spoilage of products, while packaging plays a significant role in the accumulation of waste.

This document reviews the energy requirements of the dairy sector. The literature indicates that there are significant requirements both in primary production, mainly in milking, as well as during manufacturing, mainly due to refrigeration, evaporation and drying stages. Regarding the energy mix, dairy industry energy sources are mainly comprising of fossil fuels (about 80%), followed by nuclear power (about 15%), while there is limited use of renewable energy resources. With a broader scope, this document also revises the state of the art related the environmental sustainability performance of the dairy sector. A significant number of Life Cycle Assessment (LCA) studies have been undertaken with different goals and scopes, but all agree on the significant contribution of the primary production as well as the importance of reducing the significant amount of losses and waste produced along the dairy products value chains.

Overall, although a significant body of work exists, there is still a need to develop a framework that the multiple facet of dairy products will be assessed, e.g. environmental, financial, societal. This will be an ongoing work with the document further developed thought the lifetime of PROTECT.

Introduction

In the next few decades, our planet will be undergoing many drastic changes that need to be addressed before the changes become irreversible. The global population is increasing at an alarming rate and is estimated to reach approximately 9.7 billion people by 2050 (versus 7.3 billion in 2015) (World Population Prospects 2019 2019). According to the Food and Agricultural Organization of the United Nations (FAO), the population rise will require to a significant increase of food production and efficiencies to feed the world population.

Another critical future threat for food production is Climate Change. Global warming, droughts, increased precipitation, stronger hurricanes and rising sea levels are some of the effects of Climate change that will directly affect the world's agricultural production and lead to uncertainty. It is therefore vital that measures be taken to reconstruct the food industry in order to prevent insufficiency in production due to losses caused by adverse weather conditions.

One of the most vulnerable food sectors in this future scenario will be the Dairy Industry. Milk and dairy products hold a major role in the human diet worldwide and long-term sustainability of the sector is vital. The dairy industry is responsible for producing, manufacturing and delivering products made from mammals' milk while ensuring their quality and safety for consumption. However, the upcoming environmental and social challenges will lead to uncertainty if preventive measures are not taken. The population growth accompanied by urbanization and adoption of Western diets will lead to increased demand for Dairy products. In addition, dairy production is highly prone to Climate Change due to the environmental change that can affect milk production in quality and quantity.

One of the future goals in the direction of the conservation of Dairy Sector is reducing the amount of energy of the total dairy products supply chain. The dairy industry requires a significant amount of energy, due to the need for multiple prerequisite stages in the primary production of raw milk, the complexity in manufacturing with the high energy demand processing steps such as pasteurization, cleaning of the equipment refrigeration for unprocessed milk and final products maintenance, and refrigeration during distribution. In perspective, the energy required for the production of dairy products, from the primary production until the end of product life, estimated to be around 10 MJ/L for milk, 80 MJ/Kg of Cheese and 85 MJ/Kg of butter respectively (Dallemand et al. 2015). Throughout the entire value chain of dairy products, the phase with the largest environmental burden is identified at the dairy farming. Primary production of raw milk contributes in approximately three-quarters of the total impact of the dairy product (Schmidt & Saxcé, 2016; González-García et al., 2013). Moreover, this stage is one of the most vulnerable to climate change. Dairy farms are directly and indirectly affected by climate change, for instance, the cow's living conditions and the availability of fodder mainly (FAO & GDP, 2018).

Moreover, it is vital, not only to protect the Dairy sector from the upcoming environmental conditions but also make the industry more environmentally friendly. In order to achieve that, the dairy sector should reduce the environmental pollution by reducing the energy consumption and use of fossil fuels, turning into more "green" solutions. However, detecting the environmental preserving measurements that should be taken for the dairy industry is not easy to deal with. For this purpose, there have been developed global environmental assessment tools, such as the Life Cycle Assessment (LCA), that consider the entire supply chain enabling the quantification of the environmental impact of each particular production stage (ISO, 2006). These methods allow the quantification of the environmental impact of the whole life cycle of dairy products and allow the identification of the largest environmental impact along the value chain. In other words, the identification of the hotspot helps to analyse where the largest reductions can be implemented in order to enhance the sustainability of dairy products.

Overall, it is vital to develop optimal and efficient strategies that can achieve both the extension of the dairy section in order to cover the needs of the continuing growing population, as well as reduce the environmental footprint of the dairy industry in order to preserve the environment.

Section 1: Description of the Dairy sector today in EU

1.1 The Dairy Sector worldwide

In 2019, the top five of cow milk production was composed by the European Union, United States, India, Russian Federation, and China. In the same year, the EU was the leading producer achieving a production of 156 million metric tonnes of cow's milk (which represents more than 95% of the total milk produced) and the United Stated took the second position with about 99 million metric tonnes (**Figure 1.1**).

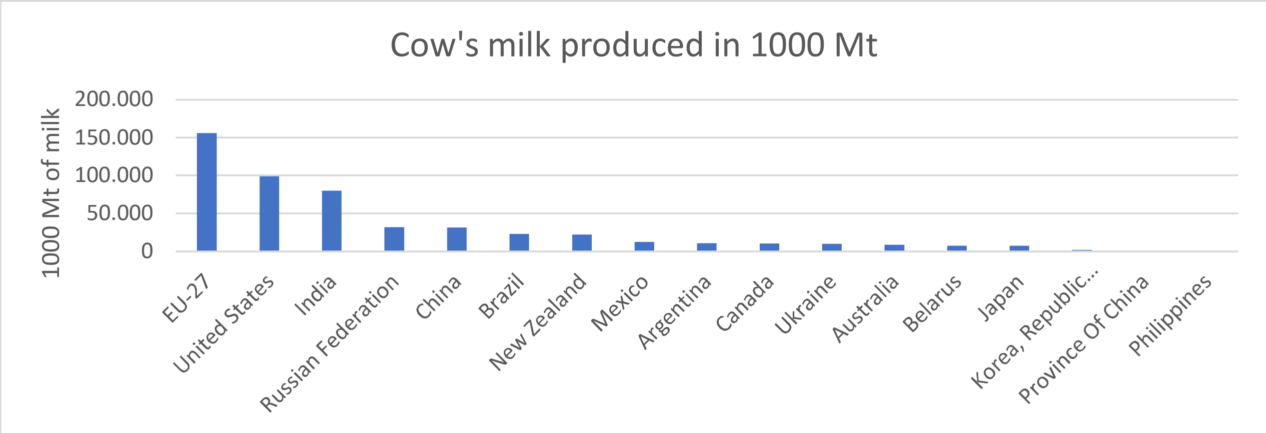


Figure 1.1. Producers of cow milk production in million metrics tonnes by the year of 2019 (Index Mundi, n.d.).

In terms of global trade of dairy products by the same year, the EU not only was recognized as the largest cow milk producer worldwide, but also as the major exporter of this product reached 900 thousand metric tonnes. New Zealand, Australia, and Belarus were the following as major countries exporters after the EU reaching quite similar numbers as showed in **Figure 1.2**. Recently the EU has opened a free trade agreements (FTAs) with Mexico and Japan, this is expected to benefit and strengthen its position as a dominant exporter worldwide (USDA 2019). Furthermore, in the import market of the dairy sector, China is recognized as the major importer of dairy products worldwide with 750 thousand metric tonnes, following by the Russian Federation, Philippines, Taiwan, and Mexico (**Figure 1.2**).

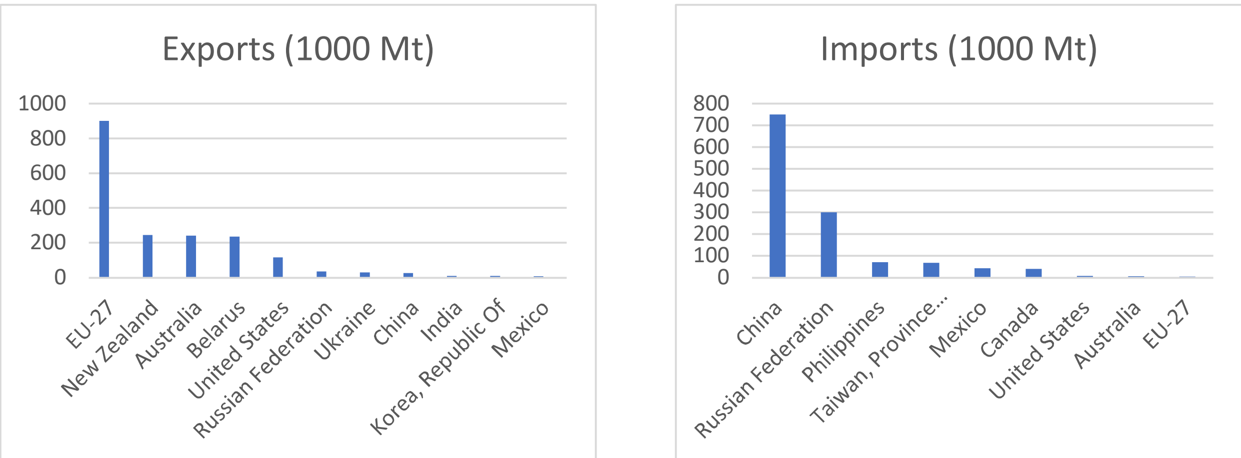


Figure 1.2. Main exporters and importers of dairy, milk, and fluids by country in 2019. Represented in thousand metric tonnes (Source: Index mundi, https://www.indexmundi.com/agriculture/?commodity=milk&graph=production)

1.2 Dairy Production in European Union

In the European Union (EU), the milk production represents 12% of the value of total EU agricultural output being the second largest agricultural sector (The EU dairy sector Main features , challenges and prospects 2018). The Dairy industry in Europe is a continuously growing sector. In fact, the total amount of milk produced in the EU in 2017 was estimated to be around 170.1 million tonnes, showing a significant increase of 1.8 million tonnes compared to 2016 (Eurostat, 2018).The main type of milk produced in EU is cow's milk which account for 97% of total production while the remaining type is derived mainly from goats, ewes and buffalos (The EU dairy sector Main features , challenges and prospects 2018).

Although European Union (EU) comprises only the 7% of world's milk population, it is the largest producer of milk worldwide with 31% of global production followed by United states (19%). Then follows, India (16%), Russian Federation (6%), China (6%), Brazil (6%), and New Zeland (4%). (Index Mundi, 2019) ***(Figure 1.3)***.

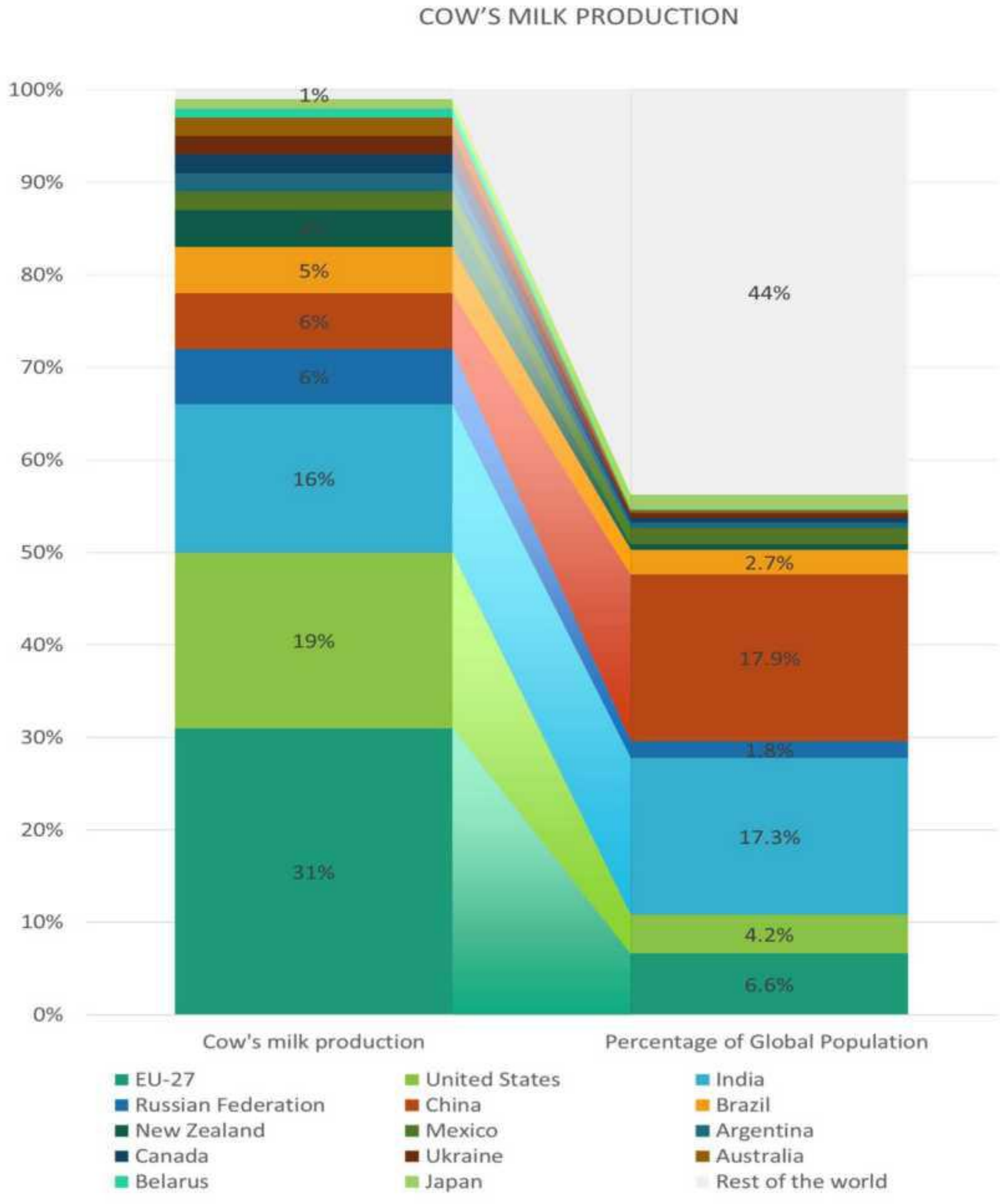


Figure 1.3. This graph represents the percentage of milk production per region compared to the respective percentage of global population. (Index Mundi, 2019)

The EU Dairy sector is a major exporter of dairy products and is the biggest cheese and skim milk powder (SMP) exporter worldwide. More specifically, from the total products produced 13% exported and 87% consumed internally (in milk equivalents) (Laiti and Fran 2016). The European Union (EU) dairy industry has successfully developed an export strategy which makes EU dairy products available to global consumers. For perspective, in 2016 the top 10 importers worldwide imported just under 50% of total EU exports (16,842,787 tonnes in milk equivalent), indicating that the EU dairy industry export strategy is both global and diversified (EDA, 2017).

The main cow's milk producers are Germany, France, the United Kingdom, Poland, the Netherlands, and Italy as shown in **Figure 1.4**, and their production accounts for almost 70% of total EU production (Eurostat, 2018). These key European countries in milk production comprise the so-called Dairy Belt , the area in the south of northern Europe and the western Europe (Epthinktank, 2015). Countries allocated in the Dairy Belt have more suitable environmental conditions and ground for pasture which results in increased production and reduced costs.

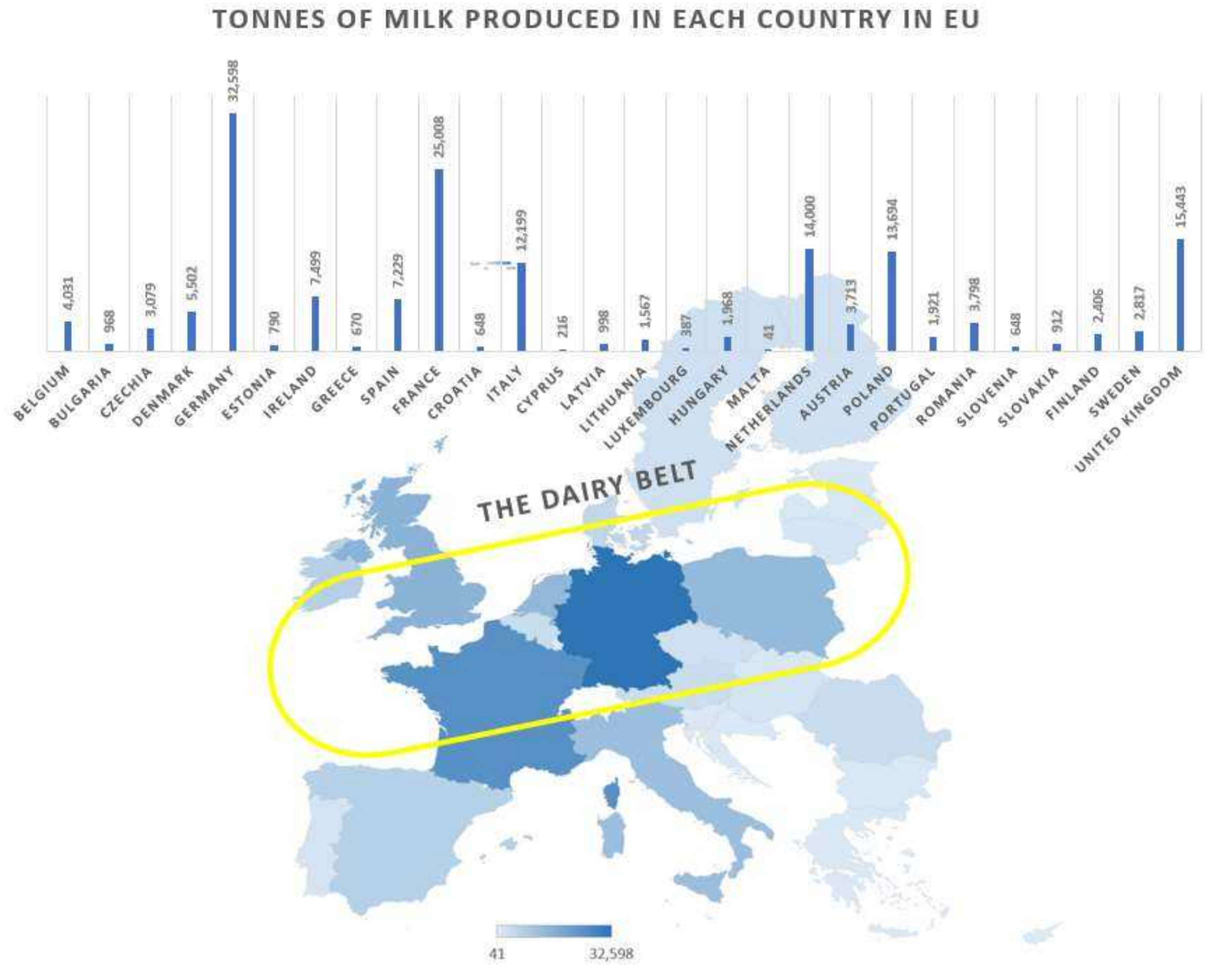


Figure 1.4. Raw cow's milk in thousand tonnes produced in EU countries in 2017 (Eurostat, 2019).

Technological advances and investments in cooling tanks and bigger milk tankers allow for efficient raw milk distribution from farms to processing plants. However, the countries with the greatest primary milk production, which are Germany, France, United Kingdom, and the Netherlands, are also the countries with the most dairy production plants and farms. Consequently, there is more distribution within these countries rather than throughout the EU. This is demonstrated in Figure 3 which shows the rate of cow's raw milk collection by country to be further processed. Germany holds the highest milk production level in the EU which is one-fifth of the EU's raw milk production as well as the highest milk processed production in about the same percentage (20.6% in 2019) (Eurostat, 2019).

EU's milk is mainly used to produce cheese and butter. In 2017, 2.4 million tonnes of cheese and butter were produced requiring 46.0 million tonnes of whole milk and generating 42.9 tonnes of skimmed milk. An additional 16.4 tonnes of skimmed milk were also produced through manufacturing of cream. This skimmed milk was used for the processing of other dairy products. **Figure 1.5** illustrates the amount of skimmed or whole milk required to produce several dairy products. 37% of total milk is used for cheese production, 29% for butter, 13% for butter, 11% for drinking milk, 4% for acidified milk, 3% for milk powder and the rest for other products.

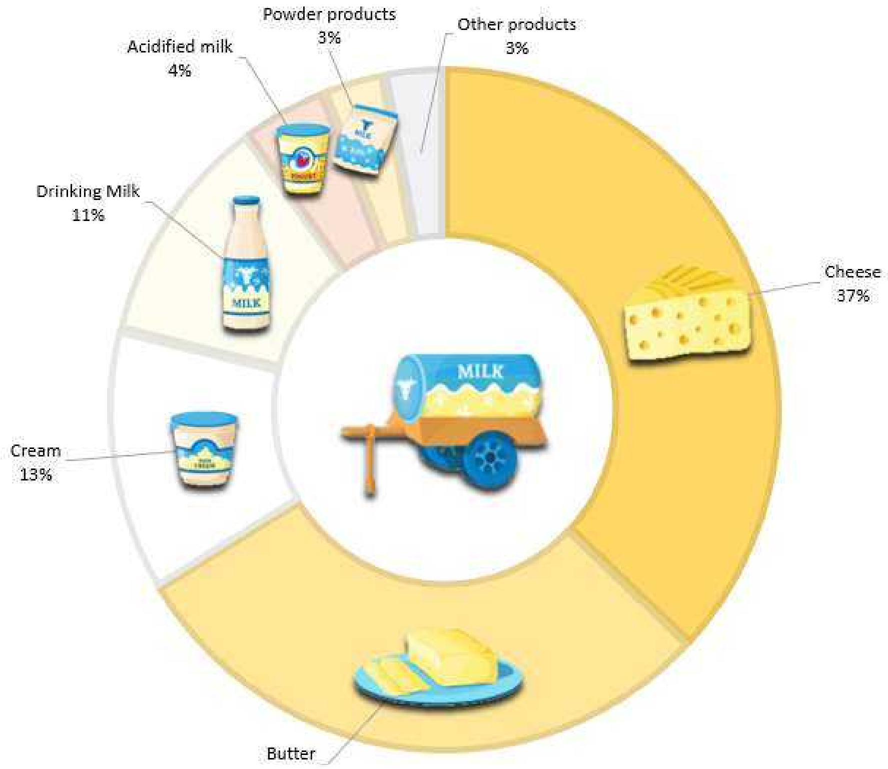


Figure 1.5. Persentage of raw milk processed for different dairy product. (Eurostat, 2018)

1.3 Dairy Farms in European Union

In 2018 there were around 23 million cows in farms of European Union Countries. **Figure 1.6** shows the number of cows measured in thousand heads in each member state as recorded in 2017 (Eurostat, 2019).

Their milk production per cow varies, mostly depending on their feed, environmental conditions and genetics. With respect to the average productivity of cows in EU, the milk yield in 2018 was 6925 kg/yr per cow (Europa, n.d.) while in US in 2019 the average milk yield was much more than that in EU, equal to 10,648 Kg/yr (Statista, 2019). As a national average, the highest cow's milk yield in 2017 was in Denmark (9611 kg/yr), followed by Estonia (9186 kg/yr) and Finland (9073 kg/yr), while the cows with the lowest average productivity where in Romania (2909 kg/year) and Bulgaria (3713 kg/year) (Statista, 2019). **Figure 1.7** shows the average milk yield per cow in each EU member state.

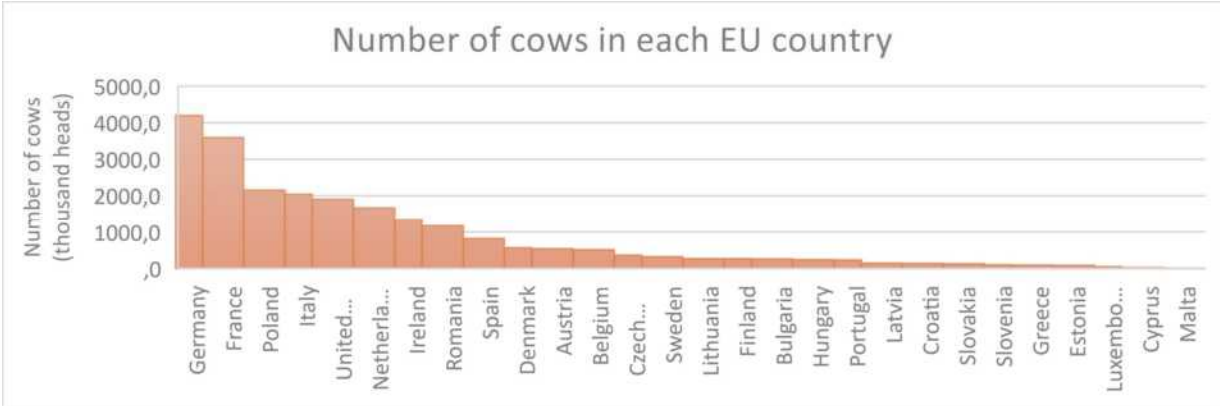


Figure 1.6. The graph represents the number of dairy cows in thousand heads in each EU country (Eurostat, 2019).

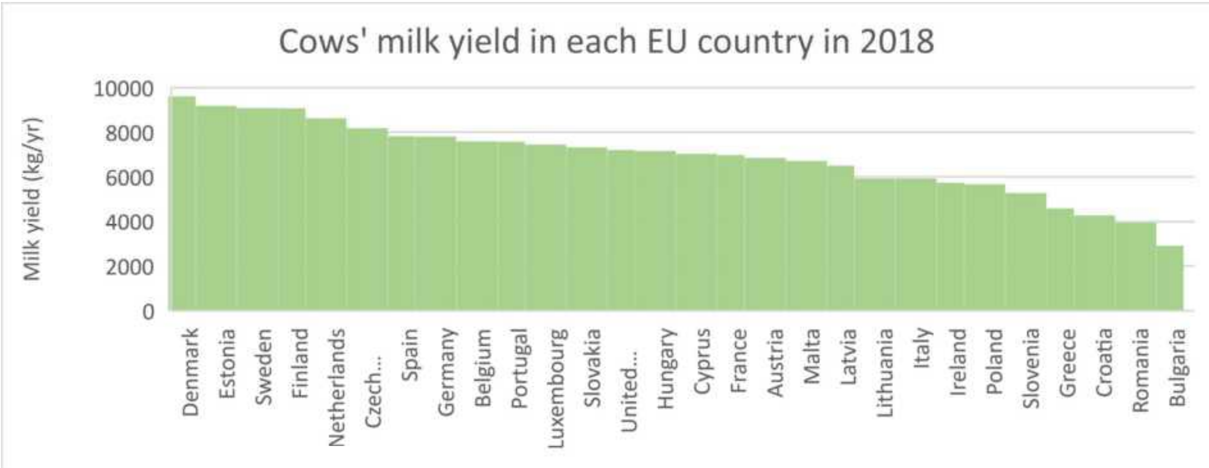


Figure 1.7 Cows' milk yield in each EU country. (Statista, 2019)

In **Figure 1.8**, the map illustrates the average cow's milk yield per year in each member state and it can be observed that the milk yield seems to depend on the geographical location of the cows. In fact, the northern countries of EU produce more milk on average than the cows at Southern Europe while in Central EU the milk yield is slightly less than that of Northern EU as shown in the graph in **Figure 1.8**. Beyond differences in farms and genetical characteristics of the cows at different countries, this could be also related to the higher environmental temperatures of the south that affect their productivity due to heat stress (Bohmanova, Misztal, and Cole 2007).

All member states of the European Union produce milk in farms which vary in type from free-range farming in Alpine areas to large specialized farms in North-West and Central Europe. EU farms have 33 cows per livestock unit and a forage area of 30 ha in average, but their number of cows and size of forage area vary enormously in each member state. The leading countries in the field which are Germany, France, the United Kingdom, Poland, the Netherlands, and Italy have on average 69 cows per livestock unit (LU)and the average LU area is 55 ha. Slovakia is the country with the biggest number of cows per Livestock Unit (LU) and the biggest forage area on average, which is 215 cows and 672 ha respectively, while Romania has the least mean number of cows equal to 4 cows per LU and the smallest forage area on average which is 2 ha. These cases could be studied further to better understand how the livestock unit size affects the production (**Figure 1.9**).

Figure 1.8. The bar chart shows the mean milk yield per region (EU, EU-15, EU-13, Northern, Central and Southern EU countries) estimated by the product of the mean milk yield per country with the number of cows per country as a weight factor, and the map represents the milk yield in kg of milk per year in each country. Data derived from Statista (Statista, 2019)

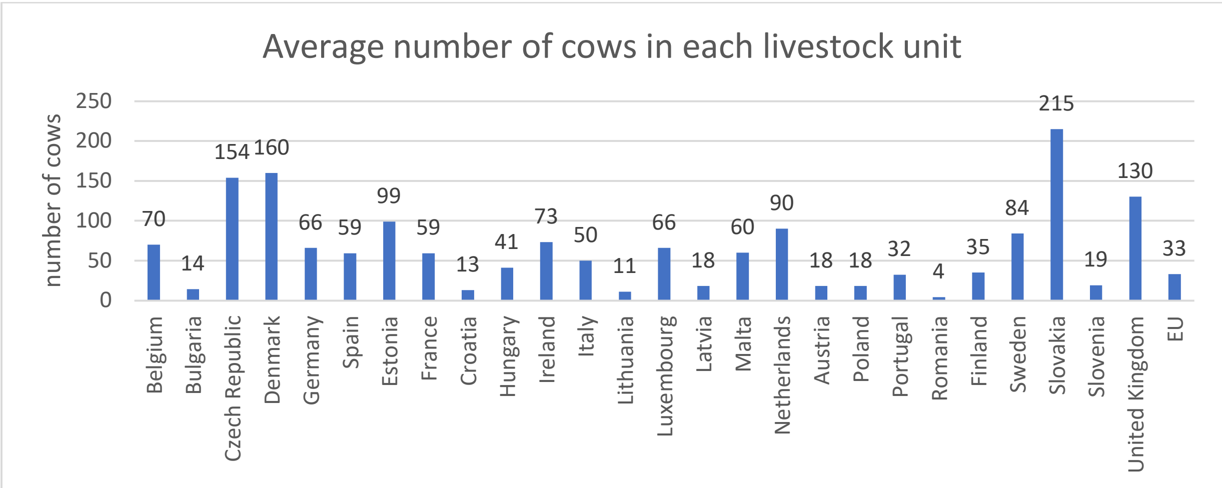


Figure 1.9. Average number of cows in each livestock unit on each EU country

In **Figure 1.9** is presented the number of cows that each worker in farm is responsible for. Interestingly, Denmark is the country whit the smallest rates of workers per cows as each worker is responsible for 56 cows. Then follows Netherlands and United Kingdom where the number of cows per worker is 52 and 48 respectively. This could be related to the fact that in these countries there are used many technological advances and automation and thus, les labour is needed.

Finally, most of the EU farms are family farms. In fact, on average 87% of EU farms are run by the owners' family members. From a statistic point of view, according to **Figure 1.10**, in most EU countries, the share of family labour is at least 60% on average. Exceptions are the Czech Republic, Estonia, Hungary and Slovakia and Denmark where the share of family labour is below 42% on average.

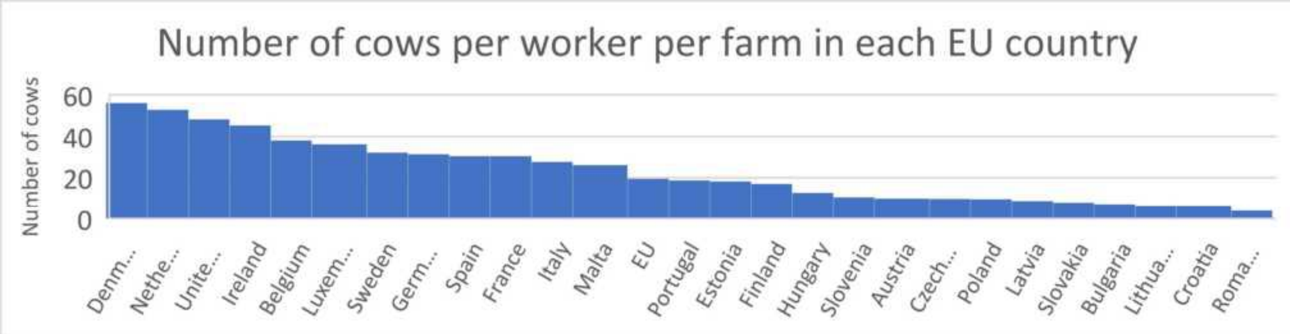


Figure 1.9. Average number of cows that each worker in farm is responsible for in each European country (Eurostat, 2019)

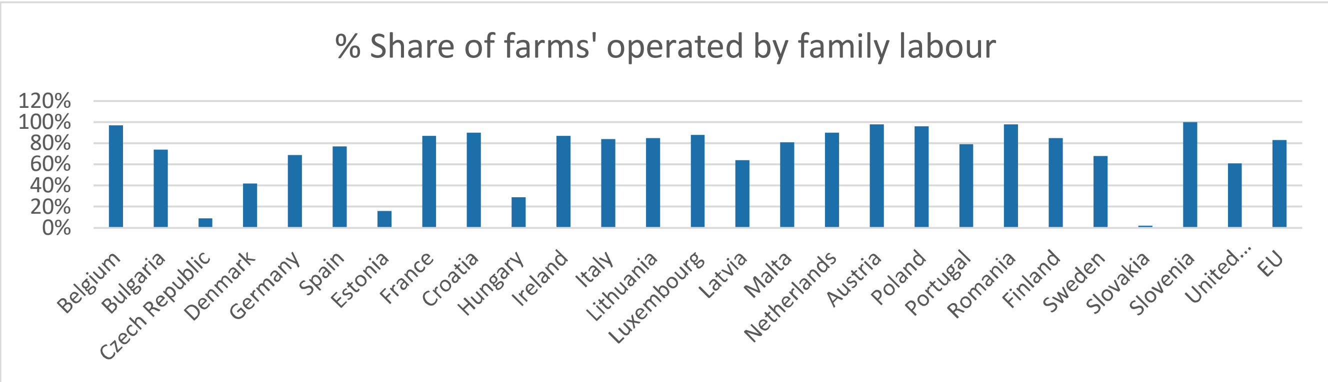


Figure 1.10. Share of family labour in average in each European country (Agriculture , forestry and fishery statistics 2016 edition 2016).

1.4 Dairy companies and manufacturers in European Union

Most of the milk produced in dairy farms is sent to processing plants for further manufacturing. There are 20 milk processors responsible of collecting and processing around 25% or 211 million tonnes of the milk produced worldwide. As shown in **Table 1.1**, Dairy Farmers of America in United States topped the market share of dairy giants leading the top 20, with 3.5% out of the 25%. In **Table 1.1** the yellow boxes highlight the companies that operates under the cooperative group approach.

Table 1.1. Top 20 of dairy companies processing (IFCN, 2018) yellow squares represent the companies that operates under the cooperative group approach.

RANK 2018	COMPANY NAME	ORIGIN & MAIN OPERATION COUNTRIES	MILK INTAKE in mill. T ME	ESTIMATED TURNOVER per kg milk im USD	MARKET SHARE in % of world milk production
1	**Dairy Farmers of America**	**USA**	**29.2**	**0.5**	**3.50%**
2	**Fonterra**	**New Zealand/Others**	**23.7**	**0.6**	**2.80%**
3	**Groupe Lactalis**	**France/Others**	**19.6**	**1.1**	**2.40%**
4	**Arla Foods**	**Denmark/Sweden/Others**	**13.9**	**0.8**	**1.70%**
5	**Nestle**	**Switzerland/Others**	**13.7**	**1.8**	**1.60%**
6	**FrieslandCampina**	**Netherland/Others**	**13.6**	**1.0**	**1.60%**
7	**Saputo (inc. MG)**	**Canada/USA/Others**	**9.8**	**1.1**	**1.20%**
8	**Dean Foods**	**USA**	**9.4**	**0.8**	**1.10%**
9	**Amul (GCMMF)**	**India**	**9.3**	**0.7**	**1.10%**
10	**Danone**	**France/Others**	**8.6**	**2**	**1.00%**
11	**DMK**	**Germany/Netherlands**	**8.1**	**0.9**	**1.00%**
12	**California Dairies**	**USA**	**7.7**	**0.5**	**0.90%**
13	**Yili Group**	**China**	**7.2**	**1.4**	**0.90%**
14	**Gianbia Group**	**Ireland/USA/Others**	**6.5**	**0.6**	**0.80%**
15	**Mengniu**	**China**	**6.4**	**1.4**	**0.80%**
16	**Agropur**	**Canada/USA**	**6.3**	**0.8**	**0.80%**
17	**Group Sodiaal**	**France**	**4.9**	**1.2**	**0.60%**
18	**Muller**	**Germany/UK/Others**	**4.6**	**1.1**	**0.60%**
19	**Schreiber Foods**	**USA**	**4.5**	**1.1**	**0.50%**
20	**Bongrain/Savencia**	**France/Others**	**4.1**	**1.3**	**0.50%**
Sum of Top 20			**211**	**1.9**	**25.40%**

Although there are plenty Dairy processing plants, there are 9 leading manufacturing companies in EU between the *world-leading multinational companies*. **Figure 1.11** Illustrates the 20 Dairy companies with the highest turnover worldwide in 2018 and the blue coloured stripes represent the EU Dairy companies (Battum and Ledman 2019).

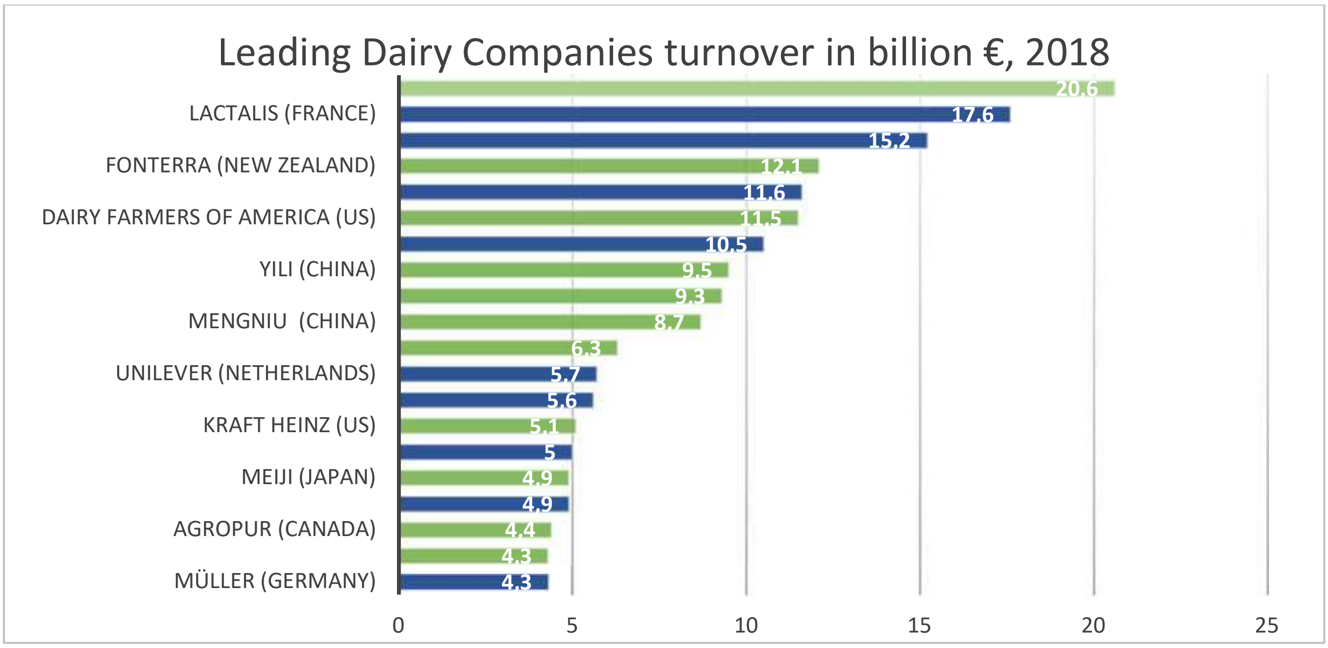


Figure 1.11. Leading dairy companies' turnover in billion € (Battum and Ledman 2019). The blue stripes represent companies based in EU countries.

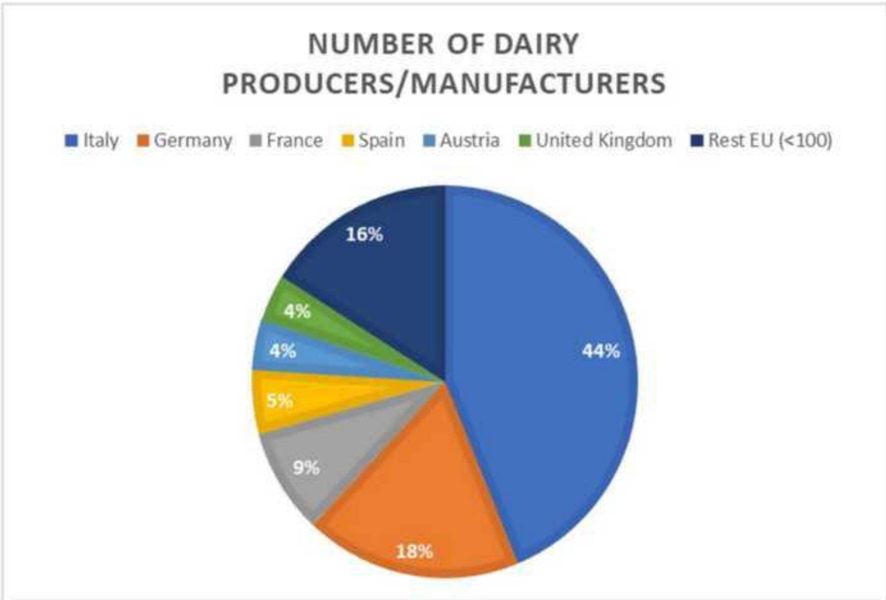


Figure 1.12. Percentage of manufacturers per country according to the database of Europages B2B search engine (Europage, 2019)

The dairy manufacturing plants vary a lot depending on the produce and in the milk capacity they process, from large factories to small and very small dairy plants. Although It is claimed that there are about 12,000 processing plants in EU, employing 300,000 people (Laiti and Fran 2016), to the best of our knowledge there are no easily available data to support the exact number. The database of Europages B2B search engine (Europage, 2019) includes information for about 3 million companies mainly from Europe, from which about 3400 are Dairy manufacturing companies in EU. Most of them are in Italy (about 1500 Dairy manufacturers), followed by Germany which has about 600 and France which has about 300 plants. **Figure 1.12** shows the percentage of the number of Dairy manufacturing plans in each country of the total 3400 plants found in Europage.

In EU the 55% of the market share of the dairy sector is organized in co-operatives, meaning that the production plants use milk which is produced from groups of individual farms (The EU dairy sector Main features , challenges and prospects 2018).These cooperative range from large multinational companies, e.g. FrieslandCampina, Arla, to small SMEs. About half of the EU world leading dairy companies are cooperatives. The largest co-operative Dairy companies in EU are the Netherlands co-operative companies

FrieslandCampina, Arla Foods in Denmark and Sweden, the German company Deutsches Milchkontor (DMK) and the French company Sodiaal (Myth n.d.).

Cooperaatives have a major market share in EU. In 2015, 64% of cow's milk processed in the Dairies is handled by cooperavive schemes. Netherlands had the highest market share of cooperatives, 86 %, followed by Poland 75%, Italy, 68%. Germany, 67% and France with 54%. (The EU dairy sector Main features , challenges and prospects 2018)

1.5 Hierarchy of the supply chain

The hierarchy of the dairy supply chain in the EU, starting from primary production to consumers, is of great interest. As shown in Figure 1, the EU Dairy is reconstructed by 600.000 farms which host 23,000,000 dairy cows. It is important to mention that the dynamic and the structure amongst the dairy farmers differ, in other words the integration might vary from a cooperative group, an individual to intermediary individual group. The cooperative group is recognized for an integrative work between the farmers and the company, the interests of both sides are aligned and work in cooperation. The individual group is characterized when farmers sell milk directly to the milk company, and the firm establish a milk fixed price to the farmers. Lastly, in the intermediary individual group, there is the presence of an intermediary that arrange a price of the milk with milk farmers and this is the responsible of selling the product to the company (GRAIN, 2012). Milk collected by EU farms is processed in approximately 12,000 dairy plants of which 10 large Dairy companies control approximately 25% of the milk volume produced. After manufacturing, dairy products are distributed through retailers, the 10 largest supermarket chains of Europe control 31.8% of the market share **(Table 1.2**) (Publications Office of the European Union 2014).

Table 1.2. EU-27 market share of biggest supermarket chains and the member states in market that the retailers operate (Publications Office of the European Union 2014).

Retailer	EU-27 market share	Member states in sample where retailers operate (in 2011)
Schwarz Group	4.7%	All 9 member states
Carfour	5.5%	Belgium, France, Italy, Poland, Portugal, Spain
Tesco	3.8%	Czech Republic, Hungary, Poland
Edeka	3.4%	N/A
Aldi	3.1%	Belgium, Denmark, France, Hungary, Poland, Portural, Spain
Rewe Goup	3.0%	Czech Republic, Hungary, Italy
Auchan	2.2%	France, Hungary, Italy, Poland, Portugal, Spain
ITM (Intermarché)	2.1%	Belgium, France, Poland, Portugal
Leclerc	2.1%	France, Italy, Portugal, Spain, Poland
Ahold	1.9%	Belgium, Czech Republic

Finally, there are about 240,000 big retail outlets in the EU and plenty of medium and small grocery stores, all of which are servicing the EU population which is around 500 million people. These numbers are represented in **Figure 1.13** demonstrating the hierarchy of the Dairy Supply Chain depicted by an hourglass shape, showing the concentrated power of the largest manufacturing companies and retail chains in the EU.

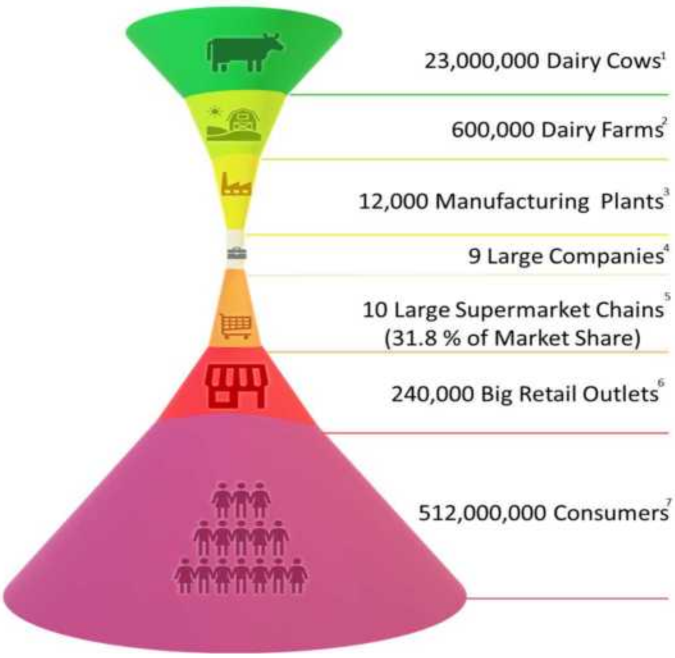


Figure 1.13: Hierarchy of the Dairy Supply Chain depicting by an hourglass shape, showing the concentrated power of the largest manufacturing companies and Supermarket chains in EU.

[1] *(Eurostat, 2019)*

[2] (Publications Office of the European Union 2014)

[3] (Laiti and Fran 2016)

[4] (Battum and Ledman 2019)

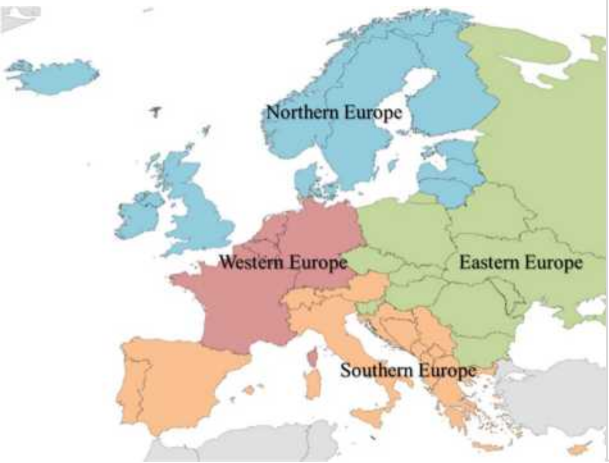
[5,6] (Publications Office of the European Union 2014)

[7] *(Europa, n.d.)*

1.6 Milk in human diet

Milk is an important source of protein and essential minerals, most important of which is Calcium, and also contains several vitamins, and thus can contribute to a balanced diet. Specifically, the cow's milk which is the most **produced** type of milk consist of approximately 87% of water, and 12-13% of solids which consist of ~4% and solids-not-fat (SNF) ~9%. The SNF include proteins, lactose, minerals and vitamins. Caseins are the most abundant type of protein about 80% which comprise of three different species: different species (αS1, αS2, β, and κ-caseins).

Dairy products play an important role in European Diet. The highest demand of milk and butter derived products among European Dietary Regions are the Northern and Western Regions. In both regions the consumption of dairy products excluding butter is about 716 g per capita each day. Slightly behind is the Southern Region where people consume in average about 590 g each day, followed by the Easter Region where people consume about 470 g of dairy products excluding butter per day (**Figure 1.14**). (FAO, 2019)



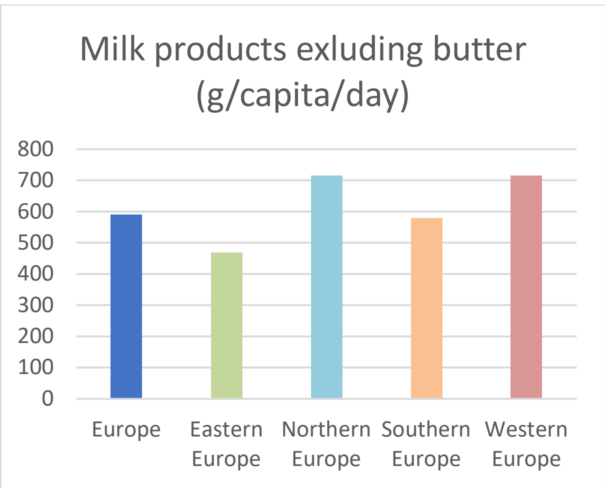


Figure 1.14: Milk products consumption (excluding butter) depending on the Region. (FAO, 2019)

If we compare the consumption of milk per day in every region, from **Table 1.3** above, it is clear that Southern European consumption is in line with the average, whereas Northern and Western Europe have +20% extra consumption versus European average and Eastern Europe is well below the European average (-20%).

Table 1.3. Dairy Products Consumption per Region compared to Total Average (FAO, 2019).

Region	Population in million	Percentage of Total Population	Milk Products Consumption excluding butter (g/capita/day)	Total Milk Consumption excluding butter per day Per region (tonnes)	% Milk Products Consumption per Region / Average milk products consumption in Total Europe	% Deviation from average consumption per region
Eastern Europe	326	42%	470	153	**80**	**-20%**
Northern Europe	105	13%	716	75	**122**	**+22%**
Southern Europe	152	19%	590	89	**100**	**0%**
Western Europe	197	25%	716	141	**122**	**+22%**
Total Europe	780	100	588	458	**100**	**0%**

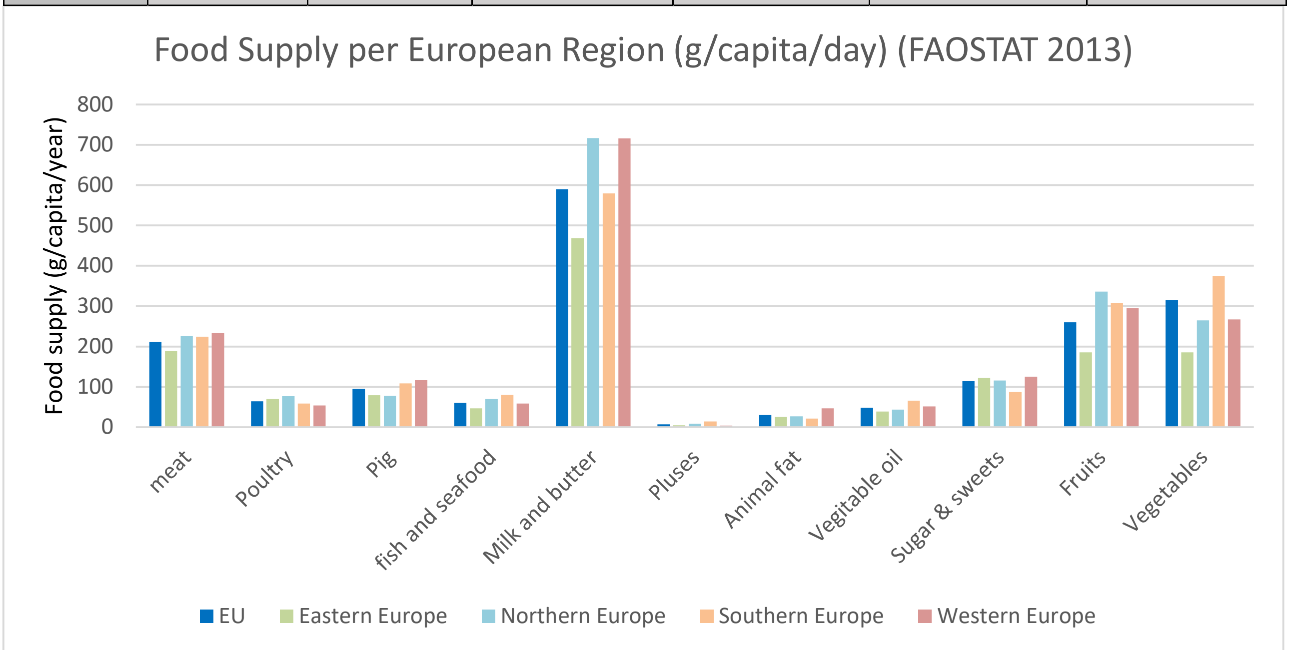


Figure 1.15: Food supply per European region for each category of food product.

Dairy product demand is much greater in Northern and Western Europe, which is where most Dairy Plants and Dairy farms exist. Nonetheless, dairy production in these areas will be most affected by climate changes, as indicated in **Section 2** and priority must be given to these areas for more efficiency in production and energy consumption (EUPHA (European Public Health Assosiation) 2017).

Section 2: Climate Change and the Dairy industry

The change of climate conditions has been of concern to the food industry globally. The Earth's temperature has been rising over the years and it is not the first time that the Earth's climate has experienced drastic changes. In the past 650,000 years, earth has been through seven cycles of glacial advance and retreat, that have been mostly caused by small variations in the planet's orbit creating changes on the quantity of solar energy earth receives (NASA, n.d.). However over the last decades, climate change has been attributed to a number of human related activities, include continuous human and ruminant livestock populations growth, world gross domestic product, global tree cover loss, fossil fuel consumption, carbon dioxide (CO_2) emissions and much more (Ripple et al. 2019). In this respect, global attention needs to be given to achieve sustainable development in various climate change scenarios. This requires both adaptation and mitigation in energy planning and implementation (Climate Change 2014 Synthesis Report Summary Chapter for Policymakers 2014). This section will focus in summarizing climate change scenarios and ways that they will influence dairy production.

2.1 Climate change effects across Europe

Climate Change effects will vary across Europe. It has been observed that the varying effects depend on geographical region, thus allowing us to better understand how each region will be affected and measures need to be taken to cope with these changes. With reference to **Figure 2.1** below, there are six geographical regions that have been defined according to their effects from Climate Change (Ian Holman, n.d.).

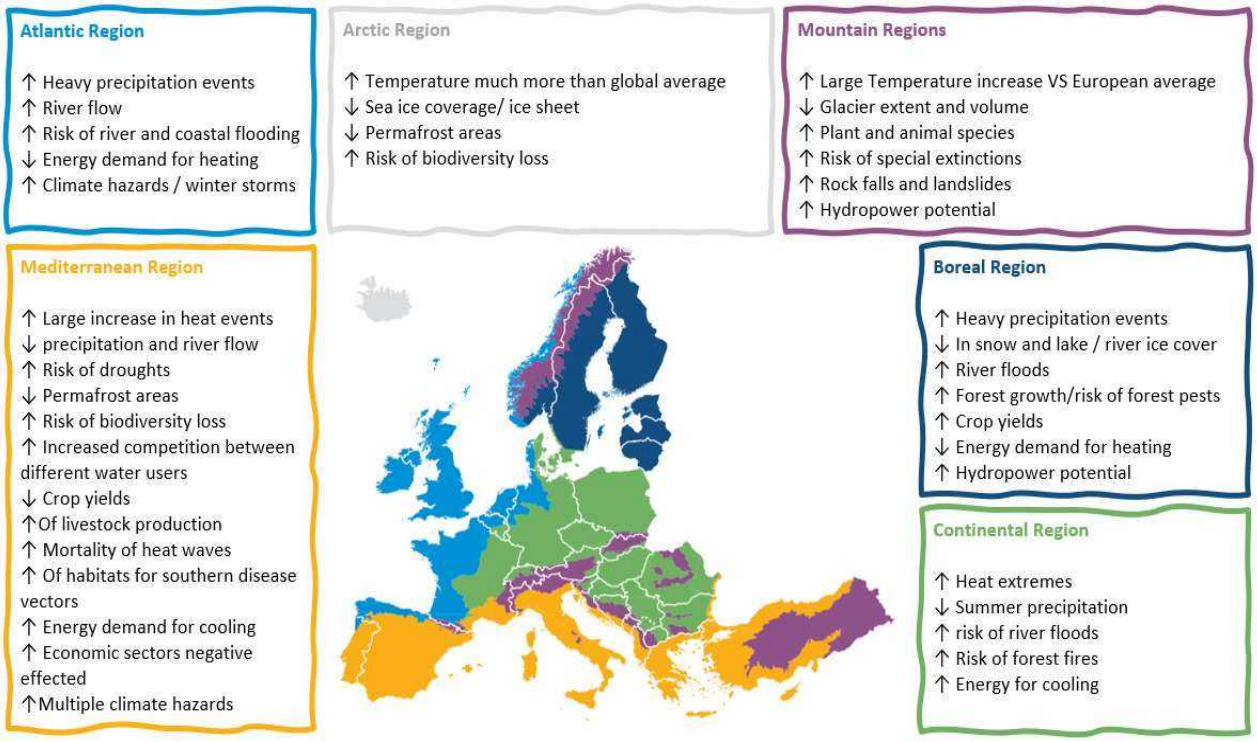


Figure 2.1. Climate change effects depending on the geographical region (No 2019).

The Mediterranean Region is comprised of the Southern European countries bordering the Mediterranean Sea. This region will undergo the most drastic effects of Climate Change. Heat waves will become more frequent, sometimes reaching extreme levels and will lead to increased mortality especially among susceptible groups. Precipitation and river flow will abate leading to increased risk of droughts, and competition for water usage between countries of this region is expected to become fiercer. This condition will result in loss in biodiversity and crop yield and negatively affect the economic sectors which currently thrive in better climate conditions with less climate hazards. Finally, the increased energy demand for cooling in the Mediterranean Region will become an essential need. Specifically, energy demand for cooling could increase six times from its recent level energy demand by 2040 (MEDENER, OME, and ADEME n.d.).

The **Continental region** covers most of the Central European countries. This region is expected to undergo extreme heat waves, thus inducing increased energy demand for cooling. Importantly, the impending heat and dry weather will lessen summer precipitation and increase the risk of forest fires. Moreover, in rainy months there will be a higher risk of river floods whereby the water table (ground in the soil) will become saturated and no longer contain the extra water.

The **Atlantic Region** covers the Western European countries bordering the Atlantic Ocean. Unlike Continental and Mediterranean Regions, this region is going to experience very heavy precipitation events, increased river flow and risk of river and coastal flooding. Generally, climate hazards linked to winter storms are going to increase. However, there will be less energy demand for heating compared to recent years.

Regarding the **Arctic Region,** its average temperature will increase compared to the global average. In the face of ongoing global warming, the poles, and here we refer to the Arctic pole, are warming faster than lower latitudes. The primary cause of this phenomenon is the “ice-albedo feedback”, whereby melting ice uncovers the land or ocean beneath, revealing the darker colour beneath which absorbs more sunlight, causing a rise in temperature. Arctic ice coverage and permafrost are decreasing substantially whilst the risk of biodiversity loss is incumbent.

The Mountain Regions, as defined by their high altitude, spread across various areas of the European continent. The average temperature in these regions, is going to increase faster than the respective European average. The ice caps will continue to melt, and glacier extent and volume will accordingly diminish. Unfavourable effects will ensue such as increased rock falls and landslides, increased risk of special extinctions, expansion of plant and animal species including more forest pest species. Finally, hydropower potential is going to increase as a result of increased river flow due to melting ice caps. Hydropower is the most important and widely used renewable source of energy and represents about 17% of total electricity production worldwide (EIA (U.S. Energy Information Administration), 2019).

Finally, there is **the Boreal Region** which covers the North East countries of Europe neighbouring the Mountain Regions. We expect less snowfall on average in these regions, as well as a reduction in lake and river ice cover. Precipitation events will be heavier and more frequent compared to recent years. Consequences of this include river floods as well as increased forest growth and crop yields. Hydropower potential is expected to increase and energy demand for heating will decrease.

2.2 Temperature and Precipitation projection in Europe

Figure 2.2 illustrates Europe’s changes in annual mean temperature and precipitation from the time period of 1971-2000, to the time period of 2071-2100. It is clear from the left-hand side map that the mean temperature is going to increase in general, but the biggest difference is going to take place in the southern and northern regions of Europe. Regarding the annual precipitation events, these are going to increase significantly in the north region of Europe and decrease in the southern part of Europe – as shown on the right-hand side map.

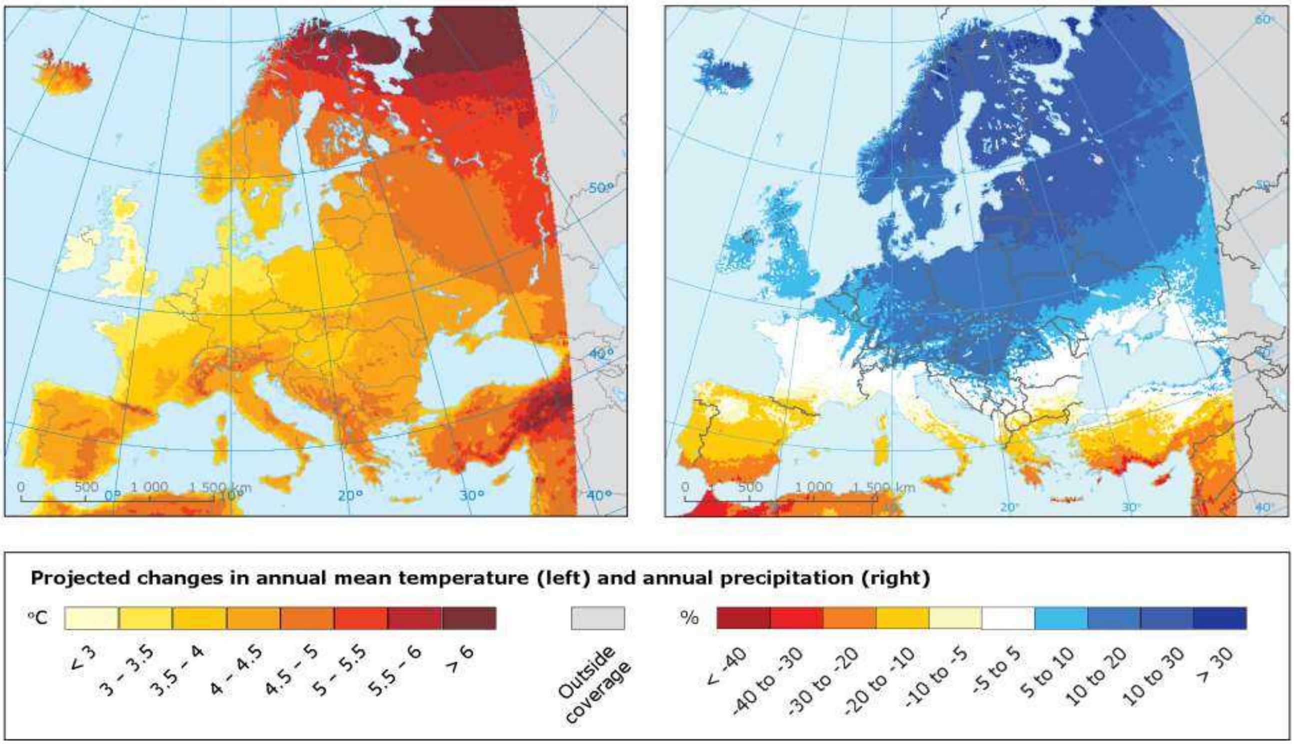


Figure 2.2. *Projected climate change between from the time period 1971-2000 to the time period 2071-2100 for a high emission scenario RCP 8.5 (Representative Concentration Pathways 8.5). Left map shows the projected annual mean temperature change and the right map presents the percentage of alteration in annual precipitation events* (Eu et al. 2015).

2.3 Climate Change impact on the European Dairy supply chain

In all stages of dairy production; primary production, processing stage, distribution, consumption, and disposal, environmental conditions play a major role in the quantity, quality and safety of the final products. Inevitably, the looming climate change effects stand as a major threat to the dairy industry.

Cow's milk productivity is directly dependent on their feed, so crops availability is essential. However, climate changes will adversely affect the European Agricultural sector. Rising temperatures and intense temperature fluctuations as well as changes in precipitation patterns and water availability are already affecting crop production, yield and livestock conditions. The situation is expected to deteriorate if measures are not taken. More specifically, there will be less water available for irrigation, livestock watering practices and even the processing and storage of agricultural products. Southern Europe will be the most affected region of Europe since water insufficiency and incumbent droughts will significantly affect the agricultural yield. Agriculture will need to be reallocated towards the North of Europe, where there will be longer growing seasons and more favourable environmental conditions. However, it should be noted that these regions will be frequently affected by weather extremes, setting the yields and livestock at risk. (Climate Change 2014 Synthesis Report Summary Chapter for Policymakers 2014)

During the primary production stage, cow's feed and living conditions directly affect the milk yield of dairy cows. When cows are exposed to a combination of adverse environmental factors including temperature, humidity, solar radiation, air movement and precipitation, they might suffer from heat stress. The higher the temperature, the more cows fall out of their thermoneutral zone which is between 5 and 25 °C (Spiers, Sampson, and Rhoads 2004). It has been reported that daily mean air temperatures above 18°C make cows more prone to heat stress (Uk et al. n.d.).

Humidity also plays a significant role in haemostasis maintenance (Bohmanova, Misztal, and Cole 2007). When cows are heat stressed, they produce less milk. Milk synthesis is directly proportional to metabolic heat load, so during heat stress conditions, milk production levels drop (Spiers, Sampson, and Rhoads 2004). It was also found that high temperature and air humidity during breeding increased cattle mortality risk by 60% in Italy (Schifano et al. 2012). According to a study of animal adaptiveness to environmental conditions (Megersa et al. 2014) among camels, goats, sheep and cattle, cattle are generally the most sensitive species to the detrimental effects of climate change.

Special attention should be given to the stability/safety of the final product during distribution process all the way to the final consumption stage. During distribution, the use of refrigerated trucks is mandatory, and the distribution distance should be optimized in order to minimize possible environmental exposure.

Climate induced trends such as heat waves and hot extremes, droughts, rainfall, changing CO_2 levels and strong winds are expected to affect the microbial population growth and will inevitably generate environmental dispersal and persistence of foodborne pathogens (Uk et al. n.d.). In this case, more restrictive safety standards for milk treatment need to be established, possibly bringing drastic repercussions to the process lines. However, although the dairy sector is a system vulnerable to climate change, at the same time this sector is a significant contributor to this global issue, being responsible for 4% of the total GHG emissions worldwide, 1.9 million tonnes of $CO_{2\text{-eq}}$ (Gerbet et al., 2010). The dairy sector is already working in the transition to sustainable practices. The environmental impact of dairy products, such as milk, cheese, yogurt, cream, and others, have been analyzed worldwide in previous years. However, there is still a need to optimize the system and intensify the actions to reduce the footprint while ensuring food security and adapting to climate change effects. For this, mandatory measures need to be taken since an increment in global production is expected to happen due to impending population growth.

Section 3: Energy of the Dairy Sector

The Dairy supply chain

The dairy industry produces a variety of products using milk from cows (97% of total milk source), but also goats, ewes and buffalos. These products include liquid milk, milk powders, cheese, butter, yogurt, cream as well as ice cream and deserts.

Milk is collected at the farms every day, sometimes even twice a day. After primary production at the farms, raw milk is sent to dairy plants that vary in size, from large industrial units to small local processing plants, for manufacturing. The milk is processed in varying ways, packaged and then distributed. The distribution to the retail outlets is typically done through refrigerated chains, depending on the requirements of the products. The Retail outlets vary in size from small grocery stores to large supermarkets (>1500 m^2). Products are placed in open chiller fridges, regular fridges or shelves depending on their maintenance needs, until they are purchased by the consumer. Finally, the end users keep dairy products in their fridge, if needed, until these are consumed. A great proportion of dairy waste (> 30%) is also generated due to spoilage of products, while packaging plays a significant role in the accumulation of waste.

Milk is produced daily in farms and should be processed within a short time at dairy plants. It is of great importance that all the processes be designed in an optimal way, given milk is a sensitive product that can be easily spoiled if left untreated for relatively long periods.

Energy Use in the Dairy industry

The Dairy Industry – one of the major food sectors – will be vulnerable in the near future if preventive measures are not taken. The two key factors driving this is the alarming rise in global population and the repercussions of global Climate Change. The Dairy industry will need to redefine its processes and distribution infrastructure by focusing on reducing energy requirements, which are significantly higher than that of other food industries. (Ladha-sabur et al. 2019)

Governments worldwide are setting targets in order to address climate change. Some of these targets are focused on saving energy and reducing greenhouse gas emissions. Thus, in order to accomplish the safe development of the Dairy Industry, in line with the new global requirements, efficient energy management is needed. However, this is not an easy goal as energy demand during dairy primary production, manufacturing and distribution is significant, and therefore it is vital to identify the most intensive activities, in order to reduce energy consumption. For that purpose, the following analysis includes, the key points of energy consumption for each operation taking place in the dairy supply chain, from the primary stage all the way to final disposal. (**Figure 3.1**)

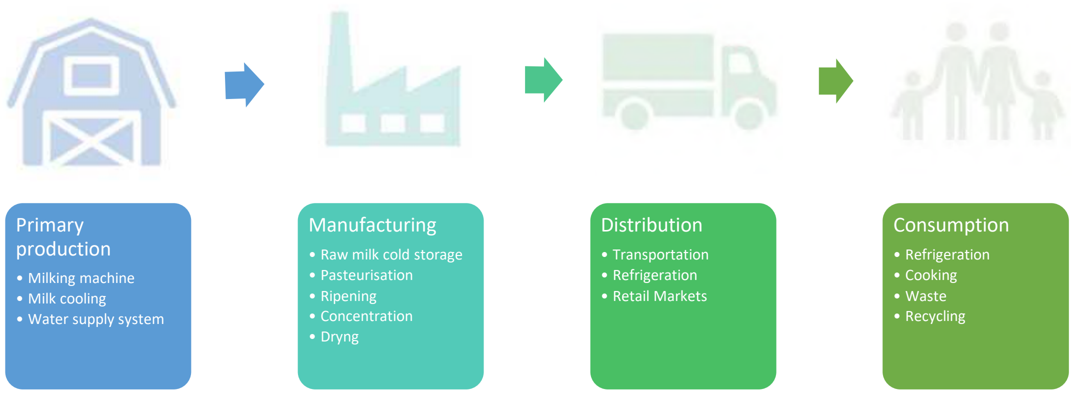


Figure 3.1. Main points of energy consumption during each step in the dairy supply chain.

3.1 Primary Production

During the Primary production there are several steps that have significant energy consumption depending on the farming system and the equipment used as well as the energy management on the farm. The following analysis includes a description of the main operations taking place in farms and their respective energy requirements. Henceforth, the energy demand in different farming systems, in milking systems, in air compressing, in milk cooling, and in water supply system is analysed.

3.1.1 Farming systems

Dairy farming can be classified as ''intensive'' and ''extensified'' livestock production systems depending on the relative productivity per cow and per livestock unit area. More specifically, when the milk productivity is high related to the livestock area and number of dairy cows, the farming is characterised as intensive, and in case of low productivity per area and per cow, then the farming is characterised as extensified. In intensive farming, cows are housed and consume processed feed such as dried grass and grass pellets, while in extensified farming, cows mostly graze (Figure 3.2). Furthermore, dairy farms in which animals consume organic feed, which does not include fertilisers or pesticides, and with restricted usage of antibiotics and hormones, are characterised as Organic Dairy farms.

One of the major differences between intensive and extensified or organic farming systems regarding energy requirements is the fact that in intensive farming, dry feed and concentrates are used while in extensified and organic farming animals mostly graze. The energy demand for drying fresh matter and for purchased concentrates is noteworthy. For perspective, the energy demand for the production of one tonne of dry matter is about 100 kWh of electricity and 3200 kWh of natural gas (Haas, Wetterich, and Köpke 2001). Additionally, energy is needed primarily, for the cultivation of grass mainly due to the extended need of fossil fuels for the machinery; consequently, the total amount of energy required to produce dry matter is even greater. As a result, the energy needs in extensified and organic farms is generally less than that for intensive farms. In a survey which took place in Finland by Seppa et al. (Seppa 2006), the average amount of energy consumed for primary production in organic farms was 4.4 MJ per 1 litre of milk produced, while, in conventional farms the level was 6.4 MJ per 1 litre of milk. Generally, intensive farming is preferred and more widely used because milk yield is higher and achieved at a lower cost compared to results from extensive farming (Alvarez et al. 2008).

Figure 3.2. Intensive farming on the left and extensified farming on the right

3.1.2 Milking System

Milking in farms, most commonly takes place twice a day. However, in some farms milking takes place 3 times a day as it was found that this can increase the milk yield per cow by 5-25% per day. Milking of cows is done either by hand or by a Milking System which is either Conventional (CMS) or Automatic (AMS). Regarding milking by hand, pails are used for the collection of milk during milking sessions, which is then poured through a strainer into a churn holding 30-50 litres. The churn is cooled to 4°C by immersion or spray chillers before being transported to the dairy (Tetrapack). In case of milking via milking system the milk is extracted from the cows by attaching a vacuum pump to cow's teats using specially designed teat cups, which relates to a vacuum vessel that draws the milk into a container vessel. The main difference between conventional (CMS) and automatic milking systems (AMS) is that in the former, all the machinery and operations are controlled manually and in the latter type, all the processes are scheduled and controlled by a computing system. Even the milking process itself is automated, as a robot places the vacuum pump on the teats of the cow (**Figure 3.3**). Both milking systems have a water heating operation allowing hot washes of the machinery in order to maintain hygiene.

According to the study of Shortall et al., automatic milking systems have the highest operational cost among the processes taking place in dairy farms, as they require about 33% (**Figure 3.4b**) of the farms' electricity needs. More particularly, the electricity requirement was measured to be an average 20.7 Wh/lt of milk. Moreover, the study showed that the electricity consumption of water heating in the AMS accounted for 61% of the unit consumption, while the vacuum pump showed 26% consumption followed by the robot with 12% consumption (Shortall et al. 2018).

Figure 3.3. Conventional Milking System requires manual placement of the vacuum pump on the cow's teats and Automatic Milking System entails automatic placement of the vacuum pump on cow's teats.

3.1.3 Air compression

Air compression is a mechanism used in several aspects of today's dairy farms. Firstly, air compressors create vacuum suction on milking machines for milk to be collected by cows' teats. Moreover, air compressors power flush systems, which are used for cleaning the milking parlour. Last but not least, air compression play a role in the operation of automatic gates and panels, allowing for easier management of the cows' movement within the parlour during the milking process or other routine processes such as vaccination of the animals (Quincy Compressor, n.d.).

According to Shortall et al. air compressing is the second most energy demanding process in dairy farms after that of milking systems. This energy consumption accounts for more than 25% of total energy needs of the farms using AMSs (Shortall et al. 2018). In a study about energy consumption for automatic milking systems, Calcante et al. (2016) calculated experimentally the energy consumption of the air compressor: the energy demand was ranging between 5.5-13.4 Wh/lt of milk; however, energy consumption of the air compressor can increase if the wrong size of air compressor is selected, so it is really important to choose an efficient and correctly sized air compressor.

3.1.4 Milk cooling

Storage of milk at a low temperature (4°C) is required to maintain milk quality and hygiene. An increase in milk temperature allows microorganisms to multiply and leads to the production of unwanted metabolic products and enzymes (Tetrapack). In some farms, milk cooling from 37 °C to 4 °C is achieved in two stages; pre-cooling and refrigeration. In the pre-cooling stage, milk passes through a Plate Heat Exchanger (PHE) where the cold stream is chilly water. The typical milk to water flow ratio in the PHE is at least 1:2 in order to bring milk's temperature close to the water's temperature, while the number of plates at the heat exchanger doesn't play a major role in the efficiency of the heat exchange. This information is based on data from PHE with different number of plates tested at varying milk to water temperatures (John Upton et al. 2010). Refrigeration is achieved in a bulk tank where the milk enters after cooling in the HPE (Group and Uladh n.d.).

According to the study of Shortall et al., milk cooling is the 3rd largest electrical consumption process, after the milking process and air compressor, which accounts for 18% of total electricity consumed in the farm. The electricity demand was on average equal to 11.3 Wh/lt of milk produced, and this quantity ranged between 6.4–21.6 Wh/lt. It is important to notice that the less time milk is kept at the farm, the smallest is the energy demand for cooling (Shortall et al. 2018).

3.1.5 Water Supply Systems

In order to ensure production, health and hygiene safety in the Dairy farm, a proper water supply system is essential. This system should be capable of supplying water for cows' drinking needs, grass cultivation, any cleaning requirements of the farm such as the cleaning of the milking system, and any usage within the labour dwelling unit. The water consumption in a dairy farm can be substantial depending mostly on the size of the farm, the number of cows, the type of farming (intensive or extensified), the technological advances and automation in water supply used and water losses.

The most common water source is a bored well, which can also be used as a supplementary reservoir with a typical capacity of 9,000 lt. From the reservoir, the water is pumped through the piping system by pumps which automatically maintain the appropriate pressure and flow demands (Group and Uladh n.d.).

Regarding the daily cow water intake, cows need 60-110 litres of water. Typically, four litres of water, correspond to 1 litre of milk. Interestingly, a way to improve milk yield of cows is by supplying water at a relatively slower rate. This happens because when cows consume water quickly, they quench their thirst well before achieving the required levels of total body hydration (Group and Uladh n.d.).

Water usage should not be overlooked in any energy consumption analysis since it is a source requiring indirect energy for its primary processing needs and direct energy for its use in farms via water pumps. According to Shortall et al. the total in-farm water consumption ranges between 3.7 – 11.7 L of water per litre of milk produced. The largest energy demands are in precooling of milk after milking where the water needs are 0.7-2.1 L of water per litre of milk, and thus it is a key operation where water conservation methods could be applied. A farm which uses more automation or applies efficient recycling strategies has a greater chance for reducing its water needs, but in general water saving depends a lot on in-farm management (Shortall et al. 2018).

Overview of the energy demand in Primary production

Upton et al. conducted a study of the daily and seasonal trends of electricity use from 22 commercial dairy farms in Ireland. The study showed that the average energy demand, which includes both direct energy (consumed in the farms) and indirect energy (consumed for the farm's supply needs such as feed) was on average 694 Wh for the primary production of 1 lt of milk. From the total amount, the 80% was indirect and 20% was direct energy use of which 60% of was electricity (J Upton et al. 2013), equating to 83.3 Wh/lt of milk produced.

The above results agree qualitatively with those of another study by Upton et al. which was a mechanistic model for electricity consumption calculation in three different sized farms, small (48 cows), medium (70 cows) and large (110 cows). More particularly, the total electricity consumed in small, medium and large farms was equal to 34 Wh/lt, 42 Wh/lt and 43 Wh/lt of milk respectively. It is clear that smaller farms require less energy consumption than larger ones. This is probably due to the fact that, the more automation and machinery used in farms, the more electricity is required whilst in smaller farms, many operations are performed through labour (J Upton et al. 2013).

Fossil fuels are used extensively in dairy farm for machinery and logistics. Sefeedpari et al. conducted a research that measured fossil fuel use in 50 dairy farms in various provinces of Tehran, Iran in 2011. They found that the mean energy requirement for fossil fuels was in total 278 Wh/lt of milk produced. The pie chart in **Figure 3.4a** represents the results of the survey, regarding the energy use from different energy sources. The main energy resources are Diesel (69% of total energy use) and Electricity (17% of total use) (Sefeedpari et al. 2014).

Regarding the electricity requirements for each operation taking place in the farm, Shortall et al. conducted a study of the daily and seasonal trends of electricity use on pasture-based automatic milking farms, they have concluded that the most intensive process regarding electricity is the milking system accounting for 33%, then follows air compressing with 26% followed by milk cooling at 18% (**Figure 3.4b**) (Shortall et al., 2018).

All in all, in primary production it is important to reduce diesel consumption, which is the most demanding source of energy and turn to renewable sources to replace diesel. Additionally, regarding the opportunities for electricity consumption, energy conserving methods and technologies could be applied for milk cooling, water heating and milking processes which have the most consumption.

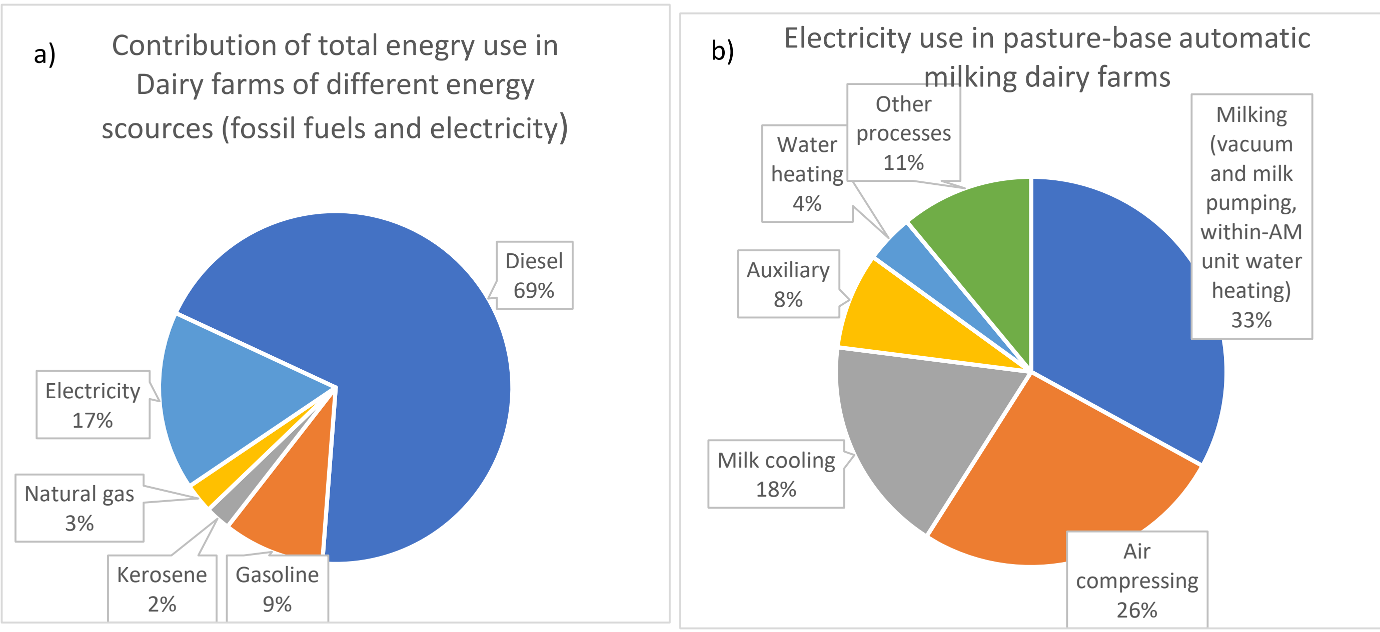


Figure 3.4 a) Resources used in Dairy (Sefeedpari et al. 2014). *b) The distribution of electricity use in different operations taking place in Dairy farms* (Shortall et al. 2018)

3.2 Milk Processes in Manufacturing Plant

Raw milk is brought from farms to dairy plants to produce a wide range of dairy products such as drinking milk, yogurt, different types of cheese, milk powder etc. Below, is an analysis of the main processing steps in the dairy manufacturing and are evaluated for energy efficiency. In the literature, there are several case studies that analyse the energy demand for each process and relatively much more literature is available which analyses each process step separately. Regarding the studies on energy demand of the entire process, the analysis is mainly based on the studies of Tomasula et al. (Tomasula et al. 2013) and Salimeh Jabbari Rad et al. (Sciences 2014). The former study (Tomasula et al. 2013) is a computer simulation study of energy use in the Dairy plants of different capacities. Specifically, small dairy plants (which processed 40 million lt/yr), medium (113,6 million lt/yr) and large (227.1 million lt/yr). The latter study (Sciences 2014) of Jabbari Rad et al. is a review article of water use, energy use and wastewater management in the dairy industry.

3.2.1 Milk reception and storage (milk testing clarification and storage)

Milk collection is typically taking place every other day, but the interval can also be every three or four days (Tetrapack). Once the milk arrives to the plant, quantitative and qualitative tests are carried out to check levels of acidity, antibiotics, water content, fat, protein and lactose, according to the ISO standards as shown in **Table 3.1** (Burke et al. n.d.)**.** If milk complies to the quality standards, it is then rated for its aroma and taste, and the price is defined accordingly (Tetrapack).

Table 3.1. Quality test of raw milk in the reception of the dairy plant with the respective ISO standards for each parameter tested.(Burke et al. n.d.).

Quality Tests of raw Milk	Acceptable limits	Standards
Acidity (Titratable)	≤0.18%	ISO 6091:2010
Antibiotic residues	Absent/0.1 g	ISO 26844:2006c
Freezing Point (added water)	-0.54 ˚C	ISO 5764:2009
Fat	0.8%	ISO 1736:2008
Protein	34%	ISO 8968–1/2:2014 and ISO 14891:2002
Lactose	>4.2%	ISO 22662:2007

After the milk **testing** follows the **clarification** process, in which particles such as sand, dust, soil and precipitated protein are removed. This process is vital for the protection of downstream equipment. Further separation in order to dissociate bacteria, spores, and somatic cells is achieved with centrifugation and microfiltration techniques (Taylor et al. 2013). The removal of these cells can prevent the formation of biofilms on the walls of *heat plate exchangers (HPE)* found in the downstream process. Moreover, bacteria removal can also prevent the contamination of aging cheese. A clarifier is a centrifugal separator with high hydraulic capacity. This treatment can be accomplished either with centrifugal clarification of cold raw milk (below 6°C), or with hot milk at about 55°C which has the advantage of having lower viscosity and allows better recirculation of milk in the clarifier.

After clarification, the milk is cooled to 4–6°C by a heat plate exchanger (HPE) and then pumped via a high-speed pump into bulk storage tanks called *milk silos* and their capacity is usually up to 265,000 litres (Tomasula et al. 2013). While milk is stored, it is mixed via an agitator in order to prevent cream separation. Milk should be kept in the storage tank for a maximum time of 24 h before being processed.

From an energy consumption perspective, reducing the time milk is being cold stored before processing leads to reduced energy requirements. Thus, it is important to minimise this temporary storage process, by optimising the scheduling and process conditions.

According to the computer simulation study of energy use in the Dairy plant of P.M Tomasula et al. (Tomasula et al. 2013) the total electricity consumption which accounted for 0.5% of total electricity demand in the dairy plant that processes 40 million tonnes per year, was 0.041 Wh/lt of milk while the chilled water demand was 0.15 L of water per litre of milk and accounted for the 13% of chilled water use.

3.2.2 Separation

The milk process begins by pumping the milk via a pipe-system from the silos to the centrifuges for hot milk **separation,** where globular milk fat is separated from the serum. This process leads to two output milk streams each having a different fat composition: A stream of cream and a stream of skimmed milk. Separation most often takes place at 50-60 °C and the fat content of the cream stream ranges between 20 to 70% w/v. Whilst the fat content in the skimmed milk stream is less than 0.5% w/v.

Separation requires energy for the pre-heating processes and for the centrifugate operation. A way to reduce energy separation is by applying cold milk separation. This offers significant savings in energy consumption and investment in thermal equipment. However, Cold milk separation efficiency is lower than for warm milk, as cream fat content cannot exceed 40-42 %.(Gy n.d.)

3.2.3 Heat treatment processes

Raw milk contains pathogenic bacteria which may cause serious diseases such as tuberculosis and typhus. Milk must therefore be properly treated in order to be safe for consumption. For this reason, after separation, the skimmed milk and cream streams should be treated accordingly in order to be decontaminated. Heat treatment is the most effective way to kill pathogenic bacteria in milk. Most of these bacteria require relatively mild heat treatment in order to be killed, although some of them such as Tubercle bacillus (T.B.) are highly resistant to heat treatment and thus require higher temperatures in order to be completely eradicated.

3.2.3.1 Pasteurisation

Pasteurisation of milk is the process that kills the pathogenic bacteria ensuring safety for consumption without significantly affecting the physical and chemical properties of the milk. There are several types of pasteurisation (**Table 3.2**). Low Temperature Long Time (LTLT) Pasteurisation involves heating milk for 30 minutes at 63 °C which are the conditions that ensure all the microbial population is eradicated. Another type of pasteurisation is High Temperature Short Time (HTST) Pasteurisation whose purpose is to kill the most heat resistant bacteria of milk which is Coxiella burnetii by heating milk to 72-75°C for 15 seconds. All these heating processes take place in heat exchangers and after the pasteurisation process, the milk needs to be cooled immediately in order to avoid milk returning to temperatures that are optimal for bacterial growth.

Other types of pasteurisation, such as Ultra Pasteurisation and Sterilisation, are even more intense methods and are applied to produce longer-life products. However, the more intense the heat process is, the more loss of texture, freshness, vitamins, antioxidants including denaturation of proteins in the final product (Tetrapack). Finally, it is important to notice that not only raw milk can be considered unsafe for consumption, but also if milk in further processing is not being treated properly or left unprocessed for a relatively long time, it may be contaminated or spoilt. Thus, it is of great importance that the process be optimised in order to achieve hygiene control and stabilisation in every step of the process (Walstra, 2005).

3.2.3.2 Thermalisation

In many dairy plants the delivered raw milk cannot be processed immediately and must ultimately be stored for hours and even days untreated. In such cases, even deep chilling is not a very effective preservation process. Therefore, milk must be heated to 63-65 °C for 15 seconds so that most pathogens are killed, and the phosphatase enzymes remain activated. This process is called **thermalisation** (Tetrapack).

Pasteurisation and other heat processes require several energy sources; energy to heat up water and use it as a hot stream in the heat exchanger, energy to refrigerate water which is used to cool milk after it is pasteurised and electricity for the pumping system of the process. Although Pasteurisation is a high energy demand process, there are many opportunities to reduce energy levels by applying pinch analysis. This methodology minimises the external heat transfers by applying possible heat exchanges between hot streams (that need to have their temperature lowered) and cold streams (that need to have their temperature increased) available in the plant.

Table 3.2. Temperature and time duration of different heat treatment processes

Process	Temperature, °C	Time
Thermization	63 – 65	15 s
LTLT pasteurization of milk	63	30 min
HTST pasteurization of milk	72 – 75	15 – 20 s
HTST pasteurization of cream, etc.	> 80	1 – 5 s
Ultra pasteurization	125 – 138	2 – 4 s
UHT (flow sterilization) normally	135 – 140	a few seconds
Sterilization in container	115 – 120	20 – 30 min

More specifically, the cold milk from the storage tank that will enter the pasteurisation process, could act as a refrigeration source for the cooling process after milk pasteurisation and simultaneously this cold stream will be preheated before being pasteurised. Thus, less energy is required to pasteurise and then cool the milk. This additional heat exchanger added for that purpose is called recovery section. A simulation and optimisation study for the pasteurisation process (Bon et al. 2010). showed that the heat exchanged during recovery section was 83.8% of the total heat exchanged showing that pinch analysis can significantly reduce the required energy in the process.

According to the computational study of Tomasula et al. (2013), the electricity consumption for pasteurisation in the dairy plant that processes 40 million tonnes of milk per year, was 0.027 Wh/lt of milk, while the chilled water demand was the highest among the demand for other processes taking place in the dairy plant, accounting for 77% of total chilled water use, equivalent to 0.83 L of chilled water per litre of milk. Milk pasteurisation can consume 17%–26% of total energy in a dairy plant. However, it was found by Ramirez et al. (2006a) that this process can achieve energy recovery by 90-94 % (Ladha-sabur et al. 2019).

3.2.4 Standardisation

The milk products have varying content levels. This is achieved by adjusting the composition during the manufacturing of milk. In order to control the composition of milk components -such as fat, protein, lactose, total solids (TS) and solids non-fat (SNF) and homogeneity of the final product composition- skim milk and cream streams and other desirable ingredients are moved to the process of **Standardisation**. In this process two sub-processes take place. The control of in-flow streams in order to achieve same composition values and the high blending for accomplishing homogenisation of out-flow. The standardisation process not only allows the industry to achieve an output of a variety of different compositions, but it also allows to produce highly nutritional dairy products. The following block flow chart represents a standardisation process for fat, protein, lactose, total solids (TS) and solids non-fat (SNF) content.

Standardisation is not considered a high energy demanding process. The energy sources used are electricity for the process controlling system, and fossil fuel for the blending process.

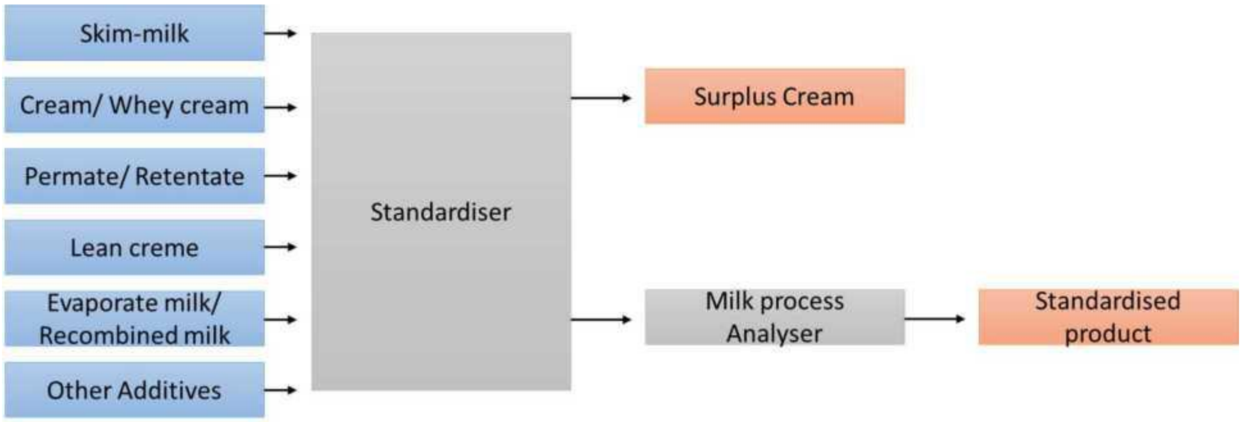


Figure 2.5 Block flow diagram of standrardisation process.

3.2.5 Concentration

Concentration is a process to produce condensed milk. Concentration can be achieved either by evaporation or by membrane concentration. Membrane concentration is typically used only when the favourable water content to be removed is maximum 12-20%. For further drying, the membrane concentration process requires higher pressures- a process seldom used since it is considered energy inefficient (Ramirez, Patel, and Blok 2006).

The most common concentration method in dairy industries is evaporation, which is mainly done by film evaporators, where milk passes from heated tubes (Ramirez, Patel, and Blok 2006). Milk is comprised of 13% solids while entering the evaporator and reaches about 52% of solids at the exit (Burke et al. n.d.). In order to minimise the damaging effect of high temperature air on the milk product, evaporation is taking place in a high-pressure environment, using a vacuum, in order to reduce to boiling temperature of milk. For perspective, the pressure in the evaporator is 160-320 hPa which is the equivalent of water boiling at temperatures between 55-70 °C. The vaporised solvent can be recovered and used as a heat exchanger hot stream.

Concentration and drying are the most energy consuming operations in dairy industry. It is a high energy required process because water should be evaporated. Evaporators can be equipped with either thermal vapour recompression (TVR) or mechanical vapour recompression (MVR).

A way to decrease the energy demand of the concentration process is to employ a multiple stage operation. The more evaporators in line, the less energy consumption results in total, to achieve the same result. This can be observed from (**Figure 3.6**), that represents the typical final energy demand per kilogram of water evaporated using mechanical vapour recompression (MVR) and the respective results using thermal vapour recompression (TVR) in different cases – for one evaporator or multiple evaporators in line. From the graph it can be seen that evaporators using mechanical vapour recompression (MVR) are more energy efficient.

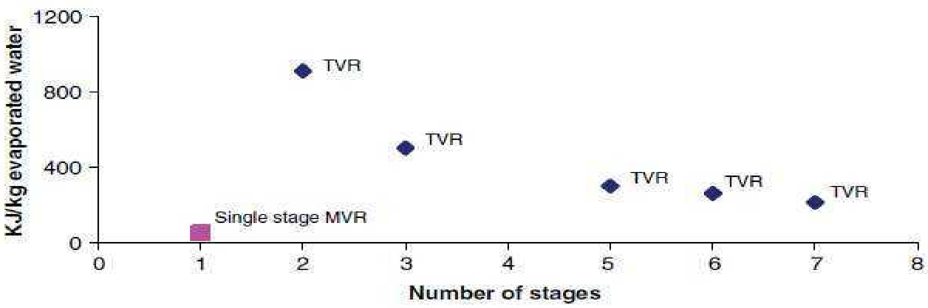


Figure 3.6. Typical final energy demand per kilogram of water evaporated using mechanical vapour recompression (MVR) and the respective results using thermal vapour recompression (TVR) in different cases – for one evaporator or multiple evaporators in line (Ramirez, Patel, and Blok 2006).

3.2.6 Drying

Milk powder was a revolutionary product in the dairy industry as it allowed the supply chain to be significantly extended by reducing the milk weight to 12%w/v without allowing the growth of pathogens yet still ensuring long life products (Burke et al. n.d.).

Milk powder is produced by raw milk, skim milk or sweet buttermilk using the **spray drying process**. There are several types of drying processes, of which the most common are: roller drying (at ambient pressure or under vacuum), spray drying (with jet or with a centrifugal nozzle), dough or paste drying (vacuum drying in cabinets or on continuous belt driers), foam drying (under ambient conditions or under vacuum) (Ramirez, Patel, and Blok 2006).The percentage of water that should be removed in milk is 85 - 90% (Tetrapack) using hot air (**Figure 3.6**).

Dryers require a significant amount of energy in order to achieve the evaporation of water to 3-4% moisture content. One of the main disadvantages of dryers is that it is currently challenging to integrate energy. Typically, dryers spend about 10-20 times more energy than evaporators, and that is the reason why it is more favourable to evaporate the milk as much as possible, before drying it. The drying process can be accomplished in multiple stages. According to the study of Ramirez et al. (Ramirez, Patel, and Blok 2006),the rate of energy of drying for milk powder production was 51%.

3.2.7 Homogenisation

Homogenisation is a process that provides many advantages to milk such as leading to less cream-line formation in standing milk, whiter and more tasty-look colour, reduced sensitivity to fat oxidation, better milk flavour, and better stability of milk products. This is the reason why this process is so commonly applied (Tetrapack). The aim of homogenisation is to break the fat globules into smaller ones, reducing their mean diameter from 3.5 µm to below 1 µm (**Figure 3.7**). Homogenisation is achieved with a high-pressure pump which passes the milk or cream through narrow gaps within a homogenisation device causing turbulence and cavitation effects that lead to the desired break of globules (**Figure 3.8**).

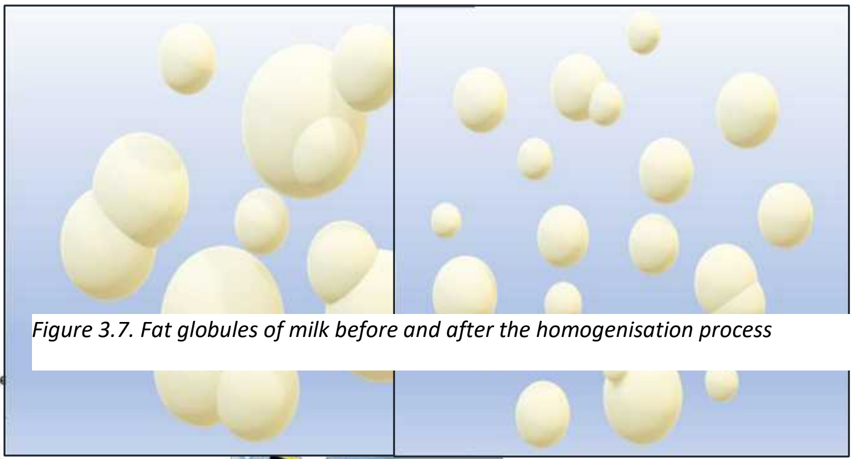


Figure 3.7. Fat globules of milk before and after the homogenisation process

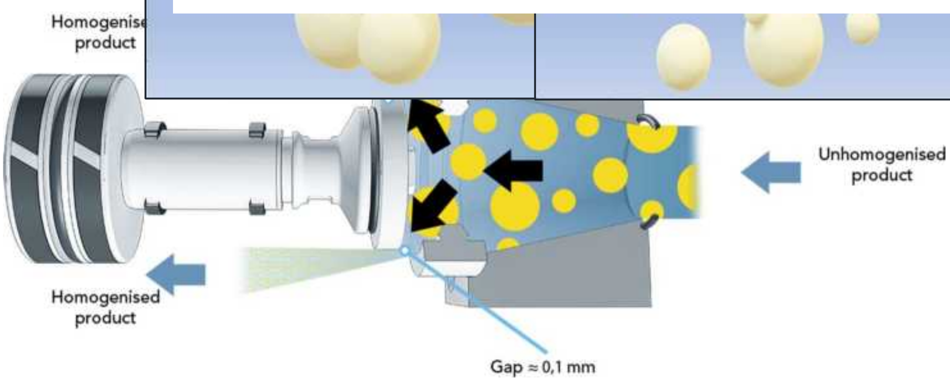


Figure 3.8. Homogenisation Device (Tetrapack).

Homogenisation is a high-energy demand process because it requires high pressure in order to break globules. Recent studies suggest applying a semi-homogenisation instead of the regular homogenisation process. In this alternative process, only the cream stream passes through the homogeniser while the skimmed-milk stream does not. Thus, as skim milk contains only 0.5% w/v fat and due to the fact that in standardisation, which is the following process, the two streams will be mixed in different ratios in order to gain the desired fat content, the contribution of the unhomogenised skimmed-milk stream will not make essential difference in milk texture to the final milk product. (Tomasula et al. 2013). In fact, according to the energy analysis of Carbon Trust for dairy industry (Carbon Trust 2009), by using semi-homogenisation, the energy requirements is 70% less than that of regular homogenisation, even though greater pumping power is required to homogenise the cream phase.

3.2.8 Clean in Place (CIP)

One of the most common challenges in the dairy industry is to ensure safe hygiene conditions. As milk is heated, proteins coagulate on the surface of the heat exchanger walls – a phenomenon called fouling. Most commonly, this type of fouling occurs when milk is heated above 65 °C. In order to avoid fouling, the pasteurisation process needs to be interrupted at regular intervals, in order to allow for the cleaning of the inner pipe-system process. Most of the dairies perform an automatic cleaning program that controls fluid circulation.

Equipment that has heating surfaces such as Pasteurisers can be a significant challenge for dairies to clean and can be a real challenge. Storage tanks, tanks, and filling equipment on the other hand, are easier to clean due to their large surface areas. In the former difficult cleaning cases, solutions of different pH are used. This process is not required in the equipment that do not include heating processes. (Memisi et al. 2015).

The steps for CIP are the following: (Tetrapack)

- Recovery of product residues in pipeline system by expulsion with water or compressed air.
- Pre-rinsing with water to remove loose dirt
- Use of detergent for cleaning
- Rinsing using clean water
- Heating or/and use chemical agents for disinfection
- Final rinse with clean water in case of use of chemical agents

Most commonly, cleaning processes are taking place daily in order to prevent bacteria growth in the equipment and permanent dirt, and thus can contribute significantly in the energy consumption of the dairy industry. More specifically, according to a simulation of the energy used in a small dairy plant of Tomasula et al. (2013), CIP accounted for about 20% of total energy use at the manufacturing stage. This results are contrast significantly with the results reported in Australia (Sciences 2014) where CIP accounted for only 14% and 9% of total energy use in a milk plant and another cheese and milk powder plant, respectively. In the study for energy use and efficiency in the European Dairy industry, (Ramirez, Patel, and Blok 2006) it was reported that about 70% of the energy used in evaporators and 10 - 26% of the energy used in dryers is for their cleaning via the CIP process. Moreover, CIP accounts for between 9% and 27% of homogeniser energy needs (Carbon Trust 2009). According to a study (Panchal et al. 2018) regarding solar energy use in dairy processing plants, it claims that CIP - which typically uses temperatures in the range of 65°C to 75°C- has great potential to use solar energy as an alternative energy source.

3.3 Process analysis for different milk products

The dairy products produced in a dairy manufacturing plant are numerous and vary in the composition of fat, water, protein content and shelf life. **Figure 3.8** illustrates the different milk product categories that can be produced in a Dairy plant whilst **Figure 3.9** illustrates a schematic overview of the main processes in the dairy sector (Ramirez, Patel, and Blok 2006).

Liquid milk is produced from raw milk ether by pasteurisation, sterilisation or treatment in ultra-high temperatures (UHT). Moreover, liquid milk can be classified as whole milk with fat content of around 3.9%, semi skimmed milk with fat content between 1.5 to 1.8% and skimmed milk, with fat content of around 0.1%.

Fresh milk products include butter, cream, fermented products such as yogurt, cultured cream and buttermilk, and milk drinks, which are made from milk and additives such as sugar, cocoa, coffee etc.

Cheese is a solid dairy product that consists mainly of protein and fat and is categorised as rennet (or natural) cheese, Fresh cheese and processed cheese. Rennet or natural cheese is mild, and is made using proteolytic enzymes (rennet) and acid, fresh cheese has relatively high acidity and is not processed by proteolytic enzymes, and processed cheese is made by thermal treatment of rennet cheese, which makes it more shelf-stable.

Condensed milk can be unsweetened or sweetened. Unsweetened condensed milk is produced by sterilised milk and has about 60% less water than liquid milk. It has a light yellowish colour and has a creamy appearance. Sweetened milk is produced by adding sugar to unsweetened milk. It has a more yellowish colour and is more viscous.

Finally, dry milk products include Whole milk powder (with 2-5 % water content) and Non-fat milk powder (contains 1.5 % less fat and less than 2% water content), Casein powder (which is the most abundant type of protein in milk - 80% of total protein content), and finally Whey powder (the dried liquid residue of cheese and casein production) (Ramirez, Patel, and Blok 2006).

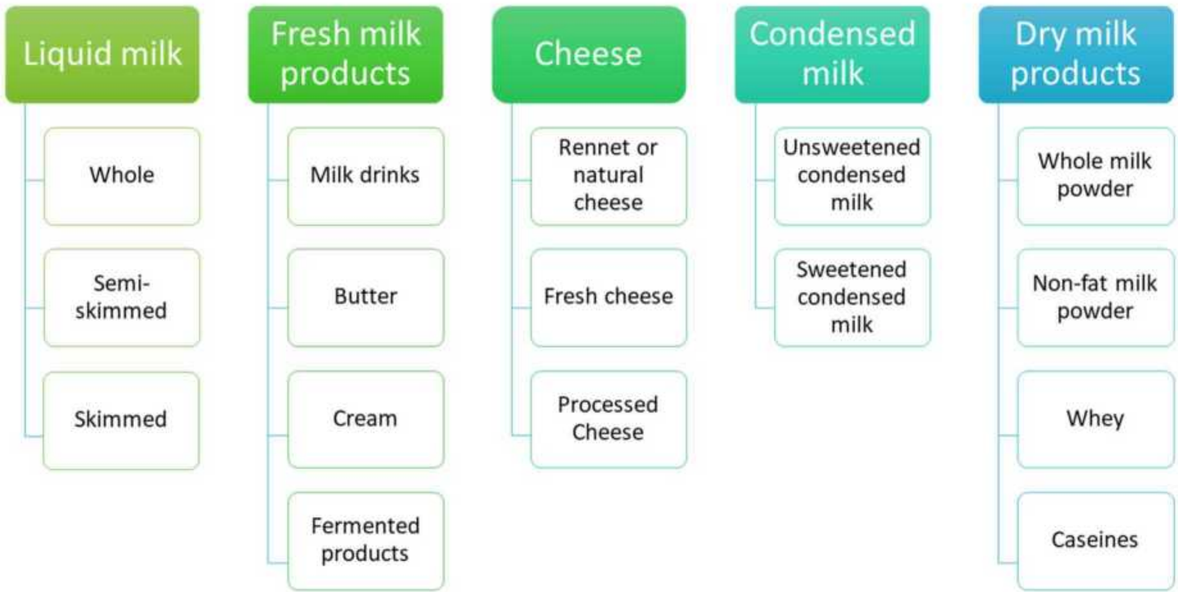


Figure 3.9. Key product categories of the Dairy Industry.

3.3.1 Butter Processing

Butter is made from cream which is the high fat content stream resulting from the milk separation process. The cream is standardised, homogenised and then pasteurised in order for bacteria to be killed, making milk a proper substrate for proliferation of starter bacteria added next. Starter proliferation produces enzymes that affects the physicochemical properties of cream causing cream to sour and butter to crystallise- a process called **ripening**. Then the churning process starts, during which the ripened cream is shaken up leading to the formation of butter grains and buttermilk. The next step is the separation of butter by draining the buttermilk. Subsequently, the butter grains are transformed to a continuous butter mass. In this step, salt or herbs can be added. The butter can then be packed, or cold stored for a time period before being sold, which will allow further homogenisation. After each step, it is mandatory to apply cleaning in place (CIP) methods, to avoid contamination of the product.

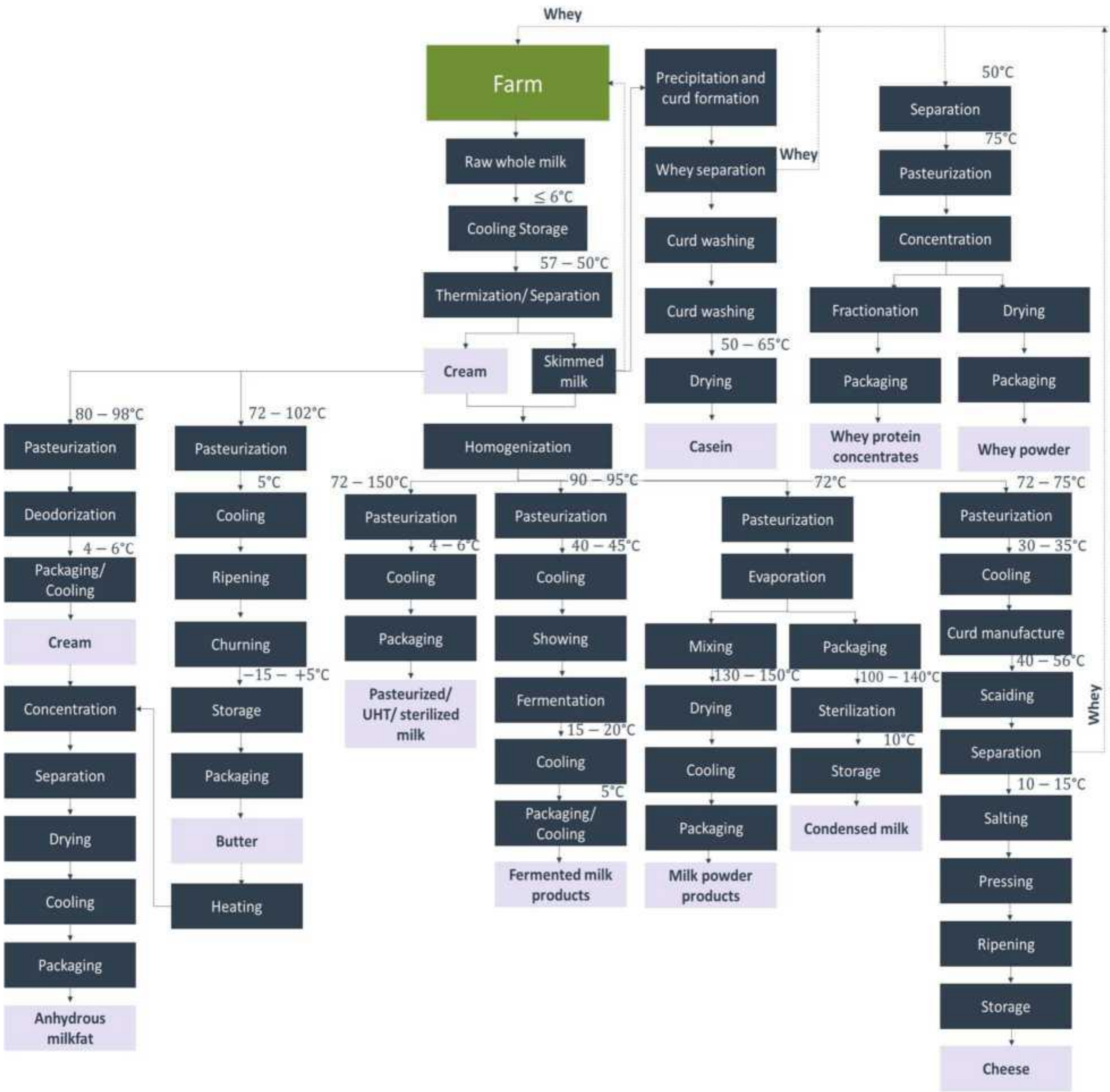


Figure 3.10. The processes in the dairy industry for different products production (Ramirez, Patel, and Blok 2006).

According to the estimation of Finnegan et al., 39% of energy demand is required for refrigerating in butter manufacture, 13 % for churn and 8 % for packaging. It is essential that the refrigeration needs should be optimised in order to reduce the electricity consumption. Moreover, regarding the thermal energy needs, pasteurisation requires 56% of total thermal needs, while CIP and processes taking place during milk reception account for 22% each. (Finnegan et al. 2016). The total energy consumption for butter production during manufacturing was estimated to be about 2.1 MJ/kl of butter (Xu and Flapper 2011).

3.3.2 Cheese processing

About one quarter of total milk produced worldwide is used for cheese making (Xu, Flapper, and Kramer 2009). The first step in cheese processing is milk clarification, followed by separation and standardisation in order to control the fat and protein content at the desired levels. The standardised milk should be pasteurised in order to meet hygiene requirements. The next step is the adding of a starter, which differs depending on the type of cheese to be produced, while the milk temperature and pH is controlled. This will lead to coagulation and formation of curd which is a semi-solid matter and mainly consists of protein, fat and water

(**Figure 3.11**). Then, the liquid remainder, which is the so-called whey, is drained off from the curd and used for whey powder production. Curd is then salted in order to prevent further microbial growth and shaped in blocks.

Figure 3.3. Curd formation during cheese production.

In case of fresh cheese production, the resulting product is ready to be packaged and sold. Yet, in case of the production of mature cheese, the product requires further process. The cheese blocks are stored at standard temperature and moisture levels, allowing the controlled ripening of cheese, which produces cheese of varying flavours and appearance. Then, the mature cheese is appropriately packaged, ready to be sold. After each cheese processing step, cleaning in place (CIP) is mandatory in order to prevent contamination and ensure hygiene control.

During the cheese manufacturing process, the main energy sources used are natural gas (for thermal energy, which is mostly used for processes such as pasteurisation, evaporation, and cleaning,) and electricity (which is mainly used for pumps, refrigerating storage, separation and cleaning) (Xu, Flapper, and Kramer 2009). The final energy requirement per kg of cheese, mainly depends on the type of cheese, the equipment used on the processing plant and any applied energy saving methods. As Tengfang Xu et al. (Xu, Flapper, and Kramer 2009) reported in their survey about energy use in global cheese processing in 2009, the average energy consumption per Kg of cheese worldwide is ranging between 8.4-9.6 MJ/kg while the lowest and the highest rate recorded were 2.3 MJ/kg of cheese and 68.2 MJ/kg respectively. According to the same study, the most energy consuming processes are pasteurisation and cheese storage which together account for the 29-58% of total energy consumption for cheese making.

Cooling needs for cheese are huge and require significant electricity consumption. Interestingly, in the cheese ripening process, which typically needs to be done in refrigerated conditions, if this process last more than 14 days, this can increase the overall energy demand more by 9-65% (Ladha-sabur et al. 2019).

3.3.3 Milk powder processing

Milk powder is a dairy product, that can vary in fat content, and has the advantage of having a relatively long shelf-life and for that purpose it is easily sold and distributed. The manufacturing of this dairy product includes processes that result in the removal of the water content from milk. The first step for milk powder manufacturing is milk standardisation and pasteurisation. Then follows the process of concentration via an evaporator, which reduces the water content of milk. Then, milk is preheated again so that its viscosity decreases, before entering the dryer. The drying step is normally done via a spray dryer, where the concentrated milk turns into powder. Optionally, in order to eliminate the oxygen in the powder, gas flushing can be used. This process contributes to lengthening the shelf-life of the product. Finally, the product is packed and is ready to be distributed.

During the manufacture of milk powder, the largest consumption of electrical energy is the dryer (24%) and the largest consumption of thermal energy are the dryer (52%) and the evaporator (39%)(**Figure 3.8 b**)(Ramirez, Patel, and Blok 2006).

3.3.4 Packaging

The role of Packaging is to contain and protect goods. Packaging design and material play a significant role for the distribution process, shelf-life extension, storage and added value of the dairy products. The technologies applied for the packaging design, apart from satisfying their main aim, which is preventing the interaction of the product with the external environment until the product is consumed, should have a minimum production energy use and environmental impact.

The material used for milk products packaging derived from natural resources including plastic, paper-based materials, glass, tin plate, aluminium foil, timber and laminates, and other materials. Considering the rising population which leads to increased packaging demand and the natural resources depletion, it is of great importance to optimise material usage, and widely recycle the packaging waste remaining after consumption.

Table 3.3. represents different packaging types that are used for dairy products mentioning the mean volume and mass for each packaging type, the material and the end life options as well as the percentage of recycled material that is generally contained in the package (Ghenai, 2015).

The most energy-consuming phase of the entire packaging process (which includes primary material production, manufacturing of packaging and logistics) is the material production phase requiring 75.8% of total energy. The manufacturing process and transportation account for 16.4% and 7.2% of the total energy, respectively. The energy consumption during the usage phase is negligible (0.4%). **Table 3.4** represents the energy demand for each step of the packaging process per material (Ghenai, 2015).

Table 3.3. Characteristics of different packaging types for milk products (Ghenai 2015).

	Plastic Bottle	Glass Bottle	Cartons Bottle	Aluminum Can
Milk Volume (l)	0.946	1	0.942	50
Mass (Kg)	0.051	0.410	0.057	8.1
Material	High Density Polyethylene HDPE	Soda Lime - 0070	Cardboard Pine (softwood) and Polypropylene PP (coating)	Aluminum, Wrought - T87
End of life options	Recycle, down cycle, combustion, landfill	Recycle, down cycle, landfill, reuse	Recycle, down cycle, combustion, landfill (Pine) Recycle, down cycle, combustion, landfill (PP)	Recycle, down cycle, remanufacture reuse, Landfill, reuse
Recycle fraction %	8.02 – 8.86	23 – 25	8.55 – 9.45 (Pine) 5.26 – 5.81 (PP)	40.5 – 44.7

Table 3.4. Energy consumption in MJ /lt of milk for material production, manufacturing and transport phases of the type of packaging presented in Table 3.3.

	Material Production	Manufacturing	Transport
Plastic	4.84	1.05	0.46
Glass	8.02	3.64	0.614
Carton	1.106	0.197	0.031
Aluminum	33.6	1.448	12.7

Overview in Energy demand in Manufacturing

Dairy manufacturing requires significant levels of heating and cooling processes which have a high energy cost (Sciences 2014). Energy consumption in the manufacturing plant could resulting from electricity of fuel use. Specifically, milk pumps, refrigeration, automations and separation require electricity whilst thermal energy, which is produced from fossil fuels, is required for cleaning and thermal treatment.

Figure 3.12 shows the amount of electricity and fuel used for the production of different dairy products during manufacturing, according to Ladha-Sabur et al. Powder products require the highest amount of energy compared to the rest of the dairy products due to the high energy demands of both drying and evaporation processes (Ramirez, Patel, and Blok 2006). More specifically, milk powder requires about 16 MJ/kg and whey powder about 10 MJ/kg. For perspective, cheese, casein and lactose, concentrated milk, and ice cream need about 5 MJ/k while fresh milk, butter and cream require less than 3 MJ/kg (Ladha-sabur et al. 2019).

Many processes apart from concentration and drying require a lot of energy. Cleaning in place (CIP) operation, consumes relatively high amounts of energy due to the high hygiene standards required of dairy products. **Figure 3.13** shows the percentage of energy consumed in each process for the production of milk, cheese, milk powder and butter according to the research of Ramirez et al. (Ramirez, Patel, and Blok 2006).

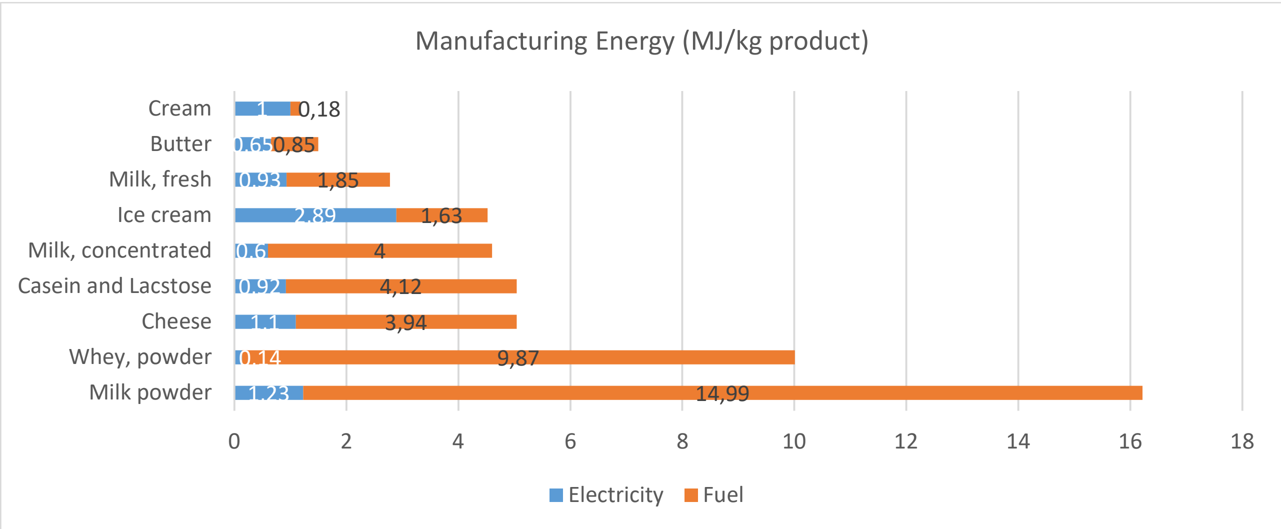
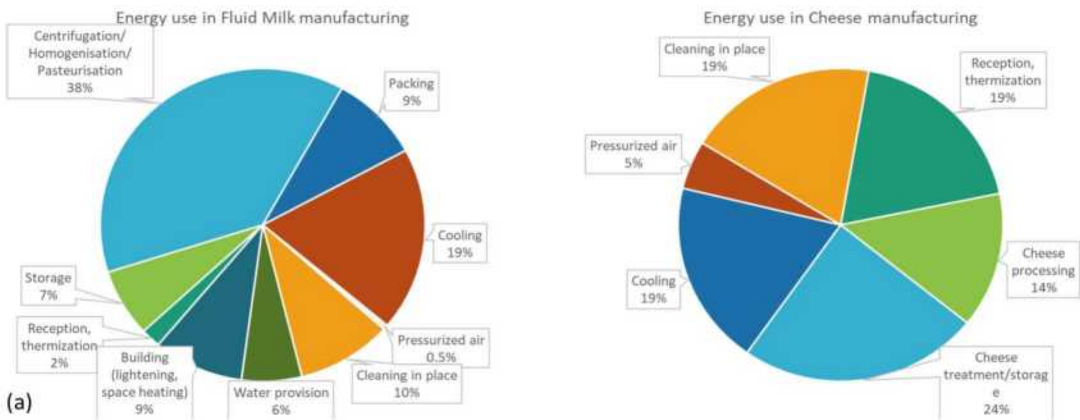


Figure 3.12. Energy demand of electricity and fuel for each dairy product during manufacturing stage (Ladha-sabur et al. 2019).



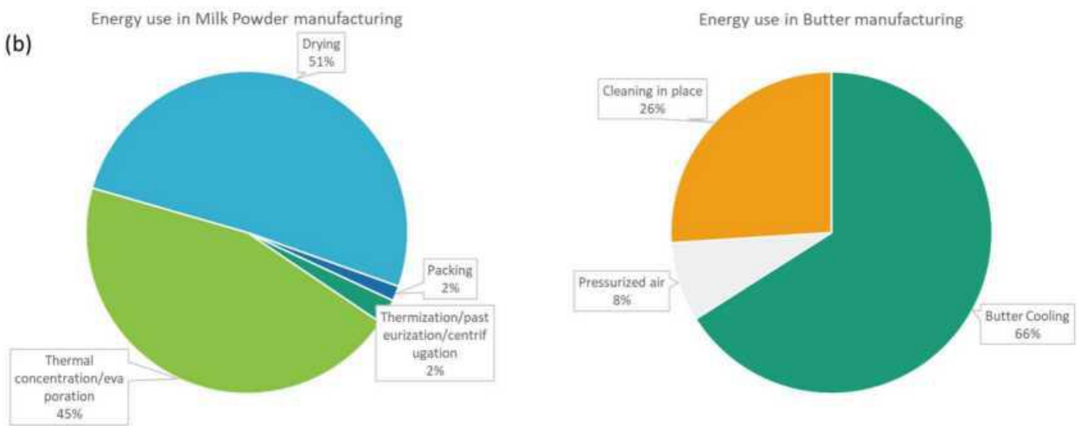


Figure 3.13. (a) Energy use in each process for Milk and Cheese, and (b) Butter and Milk powder (Ramirez, Patel, and Blok 2006).

3.4 Distribution

Milk is transported from farms to Dairies (primary distribution), and after processing milk and other dairy products is then distributed to retail outlets (secondary distribution). Since the transportation time period may be substantial and at the cost of creating hazardous consequences, it is crucial that the milk is kept at low temperatures during transportation. The main type of transportation is by refrigerated vehicles with a capacity of 32t to 44t (Ladha-sabur et al. 2019).

Dairy production is largely centralised, meaning that the logistics of transportation and distribution are significant (Ladha-sabur et al., 2019). Logistics require fuel for transportation and refrigeration. To cut energy losses and production of hazardous greenhouse gases minimising transportation distances, and improvement of truck insulation are important steps to minimising energy use/loss.

3.5 Dairy waste

Food waste is a major issue that is augmenting as demonstrated by the ever-increasing food waste being transferred to landfills. Food becomes waste for several reasons, principally over consumption but also losses during primary production and manufacturing and due to heightened concerns regarding food safety.

As a matter of fact, losses before the consumption phase are substantial. About 30% of all food produced worldwide is lost or wasted before reaching the consumer. Furthermore, in industrialised countries, over 40% of food waste is created in the retail or consumer stage (Bautista et al., 2014). During the primary production the largest losses related to dry matter, energy, and protein occur, but in terms of wet mass, most of the losses occur in the processing phase. Consumer behaviour and production practices are two important factors that need to be considered in the efficiency of food systems in order to make a reduction in losses. From the consumer's side, diets have a significant influence on this issue, for instance, over-eating is considered an important contributor to food system losses. These are potential factors that should be considered to reach sustainability and ensure food security (Alexander et al., 2017). The impending global population growth is going to exacerbate the food waste worldwide and thus; it is vital that the food industry take preventive measures in order to reduce losses.

Regarding the dairy sector, nearly, 16% of milk produced worldwide is lost or wasted (The Guardian, n.d.). Since waste and losses occur throughout the whole value chain of dairy products, all the phases from farm to the grave need to be included in the framework of a sustainable dairy sector. During the consumer phase, industrialised regions have the highest percentage of milk and dairy waste.

In contrast, in developing regions most of the milk waste is associated with the post-harvesting and distribution phases as shown in **Figure 3.14** (Gustavsson et al., 2011). In the consumer phase 4% of the milk, 10% of yogurt, 5% of butter and butter blends, and 3% of cheese is wasted (Flysjö, 2011). At the primary production phase, one of the main losses is associated to the use of drug treatments due to the cow sickness as mastitis, this means that 3.2% of the milk produced is not suitable for human consumption. Moreover, there are also losses during transportation from the dairy farms to the processing plant due to spillage and spoilage of the raw milk. One the raw milk is at the processing plant, the losses are mainly related to the spillage in which milk is treated under processes described in detail in this section (Bareille et al., 2015). Losses and waste of dairy products along the dairy supply chain represent a significant part of the total environmental impacts. During the consumption phase, 63 million tonnes of CO_2e are emitted due to the milk and dairy products wasted. Europe and North America are responsible for 60% of these emissions (Gustavsson et al., 2011).

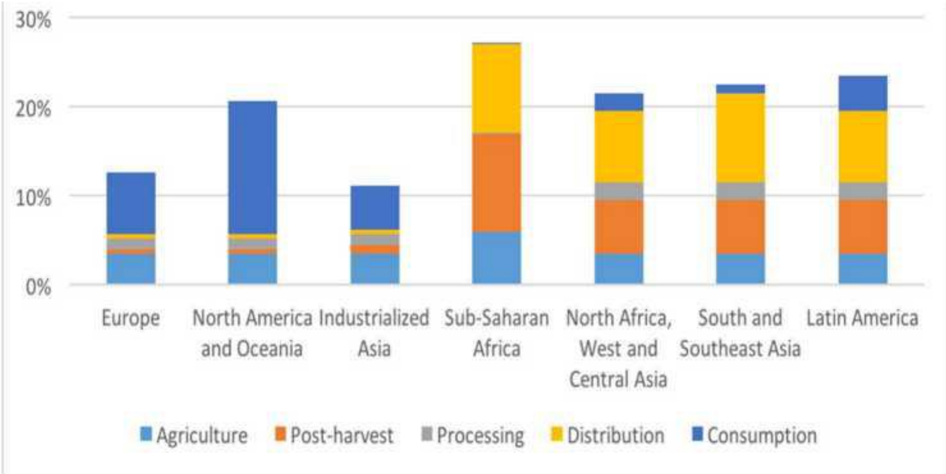


Figure 3.14. *Losses and wasted dairy products including milk throughout the value chain in different regions worldwide. At agriculture production, losses and waste refer to a decrement of milk production related to mastitis. During post-harvesting, losses occur during transportation due to spillage and degradation. At processing phase, the losses and waste are related to spillage during industrial processes. The losses and waste at the distribution phase occur at the sale-markets and at the consumption phase arise due to households (Source: Gustavsson et al. (2011).*

Substantial waste is generated from the dairy industry, so in effect, the energy consumed in all the processes for manufacturing, refrigeration, packaging and transport is translated into loss (due to waste generation).

Overview of Energy demand in Supply Chain

The energy demand within dairy industry and its supply chain is considerable. A survey by Dallemand et al. (2015) has provided a general overview on energy use of food products at every stage of the supply chain, starting from the primary production at the farm all the way to the disposal stage. The amount and the rate of energy consumed at each step was identified for milk (MJ/lt), cheese and butter (MJ/kg). According to the author's estimations, one kilogram of Cheese requires about 75 MJ, one Kg of butter around 25 MJ while one lt of milk about 10 MJ.

Figure 3.15 represents the energy consumption for milk, cheese and butter during the entire supply chain. During butter production, more than 80% of total energy used is consumed in the primary production or otherwise called agricultural step. On the other hand, in cheese production, only 35% is consumed in the agricultural step while in the processing stage 50% of energy is consumed. In terms of pasteurised milk production, there is a relative high amount of energy compared to the other products is consumed in Packaging - 25% for milk compared to 5 % for butter and 1% for cheese respectively.

Regarding the energy mix used to produce milk, cheese and butter, all the products require a similar energy mix. Fossil fuels comprise the major source of energy (about 80%), followed by nuclear power (about 15%), while there is limited use of biomass, geothermal energy and hydropower (Dallemand et al. 2015).

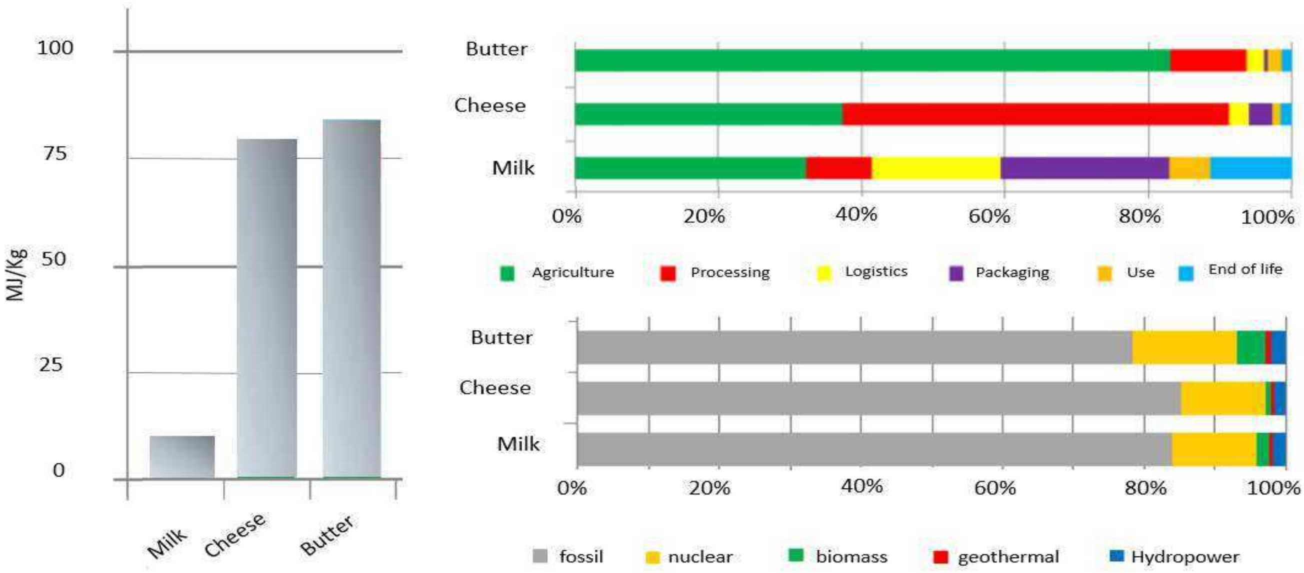


Figure 3.15. Energy requirement to produce milk, cheese and butter. The bar-chart in the left shows the actual energy need for all stem in dairy supply chain. In the right the bar-chart above, is the relative energy use regarding the supply chain step for each product, and behind is presented the relative energy use depending on the energy source (Dallemand et al. 2015)*.*

According to a study about the environmental impact of the Irish dairy processing industry (Finnegan et al. 2016), it is clear that energy usage overall has the most adverse effect on the environment. From the breakdown of processing steps and evaluation of their energy demands, the most energy consuming processes were identified. Specifically, in the processing stage the key contributing processing units requiring the most energy consumption are: evaporators, dryers, refrigeration units and heat treatment units. More energy efficient methods should be identified and applied with focus on the aforementioned areas. Finally, minimising the distance of milk transportation by optimising the collection routes will reduce fuel consumption.

Section 4: Sustainability of the Dairy Sector

4.1 Sustainability of the dairy sector

4.1.1 Actions towards a sustainable dairy sector

There is a global a recognition of the need to move towards a sustainable development agenda within food systems, which involves the participation of the dairy sector. The term sustainable development was described in the report 'Our Common Future' commonly known as the "Brundtland report" by the World Commission on the Environment and Development (WCED, 1987). It takes into consideration economic, social, and environmental concerns as three main pillars to achieve sustainability. The term was defined as:

"development that meets the needs of present generations without compromising the needs of future generations"

In 2015, the United Nations (UN) developed an agenda projected to 2030, containing 17 Sustainable Development Goals (SDGs) with 169 specific targets to achieve prosperity while fostering economic, social and environmental protection. The dairy sector, as an important player on GHG emissions and other impacts, has an important role in achieving these goals since the SDGs are directly or indirectly connected with food provisioning and dairy sector (EDA, 2017).

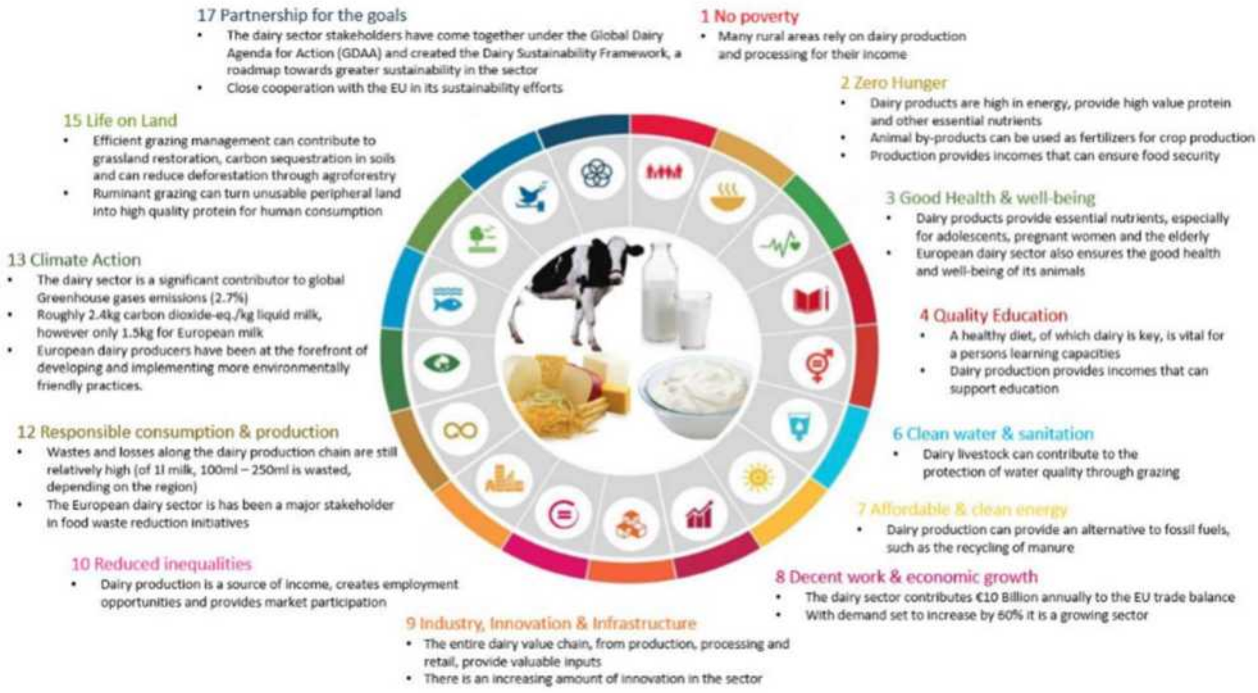


Figure 4.1. Influence of the dairy sector in the fulfilling 13 of the SDGs (Source: Adapted from EDA, 2017).

There is a need to understand the role of dairy farmers and the dairy industry and to quantify the environmental impact of dairy products. In view of the current situation of the dairy sector, numerous initiatives have emerged to promote sustainable practices. The Dairy Sustainability Framework (DSF) was released as an international tool for sustainability within the dairy sector. This framework helps achieving sustainability increases by providing a means to measure it. According to Bellamy (2016), the DSF aligns with the SDGs described in the International Development Agenda, allowing dairy companies and organizations to make an effective positive contribution. Life Cycle Assessment (LCA) is a tool used internationally to assess the potential environmental impacts associated with the production of a dairy product along its entire life cycle. The LCA has been standardized by the ISO 14040 and 14044 (ISO, 2006) and, depending on its goal and scope, two approaches might be followed: i) an attributional LCA that *"assigns elementary flows and potential environmental impacts to a specific product system typically as an account of the history of the product"* and ii) a consequential LCA that "*studies the environmental consequences of possible (future) changes between alternative product systems*" (ISO, 2006). The quantification of the environmental impact of the dairy product might consider different system boundaries, such as the cradle-to-grave approach where all the phases throughout the life cycle of the dairy product are analysed from the extraction of raw materials, processing, transportation, usage and to the disposal phase (**Figure 4.2**).

Figure 4.2. A common life cycle of dairy products.

In order to harmonize comparability and communication of the LCA outcomes, several guidelines have been developed to continue strengthening the LCA methodology and accuracy of the assessment of the environmental impacts of dairy products (IDF, 2010). For instance, the International Dairy Federation (IDF) created guidelines that are used when assessing the environmental impacts of the dairy sector. Their methods are commonly used in 46 countries, which represents 75% of the milk produced in the world (IDF, 2017). IDF also developed guidelines for the assessment of the carbon footprint specifically for dairy products –A Common Carbon Footprint Approach for Dairy-, taking into account an LCA approach. This methodology benefits the comparison of GHG emission studies across dairy products in different regions. As part of its standardization, this guideline takes into consideration allocation rules, system boundaries, and emission factors. As a highlight, the IDF guidelines only focuses on the GHG emissions, the rest of the impact categories commonly included in LCAs will be integrated into future improvements of this method (IDF, 2010). Using the same approach, the IDF has developed a guide to quantify the water footprint of dairy products –The IDF Guide to Water Footprint Methodology for the Dairy Sector. It is supported by the Livestock Environmental Assessment and Performance (LEAP) guidelines for water use and considers a Tier 1. This method standardizes the data, steps, and models that need to be included in the LCA when calculating the water footprint of dairy products. Due to its standardization, this method allows cooperativity with other products within the same category (IDF, 2017).

Furthermore, as other relevant methodologies developed within the LCA, there is the contribution of the Product Category Rules (PCR) by the International Environmental Product Declarations (EPD) system. PCRs are guidelines and standards that state the decisions that need to be taken when performing an LCA, such as functional unit, system boundaries, and allocation in order to guaranty comparability between LCA's outcomes. Depending on the category of the product, there is a specific PCR, for example, raw milk and processed liquid milk (PCR, 2017a; PCR, 2017b).

Regarding the initiatives from the dairy industry, in this report, the position of the dairy companies is based in the position of two partners within PROTECT: Arla Foods and CLUN (United Dairy Cooperatives in English). Both are recognized for working under a cooperative framework and even though they do not share geographical characteristics and their scale-scope markets differ, they face the same particular challenges on supplying future dairy demand under sustainable practices. Supporting a sustainable dairy sector has potential environmental and climate benefits. Properly and responsible livestock farming practices can offer ecological services to the ecosystem as well as boost biodiversity. For instance, it helps to diminish degraded soils and restore ecosystems since cows enrich the microbial life in the soil due to the ruminants' activity on the land. The trampling of the cows enhances the mix of manure with the soil, and thus, the soil is opened up and the organic matter is deposited, fertilizing the soil and allowing plant roots to grow deeper. Regarding the climate benefits, cows through dairy farming promote soil carbon sequestration, which is the process of transferring the carbon dioxide released to the atmosphere into the soil, so the carbon dioxide is not re-incorporated into the atmosphere again. Soil carbon sink in pastures has a positive influence on land degradation and climate change. Cows work as carbon storage in the ecosystem since they can help to sequester carbon in the soil and grazing land sequesters the carbon pool on the planet. Climate conditions, soil type, management practices and production systems implemented on the farm are important factors that need to be considered by dairy farmers when the soil carbon practices are panned on the land unit. Grazing animals such as cows stimulates the process of carbon sequestration since they consume vegetation that promotes plant growth and increases organic matter (Knudsen et al., 2019; Garnett et al., 2017). Moreover, according to literature, it is very relevant to include carbon sequestration when performing the carbon footprint of dairy products such as milk. For instance, the GWP of milk is reduced in 5-18% when the soil carbon is included in the LCA (Knudsen et al., 2019).

Consumers, as well as decision-makers, need to understand the role of cows in the environment and ecosystem. New paradigms as the circular bioeconomy are required to be integrated into the sustainability of the dairy sector (FAO & GDP, 2018). The dairy husbandry might be an important key element in the carbon cycle and the circular bioeconomy. Raw materials such as milk, packaging, water, carbon, nitrogen, and phosphorus cycles are taken into account in the circular approach in order to reduce, recycle and reincorporate inputs (De Wit et al., 2016). There is a novel integrative concept known as "Handprint". This approach includes in the assessment, not only the negative environmental impacts of the product portfolio but also as a novelty, the contribution of the positive impact on the environment and society. The dairy sector has a great responsibility in facing climate change but also this sector has the opportunity to contribute positively and help solve the challenge and therefore increasing its handprint (Biemer et al., 2013).

Other actors involved in the sustainability of the supply chain of the dairy sector, there is the National Federation of Dairy Industries (FeNIL for its abbreviation in Spanish) composed of approximately 60 dairy companies. FeNIL is a Spanish association that guides the dairy sector towards sustainability, either national or internationally, under the context of the pillars for the sustainability of the dairy sector developed by the GDAA. In 2013, together with the Ministry of Agriculture, Food and Environment (MAGRAMA for its abbreviation in Spanish), the dairy industries, and distribution companies have created the Sustainable Dairy Products (PLS) program. The PLS logo aims to guarantee the quality and sustainability of the Spanish dairy products and milk value chains to the consumer (Fenil, 2019).

4.2 LCA case studies on dairy products

4.2.1 Impact of the dairy sector

The whole dairy production cycle contributes to soil-degradation, eutrophication, and water pollution and consumption, both directly and indirectly along the production chain, and to a relevant share of the worldwide GHG emissions (Gerber et al., 2010; Yan et al., 2011). In 2007, this sector contributed to 4% of the total global GHG emissions releasing 1.9 million tonnes of CO_2-eq, of which 1.3 million tonnes are related to the milk industry and the rest to the meat industry (Gerber et al., 2010).

From a life cycle perspective, there is a wide variety of outputs in the form of wastewater, air emissions, and solid waste throughout the entire value chain of dairy products. Wastewater is produced in each of the phases along the value chain. For instance, at the dairy processing plant, waste streams come from the cleaning operations, milk spoilage, and spilling. The wastewater load and the waste composition vary depending on the type of dairy product processed (Verheijen et al., 1996). Most of the GHG emissions of dairy products are associated with the production of raw milk before at the dairy farms due to enteric fermentation, manure management, production and use of fertilizer (Gerber et al., 2010; Flysjö, 2011). After the farm gate, the fossil CO_2 emissions are related to the energy use for processing, packaging, transportation and cooling agents (Gerber et al., 2010). Furthermore, solid waste is another output in the dairy production chain. At the dairy industry, one of the main solid waste generated is the sludge, which is the result of the wastewater treatment. It is mainly produced during cleaning operations of the process-line and by rejected milk in the dairy reception. Wastewater has high concentrations of nutrients, and organic and inorganic contents and is harmful for the environment since it causes eutrophication – which entails the structural changes to the ecosystem such as increased production of algae and aquatic plants, depletion of fish species, general deterioration of water quality and other effects that reduce and preclude use (Verheijen et al., 1996).

A key element for a reduction of the environmental burden of dairy products is a diminution of waste and losses. The dairy waste and losses need to be accounted for throughout the whole value chain of dairy products (Flysjö, 2011). For instance, according to Berlin and Sonesson (2008), in the production of yogurt the GHG emissions at the dairy farms, there is a decrement of the 33% in the emissions when the losses of yogurt are reduced. Thus, optimization within the phases is important to prevent losses, and consumers should become more conscious and sensitive to spoiling dairy products and food in general.

In the last years, the milk dairy sector has shown an efficiency enhancement. However, it is not enough to decrease the sector GHG emissions, and there is a need of speeding up the transition to a low-carbon dairy sector. The emissions per unit of milk products have decreased by 11% in one decade, from 2005 to 2015 as illustrated in figure 4.3. Some of the main factors that have influenced this are; the efficiency in the production chain has improved, the genetic selection of the ruminants is increasing, and the production of the concentrated feed is becoming more efficient. The milk yield per cow is becoming higher, which has an influence on lowering the emissions intensities. For instance, whilst a cow with high milk yield (14 kg of milk per day) tends to use 47% of the energy consumed for its maintenance, a cow with lower milk yield (1.4 kg milk per day) requires 75% of consumed energy (FAO & GDP, 2018).

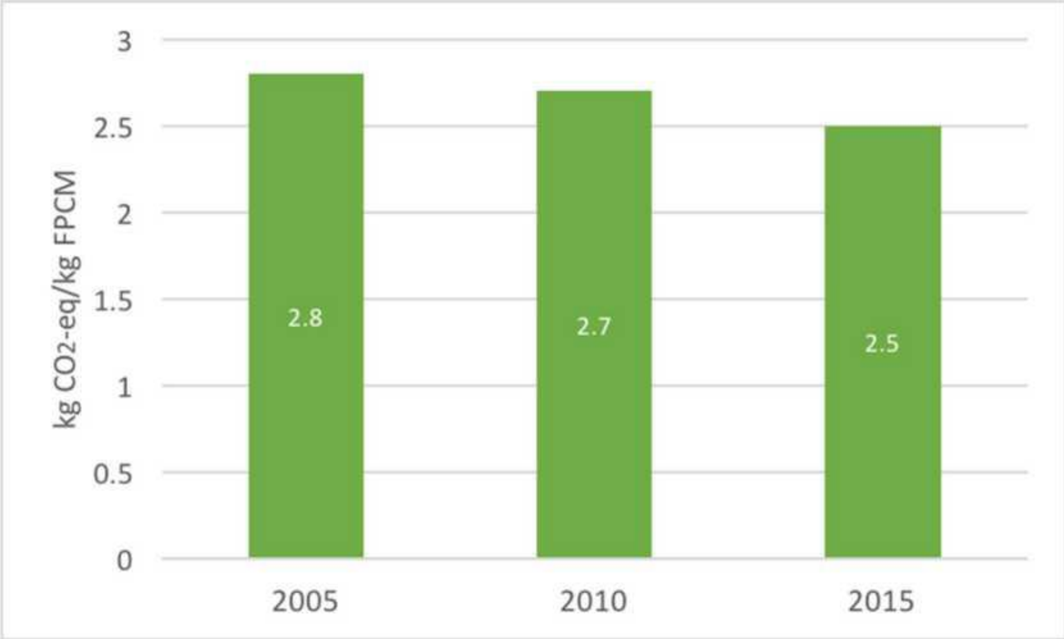


Figure 4.3. Emission intensity of milk from 2005 to 2015. (Source: FAO & GDP, 2018).

4.2.2 LCAs

The performance of LCA to evaluate the environmental impacts of the dairy sector is a well-investigated issue worldwide (**Table 4.1, 4.2, and 4.3**). Products within the large companies' portfolios such as whey protein concentrate, different types of cheeses, yogurt, cream, curd, butter, and processed milk have been evaluated (Üçtuğ, 2019).

Regarding other dairy products other than liquid milk, cheese is one of the dairy products most consumed in Europe and the rest of the world as described in previous sections. There is a wide variety of cheeses that can be found in the market since each region within each country has its particular way of producing this product (table 4.2). For instance, cheese is known to be the second dairy product most preferred by Spanish consumers. González-García et al. (2013) focused specifically on evaluating the environmental burden of one of the most popular brands of Galician cheese named San Simon da Costa. They located the hotspot on-farm practices; around 63% to 89% of the environmental impact is related to this phase. Factors such as the enteric fermentation and manure practices influenced the impact of farm units. New improvements in the chain, such as valorisation of whey into whey powder, were identified as alternatives enabling to reduce the environmental impact by 15%.

Table 4.1. Literature review on LCAs of milk production worldwide (Source: Data deviated and adapted from Grant & Hicks, 2018).

LITERATURE REVIEW ON LCA OF MILK PRODUCTION				
Reference	**Country**	**Product**	**System boundary**	**Impact categories**
Birgersson et al. (2009)	Europe	Dairy	Grave	Land use Fossil energy use, eutrophication, acidification, climate change, ozone layer depletion
Clune et al. (2017)	Global	Dairy	Varies	Global warming

Clune et al. (2017)	Global	Almond	Varies	Global warming
Clune et al. (2017)	Global	Soy	Varies	Global warming
Eide (2002)	Norway	Dairy	Grave	Global warming, depletion of the stratospheric ozone, eutrophication, acidification, ecotoxicity and photo-oxidant formation
Grant and Hicks (2018)	California	Dairy, Almond, Soy	Retail	Water Footprint, Cumulative Energy Demand, ozone depletion, global warming potential, smog formation, acidification, eutrophication, carcinogenics, noncarcinogenics, respiratory effects, ecotoxicity, fossil fuel depletion
Iribarren et al. (2011)	Spain	Dairy	Gate	Acidification, eutrophication, global warming, land competition and cumulative non-renewable energy demand
McGeough et al. (2012)	Canada	Dairy	Farm	Global warming
Roibás et al. (2016)	Spain	Dairy	Gate	Carbon footprint and water footprint
Rotz et al. (2010)	USA	Dairy	Farm	Global warming
Thoma et al. (2013)	USA	Dairy	Grave	Global warming
Van der Werf et al. (2009)	France	Dairy	Farm	Eutrophication, acidification, terrestrial ecotoxicity, climate change
Wang et al. (2016)	China	Dairy	Farm	Global warming and land use

More recently in the cheese industry, three studies have analyzed the environmental impact of cheeses in mainly in Spain and Italy (Bava et al., 2018; Canellada et al., 2018; Mondello et al., 2018) although these studies do not cover the whole life cycle, disposal and waste management phases are excluded from the system boundaries.

Not surprisingly, most frequent impact category chosen by researchers, amongst all the impact categories in the LCA, was the Global Warming Potential, followed by Eutrophication, and Acidification potentials (Üçtuğ, 2019; Thomassen et al., 2008).

Table 4.2. Literature review on LCAs of cheese production worldwide. (Source: Data deviated and adapted from Üçtuğ, 2019).

LITERATURE REVIEW ON LCA OF CHEESE PRODUCTION				
Reference	**Country**	**Product**	**System boundary**	**Impact categories**

Bava et al. (2018)	Italy	Cheese (Grana Padano)	Gate	Climate change, ozone depletion, particulate matter formation, photochemical ozone formation, terrestrial acidification, terrestrial eutrophication, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, mineral depletion and fossil depletion
Canellada et al. (2018)	Spain	Cheese	Retail	Climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion
Dalla Riva et al. (2017)	Italy	Cheese (Mozzarella)	Grave	Climate change, cumulative energy demand, ozone depletion, land occupation, terrestrial acidification, water depletion, freshwater eutrophication, marine eutrophication, human toxicity, ecotoxicity, photochemical oxidant formation
González-García et al. (2013)	Portugal and Spain	Cheese	Grave	Abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, land competition, photochemical oxidant formation, cumulative energy demand
Kim et al. (2014)	USA	Cheese (Cheddar and Mozzarella)	Grave	Cumulative energy demand, water depletion, climate change, freshwater and marine eutrophication, photochemical oxidant formation, ecosystems (endpoint), human health (endpoint), ecotoxicity
Mondello et al. (2018)	Italy	Cheese (Pecorino)	Gate	Climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, narine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, fossil depletion
Nigri et al. (2014)	Brazil	Cheese (Minas)	Grave	Carcinogens, breathing inorganic particles, organic particles breathing, climate change, radiation, depletion of the ozone layer, ecotoxicity, acidification/eutrophication and land and mineral use
Palmieri et al. (2017)	Italy	Cheese (Mozzarella)	Gate	Abiotic depletion, global warming, ozone layer depletion, human toxicity, freshwater and marine aquatic ecotoxicity, terrestrial ecotoxicity, photochemical oxidation, acidification, eutrophication

Santos Jr. et al. (2017)	Brazil	Cheese	Gate	Climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation, particulate matter formation, water depletion and fossil depletion
Vagnoni et al. (2017)	Italy	Cheese (Pecorino)	Retail	Global warming potential, acidification, eutrophication, photochemical ozone creation potential, abiotic depletion (minerals and fossil fuels), human toxicity, freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity
van Middelaar et al. (2011)	Netherlands	Cheese (semi-hard)	Retail	Global warming potential, land use, fossil energy use

Table 4.3. Literature review on LCAs of a wide variety of dairy products worldwide (Source: Data deviated and adapted from Üçtuğ, 2019).

LITERATURE REVIEW ON LCA OF THE PRODUCTION OF DAIRY PRODUCTS IN GENERAL				
Reference	**Country**	**Product**	**System boundary**	**Impact categories**
Bacenetti et al. (2018)	Italy	Whey protein concentrate	Gate	Climate change, ozone depletion, particulate matter, photochemical oxidant formation, acidification, freshwater eutrophication, terrestrial eutrophication, marine eutrophication, and mineral, fossil and renewable resource depletion
Doublet et al. (2013)	Romania	Pasteurised milk, sour cream, natural yoghurt, curd, butter, cream cheese, fresh cheese, soft cheese and semi-soft cheese	Gate	Climate change, eutrophication, acidification, human toxicity, ecotoxicity, land use, abiotic resource depletion and water depletion
González-García et al. (2013)	Portugal	Yoghurt	Grave	Abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, land competition, photochemical oxidant formation, cumulative non-renewable fossil and nuclear energy demand
Nilsson et al. (2010)	UK, Germany, France	Margarine and butter	Gate	Primary energy use, global warming potential (100 years), eutrophication potential, acidification potential, photochemical ozone creation potential
Vasilaki et al. (2016)	Spain	Yoghurt (different types)	Gate	Carbon footprint, water footprint

Since the dairy sector is one of the responsible for significant amounts of GHG emissions several LCA studies have compared the environmental impacts of this industry when using different farming systems at different intensities to produce milk. Commonly, pasture-based dairy production is socially attributed to environmental friendliness when compared with an intensive system. Therefore, Arsenault and colleagues (2009) performed an LCA in order to compare the difference of environmental impacts of two dairy systems; pasture-based and confinement-based. A total of 11 impact categories were evaluated and 1 000 kg of unprocessed milk was considered as a functional unit. A cradle to farm gate approach was taken into consideration in the scope of the study. The two systems analysed in the LCA showed a very similar footprint and this was mainly explained for the use of concentrate feed in each of the systems.

4.2.3 Hotspot in the value chain

Based on an extensive literature review (table 4.1, 4.2, and 4.3), in the life cycle of the dairy products, the hotspots are identified to be related to the raw milk production stage at the dairy farms. Around three-quarters of the environmental impacts of dairy products happens before the processing plant.

At the dairy farms, most of the GHG, such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2), comes from two main sources; the enteric fermentation from cows and the manure management. As an overview, ruminants emit methane due to its digestive process called enteric fermentation, which is a microbial fermentation process and as a result, there is a production of methane as a by-product. Diet and management practices have an important role in the amount of methane produced by cows. The second source is regarded the manure management and its production of methane and nitrous oxide. The decomposition of the matter has a methane yield several factors such as the type of treatment, storage management, and climate conditions contribute to the high or low production of this gas. On the other hand, manure, urine, and fertilizers based on nitrogen are the main promoters of N_2O and the CO_2 is strongly related to the direct and indirect use of conventional fuels at the farm (FAO & GDP, 2018). According to the report "Climate change and the global dairy cattle sector", three sources were defined as the main contributors of emissions occurring at the dairy farms. Cows enteric fermentation has the largest contribution, 58.5%, in the share of total emissions at the dairy farms. Feed production and management presented a lower influence of 20.0% and manure practices of 4.8% out of the overall emissions (Figure 4.4) (FAO & GDP, 2018).

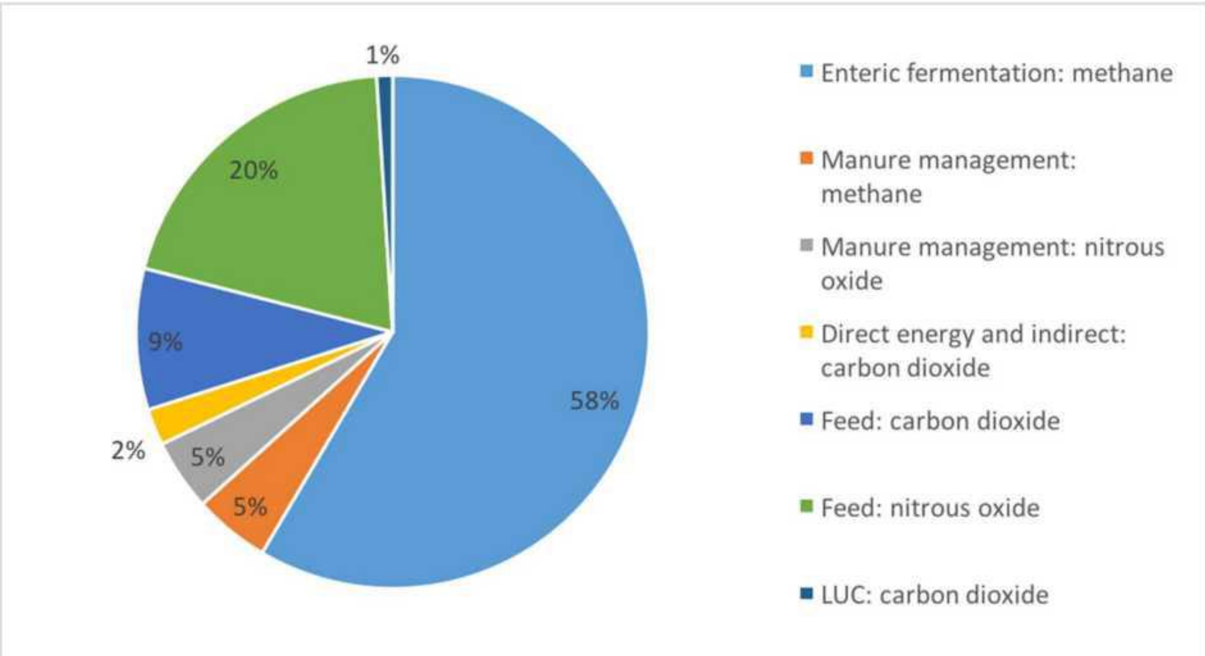


Figure 4.4. Percentage of contribution of each source emission at dairy farms in 2015 (Source: FAO & GDP, 2018).

4.3 LCA case studies on diets

Dairy products are an important source of calcium and protein in the daily diet of humans. The consumption of these products gives a wide variety of benefits to the bones and muscles of the person who consumes this product. Protein and calcium from dairy sources have a higher level of bio-availability, which means that the body is able to obtain these vital elements. For instance, the bio-availability of protein coming from milk is 98% and from vegetable sources ranges between 60 and 65%. Moreover, most of the calcium that is founded in plant-based milk is added and not naturally associated with proteins (Plaza-Díaz et al., 2017).

Different diets have different environmental impact, for instance, Roibás et al. (2016) assessed the environmental impacts and health effects of consuming naturally improved milk in Spain using LCA. This study took into account a cradle-to-gate approach and 1 litre of packaged UHT as a functional unit. In order to calculate the CF and the WF of these products in terms of nutritional value, they compared two groups of milk; the conventional and the naturally improved milk. They concluded that a switch to improved milk has environmental and health benefits. From an environmental point of view, the improved milk presented a lower CF in 10% than conventional milk and a similar WF. The factor with the major influence in the reduction of the CF is related to the enteric fermentation and a modification on the diet provided to the cows on-farm, and thus a reduction on the methanogenic bacteria. Regarding the health effect on consumers, a decrement in the risk of diseases such as cardiovascular and oxidative damage are two benefits of consuming naturally improved milk. Therefore, the role of including a new type of milk such as the one proposed in this study might have positive impacts on the health of the consumer and in a decrement of GHG emissions. Based on previous experiences of other countries on carbon footprint labelling, CLUN cooperative has obtained a carbon footprint in its naturally improved milk, which is one of the products within its portfolio. This was the first and the unique milk with this label in Spain.

Another study from Grant & Hicks (2018) compared the burden on the environment of conventional milk from a cow with soy and almond milk. For this, they developed an LCA with a cradle-to-retail perspective, taking into consideration a volumetric function unit (FU) of 1 litre of milk and a nutritional FU of 1 kg of protein. As part of the conclusions, the decision of the FU selected has a strong influence on the outcome of the LCA. In terms of volumetric value, dairy milk presented the highest impact in 6 of the impact categories out of the 12 analysed, whereas soy milk showed the highest influence in 4 of the 12 impact categories. When it comes to water use and non-carcinogenic impact, almond milk had the highest impact. However, from a nutritional value point of view, the results followed a very different trend. Almond displayed the highest impact amongst the 12 impact categories considered. Considering all impact categories, the impact of the almond milk is almost five times higher than soy milk, and close two times higher than dairy milk. The discrepancy between the results from the volumetric value and nutritional value can be justified that almond milk has a very low protein content in comparison with conventional milk from cows. The selection of the right FU to compare dairy products and plant-based alternatives is currently an open question in literature.

Lastly, another relevant study on the trade-offs between the environmental and nutritional effects of consuming milk is Stylianou et al. (2016). They did integration of the LCA and a Combined Nutritional (CONE-LCA) in order to evaluate the nutritional effects and environmental impacts of a certain diet and they used fluid milk as a case study in adults' diet from the United States. The environmental mid-point impact category considered within the LCA was global warming and respiratory organics following one serving of fluid milk (244 g) as a functional unit. Three scenarios were developed. One consisted on the addition of one serving of fluid milk in the diet of adults from the US without making a change in the diet. The other two alternative scenarios stated i) a portion of fluid milk but removing the same caloric quantity within the general diet and ii) a portion of fluid milk while removing the same portion of calories of sugar-sweetened beverages. They concluded that adding one portion of milk in the diet is related to the improvement of the health of American adults. Regarding the environmental impacts, one serving of fluid milk without any change in the diet has a higher impact than the two alternative scenarios developed.

4.4 Beyond environmental sustainability

LCA is capable to assess the environmental impact during the life cycle of a dairy product; nevertheless, aspects as economic and social are not included in the scope of the LCA. Therefore, two other methods such as the Life Cycle Costing (LCC) and the Social Life Cycle Assessment (SLCA) are commonly used to assess the economic and social impacts. The integration of the three methodologies is known as the Life Cycle Sustainability Assessment (LCSA), which is characterized by following a holistic approach (Zimek et al, 2019). However, the integration of the three elements is seldom implemented in the dairy sector and this might have an important role in the transition of the sustainability of the sector (Yan et al., 2011).

Regarding the social domain, there are guidelines to harmonize the performance of the SLCA. The United Nations Environment Programme and Society of Environmental Toxicology and Chemistry (UNEP-SETAC) has developed the “Social LCA Guidelines of the Life Cycle Initiative”, which most of the SCLA are carried out under these guidelines. These guidelines classify the social issues in 5 stakeholders’ categories and describe the social impacts that need to be included in the SLCA depending on the scope of the study (UNEP-SETAC, 2009). One of the challenges in this methodology is the limited availability of databases. The Social Hotspot Database (SHDB) is commonly used for SCLA developers, however, there is still a need to improve the data collection to be included (Chen & Holden, 2017). Chen and Holden (2017) carried out an SLCA of dairy farms using as a case study, Ireland. A total of 4 stakeholder categories and 19 social indicators were selected from the SLCA Guideline that is commonly addressed. Since the approach considered in this research was considered a cradle-to-gate, the four impacts categories only included worker, local community, society, and value chain. The fifth category, consumer, was not into the scope of this research. They reported that the average Irish farming sector has benefits on the society along its value chain for most stakeholders; the local community and values for workers are the main positive social impacted of this sector. However, from a society point that research did not consider the “worker” category, the impact on health and living conditions resulted as a negative, which comes from inorganic respiratory effects, human toxicity carcinogens, and global warming. Considering the supply chain from a cradle-to-gate approach, the largest share of the total impact on health and living conditions comes from on-farm and fertilizer production. Benoît and colleagues (2012) performed an SLCA to analyse the production of strawberry yogurt from farm to gate taking into account. In this study, two methods were considered, in the first scenario the data was obtained from the SHDB database adding a worker’s hour model, and in the second scenario, the data was obtained from a literature review. They concluded that specific sectors in some countries tend to be sensitive to social issues, for instance, the chemical industry in China, Venezuela, and Indonesia have an important risk. This study had two main general purposes, firstly, the identification of the hotspot along the supply chain of the strawberry and secondly, the revision of certification and standards useful for developing an SLCA.

Regarding the economic pillar, Schmidt and Saxcé (2016) carried out an Environmental Profit and Loss Account (E P&L). They first calculated the environmental impacts of the Arla’s product portfolio (mid-point) for the year 2014, and then they monetarized the impacts (end-point). In order to quantify the environmental impacts, they performed an LCA, taking into consideration a cradle-to-grave approach. The impact categories included global warming, respiratory effects, and biodiversity. Regarding the end-point, this was defined as “the sum of impacts on human health, ecosystems, and resources in monetary unit”. The E P&L showed that 59-62% (consequential and attributional respectively) of the total GHG emissions are attributed to the on-farm activities such as the production of the raw milk. The translation of the impacts as monetarized losses led to an estimation of 2240-4980 million EUR in the attributional LCA, and between 1840-5850 million EUR in the consequential LCA when evaluating the consequences in response to decisions. This large difference in each of the ranges was mainly attributed to the use of the valuation method implemented in the study.

Additionally, a way of integrating the three domains of sustainability, Buys and colleagues (2014) integrated them and developed a tool to assess the sustainability of the Australian dairy industry. They developed the “Sustainability Scorecard” based on a Bayesian network model in order to assess the economic, social, and environmental impacts. Since sustainability is very complex, each of the pillars is connected so the impact in one might have a positive or negative on another pillar, they developed the scorecard aiming to demonstrate the effect on the domains. They discuss that this methodology aids to identify the strategy to increase sustainability for equal in the three pillars with less negative impacts.

Whereas the LCA quantifies the potential environmental impact of products, such as dairy products, there is another methodology, the Risk Assessment (RA), that quantifies the potential exposures and hazards related to the material under specific scenarios in order to simulate absolute of estimation of risk. The integration of LCA and lifecycle-based RA might help to improve regulatory long-term decisions in sectors, specifically in the dairy (Linkov et al., 2017). For instance, Lindqvist and colleagues (2002) carried out a microbial risk assessment in order to quantify the risk of *Staphylococcus aureus* in cheese. Within the study, they analysed the probability of finding 6 log cfu of these bacteria in unripen cheese in consumption. They concluded that one of the main factors that has a strong influence on the presence of *Staphylococcus aureus* in cheese is pH. This might help to improve safety, the use of buttermilk as starter cultures is proposed in order to maintain a pH of 5. Grace and colleagues (2008) assessed the risk of obtaining an infection due to Shiga toxigenic *Escherichia coli* (STEC) from unpasteurized milk in markets located in East Africa. Based on a fault-tree scenario and a modular process risk model, they were able to conclude a moderate risk of obtaining an infection. In terms of numbers, for every 10,000 unpasteurized milk servings consumed, at least three symptomatic STEC infections would be expected. In Italy, a study to quantify the risk of getting campylobacteriosis and hemolytic uremic syndrome (HUS) was carried out by Giacometti and colleagues (2012). In this region, raw milk is sold in vending machines. Dairy farms, storage facilitations, raw milk production were in the scope of this research, considering expected milk contamination in these processes. The sample was divided into two age groups, one with a range of age from 0 to 5 years' age and the second group with a range of >5 years' age group. Based on this, they concluded considering the best and worst storage conditions, there is 2.12 and 1.14 campylobacteriosis cases for every 10 000 to 20 000 milk portions for group 1 and group 2 respectively. For the HUS, the number decreased to 0.1 (group 1) and 0.5 (group 2) cases for the same milk servings. Milk practices such as boiling and storage temperature are factors that have a significant role in risk management.

Conclusions – Next Steps

Cow milk, and in general dairy products, are major components of the human diet, being responsible of a significant provision of the dietary protein supply in Europe. However, the sustainability of dairy products has been questioned due to their contribution to environmental degradation.

This document shows that dairy products have been extensively assessed both from a broad perspective, considering their whole life cycles as well as a set of environmental impact categories, and from a more dedicated perspective focus on the energy demand.

The dairy sector is already taking action in order to improve its sustainability performance; however, this sector needs to speed up its efforts and train a new generation of researchers able to use and develop predictive modelling tools to evaluate the implications of and effects of climate change on food safety and in particular on dairy products demand and supply. The integration of relevant methodologies, such as energy efficiency analysis, risk assessment and life cycle assessment, is a key element in this transition when the three domains of sustainability are considered. Analysing each of the systems and phases along the value chain of dairy products will enable to identify key hotspots and to enable move to more sustainable and efficient systems. Moreover, a switch to a circular dairy economy will help to understand an efficient re-use of different value streams from the dairy chain.

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