

**D3.4 Extended Value Stream Maps of  
NACE 10.5:  
YOGHURT AND SEMI-SKIMMED  
MILK, CURED CHEESE, AND BUTTER**

Prepared by:  
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## About this document

This report corresponds to D3.4 of the SCOoPE project “Extended Value Stream maps of NACE 10.5”.

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## 0. Preface

This preface describes the proposed methodology for developing a Lean & Green Value Stream Map for virtual plants.

### i) Value Stream Mapping

In order to increase the capacity for generating and delivering value to customers and to other major stakeholders, Lean production systems focus on both reducing waste and improving material flow (King and King, 2015). But we only can reduce or eliminate waste, if we can understand where it exists in the current production processes. A value stream map (VSM) is designed to enable us to see waste and its causes. Toyota developed its “material and information flow maps” specifically to do just that. Toyota defined seven types of waste:

- 1) Overproduction: making more than the customer needs, or making it sooner than needed.
- 2) Unnecessary inventory: material not currently being processed, including raw material, work in process, and finished product inventory.
- 3) Defects: parts of material that do not meet required specifications.
- 4) Waiting: time that operators or anyone else spend waiting for material or for the equipment to be ready to use.
- 5) Transporting: movement of material, either from one process step to the next step or into or out of inventory.
- 6) Unnecessary motion: walking around the equipment to get where they are needed, or to get changeover parts or tools.
- 7) Inappropriate processing: Excessive processing, doing more to the material than the customer requires.

The first five of these can be readily seen from a well-constructed VSM. The remaining two require more detailed analysis, using Lean tools such as motion charts called “spaghetti diagrams”. In our VSM exercises, we will focus in understanding the impact of the first four (overproduction, unnecessary inventory, defects, and waiting) not only on operational performance but also on energy efficiency and carbon footprint reduction.

An eighth waste is often added to Toyota’s seven:

- 8) Lost people potential: the waste of human knowledge, creativity and potential.

This also is something that cannot readily be seen on a VSM; it requires an in-depth analysis of work place culture, attitudes, behaviors, and participation in continuous improvement processes (King and King, 2015).

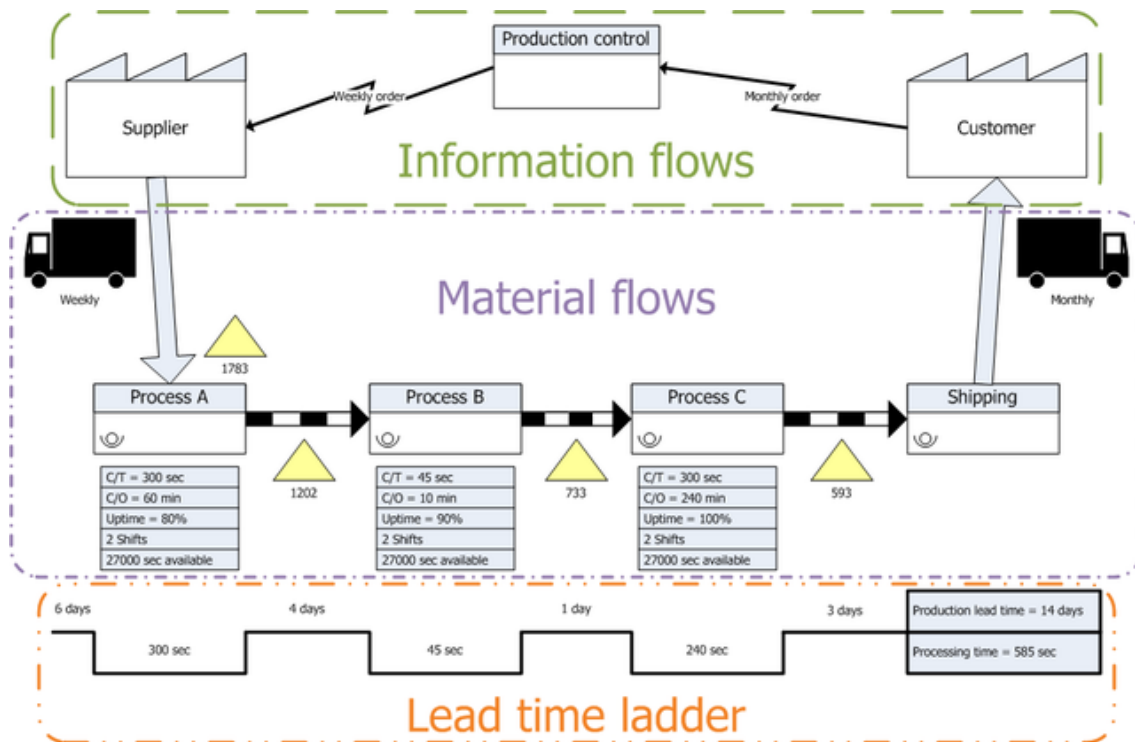


FIGURE 1: SCHEMATIC REPRESENTATION OF CURRENT VSM

SOURCE: DANIEL PENFIELD - OWN WORK, CC BY-SA 3.0,  
<https://commons.wikimedia.org/w/index.php?curid=28553995>

Some typical Lean metrics in a VSM are:

- 🔗 **Throughput or effective capacity:** The average output of a production process (machine, workstation, line, plant) per unit time (e.g., parts per hour) is defined as the system's throughput, or sometimes throughput rate (Hopp and Spearman, 2001).
- 🔗 **Capacity or maximum capacity:** An upper limit on the throughput of a production process is its capacity. It is the throughput you could expect from a production process step under "perfect" conditions: i) no yield losses or defects; ii) no rate reductions, due to mechanical, electrical or control system equipment minor failures; iii) no unscheduled downtime, due to breakdowns or to not availability of inputs or operators when needed; iv) no time for preventive maintenance; v) no time for line cleaning and disinfection; and vi) no time for changing from a product type to another or changeover.
- 🔗 **Reliability:** The percentage of time that the machine is not down because of mechanical, electrical, or control system equipment failure.
- 🔗 **Adjusted maximum capacity:** We will define this parameter as the maximum capacity of a machine multiplied by its reliability.
- 🔗 **Cycle time:** The cycle time (also called variously average cycle time, flow time, or throughput time) of a given routing is the average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing (Hopp and Spearman, 2001).



- ⌚ Process cycle time or machine cycle time (C/T): They can be defined as the inverse of the effective capacity or of the adjusted maximum capacity. The result would be named as the effective cycle time or the adjusted minimum cycle time respectively.
- ⌚ Changeover (C/O) Time: The time to change from one product type to another, including the time to get the full rate on the new product and get all properties within quality specifications.
- ⌚ Uptime or OEE (Overall Equipment Efficiency): The percentage of time that a machine or a production line is up and running. For calculating the Uptime or the OEE is needed take into account:
  - yield losses or defects
  - rate reductions
  - unscheduled downtime
  - preventive maintenance
  - line cleaning and disinfection
  - changeover time

One of the major Lean wastes is unnecessary inventory. However, in most cases, we need to carry cycle stock and safety stock. Cycle stock is the inventory carried to accommodate the cyclic nature of material delivery or production. Safety stock is the inventory held to satisfy demand in cases where actual demand is higher than expected, or where next cycle is late in starting (King and King, 2015). Frequently the throughput, the cycle time and the service level of a production line can be improved by sizing correctly the intermediate or buffer inventories (a combination of cycle stock and safety stock). Lean is not about eliminating inventories. The priority of Lean is holding only the inventory needed to reach a very high service level for the current operational conditions. Of course, inventory can be reduced by decreasing other Lean wastes such as overproduction, defects or waiting.

The Lead Time Ladder or Timeline appears as a square wave at the bottom of a VSM, and it is intended to contrast non-value-add (NVA) time and value-add (VA) time. Typically, only the processing time (with the machine up and running) is considered value-add (VA) time.

## ii) Lean & Green Value Stream Mapping

In recent years, researchers (Bermiller, 2006; Zokaei, 2012) and the US Environmental Protection Agency (EPA) have sought to “build a bridge” between Lean and Green manufacturing systems. The term “lean” in the “Lean and Green” name comes from the lean manufacturing system, a set of tools and methodologies initially developed by Toyota Motor Corporation. Now it is being used by companies all over the world to identify and eliminate waste (be it wasted time or energy), improve product quality, and reduce production time and costs. The “green” component came from the EPA’s view that lean production systems can enhance environmental performance. This view was based on a study performed by EPA in 2003 and that provided empirical evidences suggesting that the implementation of lean manufacturing systems were inherently good for the environment. This study also suggested that applying lean initiatives can have even more benefits for environment and energy efficiency if these kinds of wastes are explicitly considered when applying lean methodologies and tools. Typically, “Lean and Green” methodologies and tools consider environmental performance and



energy efficiency (PLANET) as a component of Value together with the economic efficiency (PROFIT) and the social efficiency (PEOPLE). For reducing waste, Lean methodologies use a well-established set of metrics for measuring seven sources of waste: Over Production, Defects, Unnecessary Inventory, Transporting, Waiting, Inappropriate Processing, Unnecessary Motion, and Lost People Potential (Figure 2).

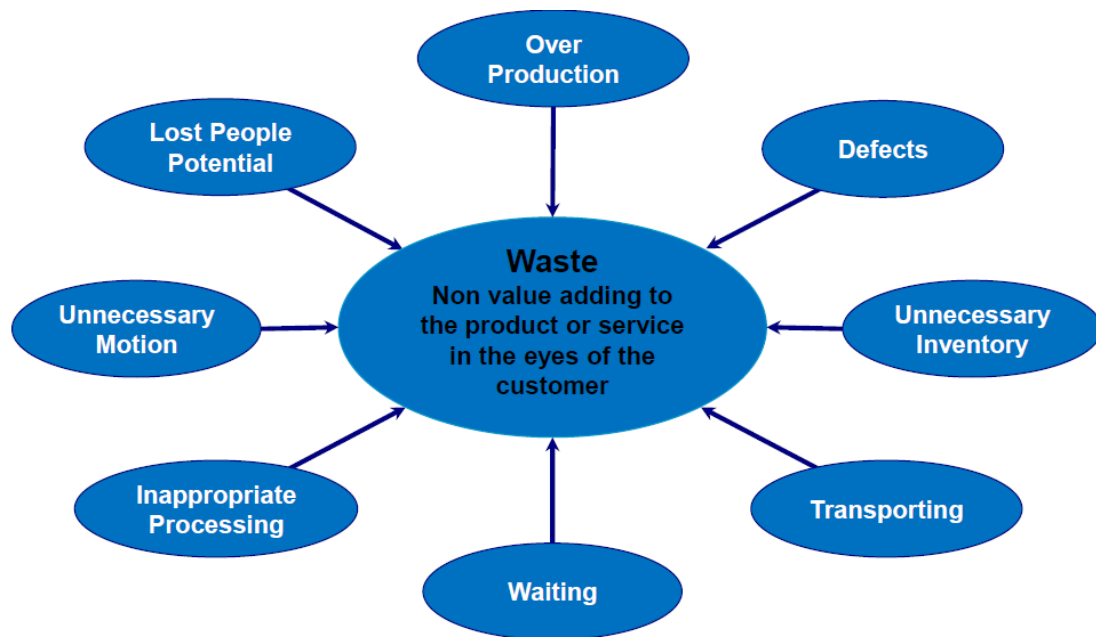


FIGURE 1: LEAN WASTES

SOURCE: Keivan Zokaei. 2016. Introduction to Lean & Sustainable. Presentation in the Seminar on Improving Competitiveness and Sustainability in Agri-food Value Chains. Technical University of Madrid, June 13th 2016, Madrid.

The primary wastes targeted by a typical Green manufacturing system include: Energy Consumption, Physical Wastes, Water Consumption, Emissions, Land Contamination, Discharges to Water, Noise & Nuisance, and Lost People Potential (Figure 3). Therefore, reducing energy use and improving energy efficiency is a key issue when implementing green manufacturing systems. Under a product life cycle perspective, energy use and energy sources are also related with other environmental wastes such as greenhouse gases emissions. “Lean and Green” methodologies use metrics to measure simultaneously Lean wastes and Green wastes taking into account their relationships.

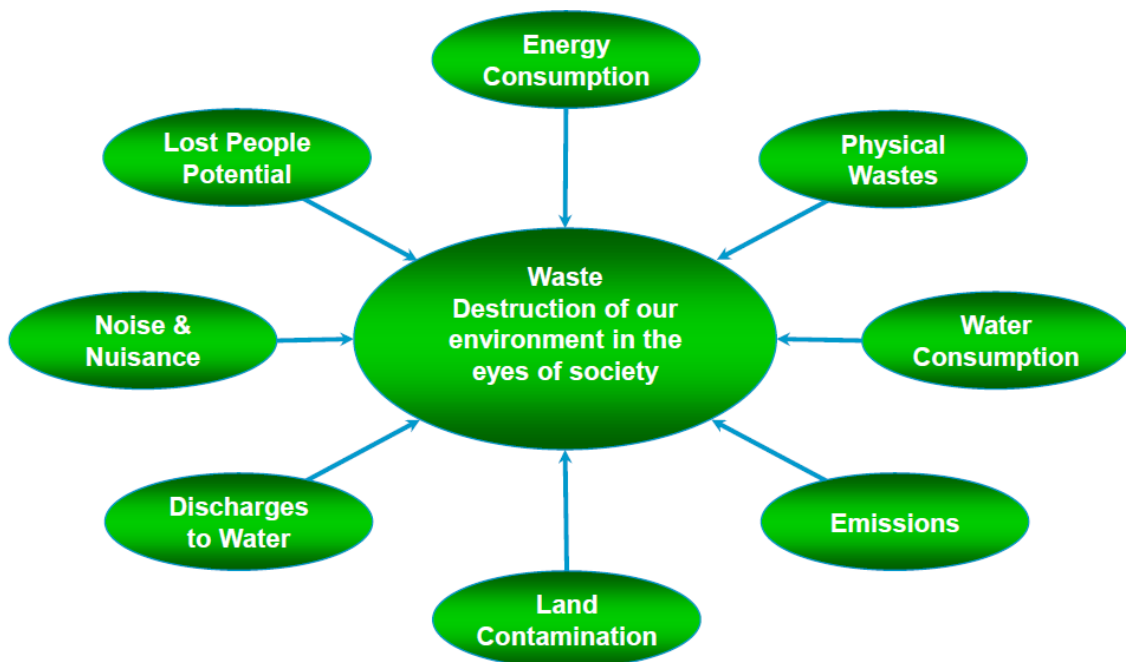


FIGURE 2: GREEN WASTES

SOURCE: Keivan Zokaei. 2016. Introduction to Lean & Sustainable. Presentation in the Seminar on Improving Competitiveness and Sustainability in Agri-food Value Chains. Technical University of Madrid, June 13th 2016, Madrid.

Extended Value Stream Mapping is a Lean methodology that is being used for “Lean and Green” waste reduction initiatives. Energy consumption can be easily incorporated to Lean & Green Value Stream Maps. Machines will consume energy when they are up and running. But energy is also consumed for lighting, cooling or heating when machines are down. Inventories are consuming energy all the time in the case of refrigerated chambers. In terms of energy efficiency, it should also be taken into account the role played by the power installed for the different machines. It has an influence on energy cost.

Recently, Verma and Sharma (2016) have proposed to develop energy value stream mapping for estimating value adding energy and non-value added energy consumption. Basically, the energy used by processing equipment and machines when they are running is value adding energy while the energy consumed by lighting and the heating and cooling of facilities is non-value added energy. The energy consumed for cooling or refrigerating inventories could also be considered as non-value added energy.

### iii) A Methodology for Developing a Lean & Green Value Stream Map for a Virtual Plan

While the traditional approach for value stream mapping can be considered as developing materials and information flow maps, we are going to focus on mapping the materials and energy flows. Water consumption will also be mapped when it is an especially relevant Green waste and information is available. Since Lean & Green Value Stream Mapping for the different



industries has to be completed before visiting the different facilities to be benchmarked in the SCOOPE project, the mapping will be performed for virtual plants with one or more production lines.

In the field of engineering, production lines has to be designed when a new industrial plant is being designed. The starting point is the products or family of products to be manufactured and the production capacity of the new plant. Subsequently, for each product or family of products, the processes are designed and the equipment and machines to carry out the different processes are selected.

Technical parameters such as the maximum capacity (name-plate capacity) and the installed power has to be known for each machine and equipment in order to make a basic design of a production line. Sometimes equipment suppliers can provide information on equipment reliability, average time between breakdowns or average time for repairing a breakdown. This information is very useful for designing the preventive maintenance plans but also for a better design of the production line. The more sophisticated engineering companies can use discrete simulation techniques or virtual reality for evaluating the operational performance of different production line layouts. We will design production lines for the major products or families of products being manufactured by the plants to be benchmarked in the SCOOPE project. For mapping the materials and energy flows, optimistic and “average” operational scenarios based on a set of operational assumption will be set up.



## 1. Introduction

This document describes:

- 1) The development of the Current Value Stream Map and the Sankey Diagrams for a virtual plant producing yogurt and skimmed milk with two scenarios of operational performance.
- 2) The development of the Current Value Stream Map and the Sankey Diagrams for a virtual plant producing cured cheese.
- 3) The development of the Current Value Stream Map and the Sankey Diagrams for a virtual production line for producing butter.

In the process of developing the different Current Value Stream maps are also described the industrial processes involved including:

- 1) The production processes
- 2) The equipment used for each process with their technical characteristics (mainly their maximum production capacity and the power installed)
- 3) The operational performance assumptions used for calculating the energy consumption in each process and each particular equipment

This approach allows not only highlighting the most relevant processes from the energy point of view but also showing the interrelation between operational performance and energy efficiency. The results of the task will serve as a basis for the further tasks in the project, principally in Task 3.6 (development of a self-assessment software) and in Tasks 2.1 (setting up of benchmarking baselines in thermal processes) and 2.2 (setting up of benchmarking baselines for electrical consumption).

### 1.1 Assessment of the Current Situation in the Dairy Sector

In a review of the energy utilization in the dairy industry (Rad and Lewis, 2014), the energy utilization measured in GJ per tonne of product was reported for different dairy products and different sources. The values reported for the different products considered in this document (skimmed milk, yoghurt, cheese, and butter) were the following one:

- 1) Fluid milk: 0.7 (UNIDO, 2010), 0.24 – 0.7<sup>1</sup> (UK Environmental Energy, 2009), 1.43 (Klemes *et al.*, 2008), 0.66 (Foster *et al.*, 2006), 0.5 – 1.2 (UNEP Working Group, 2004).
- 2) Milk & yoghurt: 0.31 – 3.9 (FDM BREF, 2006), 0.25 -1.58<sup>1</sup> (Nordic Council of Ministers *et al.*, 2001).
- 3) Yoghurt: 0.96 (Bartholomai, 1987).
- 4) Cheese: 3.3 (UNIDO, 2010), 0.21 – 7.2<sup>2</sup> (FDM BREF, 2006), 5.1 (Foster *et al.*, 2006), 0.39 – 0.95 (UNEP Working Group, 2004), 1.4 for Mozzarella production (Bartholomai, 1987).
- 5) Butter: 1.8 (UNIDO, 2010), 4.24 (Foster *et al.*, 2006).

The *Reference Document on Best Available Techniques in the Food, Drink and Milk Industries* (FDM BREF, 2006) is currently being updated. It is expected new values on energy utilization

<sup>1</sup> The conversion from kWh / kg to GJ / t has been calculated by the authors (Rad and Lewis, 2014)

<sup>2</sup> The conversion from kWh / kg to GJ / t has been calculated by the authors (Rad and Lewis, 2014)



reflect the efforts that dairy industry is doing for improving energy efficiency. The wide ranges in the values of energy utilization is the result of a large variety of specific type of products, the use of technologies with large differences in their energy efficiency, and the very diverse levels of operational performance in the plants.







Energy efficiency can be improved by introducing technological innovations such as CHP regenerative heat-exchange in pasteurization, continuous pasteurizers instead of batch ones, partial homogenization, multi effect evaporators, multistage evaporation, efficient pre-treatment of milk, elimination of fine particles during spray drying, ultra-filtration for protein standardization, shortening of the ripening process, absorption chilling by using waste and solar heat, new high temperature heat pumping systems and solar heat collectors in industry, recovery of heat and water present in the used drying air and effective cleaning processes, storage of energy or cogeneration. Organizational innovations such as the implementation of energy management systems certified according to the ISO 50001, the use of intelligent energy consumption control systems based on the installation of real time sensors in the production lines or the application of Lean & Green methodologies and tools for the simultaneous and continuous improvement of energy efficiency and operational performance could also contribute to substantial energy efficiency improvements in the dairy industry.

## 2. Semi-Skimmed Milk and Fruit Creamy Yoghurt

For designing of a production line for a virtual factory, we have used as a reference an engineering project for a new factory producing fruit creamy yoghurts and semi-skimmed milk (Hernández, 2015). In Spain, food engineers have to defend an engineering project in order to get the engineering degree. Most projects are about the design of new plants in different food & drink industries.

The engineering project include all the technical calculation for the construction and the operation of a plant designed for producing daily 3,500 liters of semi-skimmed milk and 15,000 fruit creamy yoghurts of 125 g per unit. The production lines for semi-skimmed milk and fruit creamy yoghurt were designed assuming a daily working time of 8 hours with the possibility of paying extra hours in the case that the production scheduled for a particular day has not been completed after 8 hours. For the design of the production line, no assumptions on operational performance were considered because the production overcapacity of the plant should allow to cope with unscheduled downtimes.

The approach used for modeling the operational performance and the energy consumption of the virtual plant was based on assuming two operations scenarios for the Uptime or OEE (Overall Equipment Efficiency) of the production lines. As it was abovementioned, for calculating the Uptime or the OEE is needed take into account:

-  yield losses or defects
-  rate reductions
-  unscheduled downtime
-  preventive maintenance
-  line cleaning and disinfection
-  changeover time

For a daily working time of 24 hours, 7 days per week, once we have set up two “reasonable” scenarios, an “average” and another “optimistic”, for the daily uptimes, we can estimate the daily



expected productions of semi-skimmed milk and fruit creamy yoghurts as well as the daily energy consumptions associated with each production line, with each production process and with each workstation or equipment unit. From these data, it is possible to develop the Current Value Stream Map and different Sankey Diagrams for each scenario. Because, in this type of engineering project, not only the energy installed for each machine or equipment in the production lines is established but also the energy installed that is required for other auxiliary equipment as refrigerated chambers as well as the energy required for lighting and for heating and air conditioning has to be calculated, it is also possible to estimate the energy consumption for the whole plant. From the expected daily outputs of final products and the expected energy consumptions for production lines and for the plant as a whole, it is possible to estimate different measures of energy utilization or energy efficiency for each scenario.

This modelling approach assumes a certainty environment for decision making. The UPM team could also use discrete simulation software, such as SIMUL8 or SIMIO, for developing each Current Value Stream Map by assuming a risk environment for decision making. However, it has been considered more suitable for tasks 3.2, 3.3, 3.4, and 3.5 to make use of a simpler methodology that only requires working with Excel files. This facilitates not only the execution of these tasks to the teams of ENEA, Service Coop de France, and Spanish Coop but also the review of these tasks by the UPM team. Likewise, the software to be developed by CIRCE will also apply a deterministic approach and deterministic Value Stream Maps will fit better with such approach. Probabilistic modelling with SIMU8 will be only used for validating the results of the Beta versions of the self-assessment software that will be developed in task 3.6 of WP3.

For developing the Current Value Stream Map for each scenario, we have adopted the following operational assumptions:

- ⌚ DAILY WORKING TIME: 24 hours (3 shifts of 8 hours), 7 days per week
- ⌚ RELIABILITY: The reliability value is assumed to be 0,95 (95 %).
- ⌚ PRODUCTION CAPACITY FOR WORK STATIONS: It will be assumed that the production capacity when the equipment is up and running will be equal to the adjusted maximum capacity (maximum capacity multiplied by reliability). The machine cycle time will be the adjusted minimum cycle time (the minimum cycle time divided by reliability)
- ⌚ ESTIMATION OF CHANGEOVER TIME: 5 minutes (optimistic) or 30 minutes (average)
- ⌚ ESTIMATION OF CLEANING AND DESINFECTION (AT THE END OF DAY): 1 hour (optimistic) or 2 hours (average)
- ⌚ ESTIMATION OF PREVENTIVE MAINTENANCE TIME PER DAY: 30 minutes (optimistic) or 60 minutes (average). We are assigning a preventive maintenance time per day when, in a real setting, the total weekly preventive maintenance time could be concentrated and scheduled for a particular day of the week
- ⌚ ESTIMATION OF LINE DOWNTIME PER DAY: 1 hour (optimistic) and 3 hours (average)
- ⌚ ESTIMATION OF PORCENTAGE OF DEFECTS (AT THE END OF THE PRODUCTION LINE): 1% (optimistic) and 5% (average)

## 2.1 Processes description and equipment

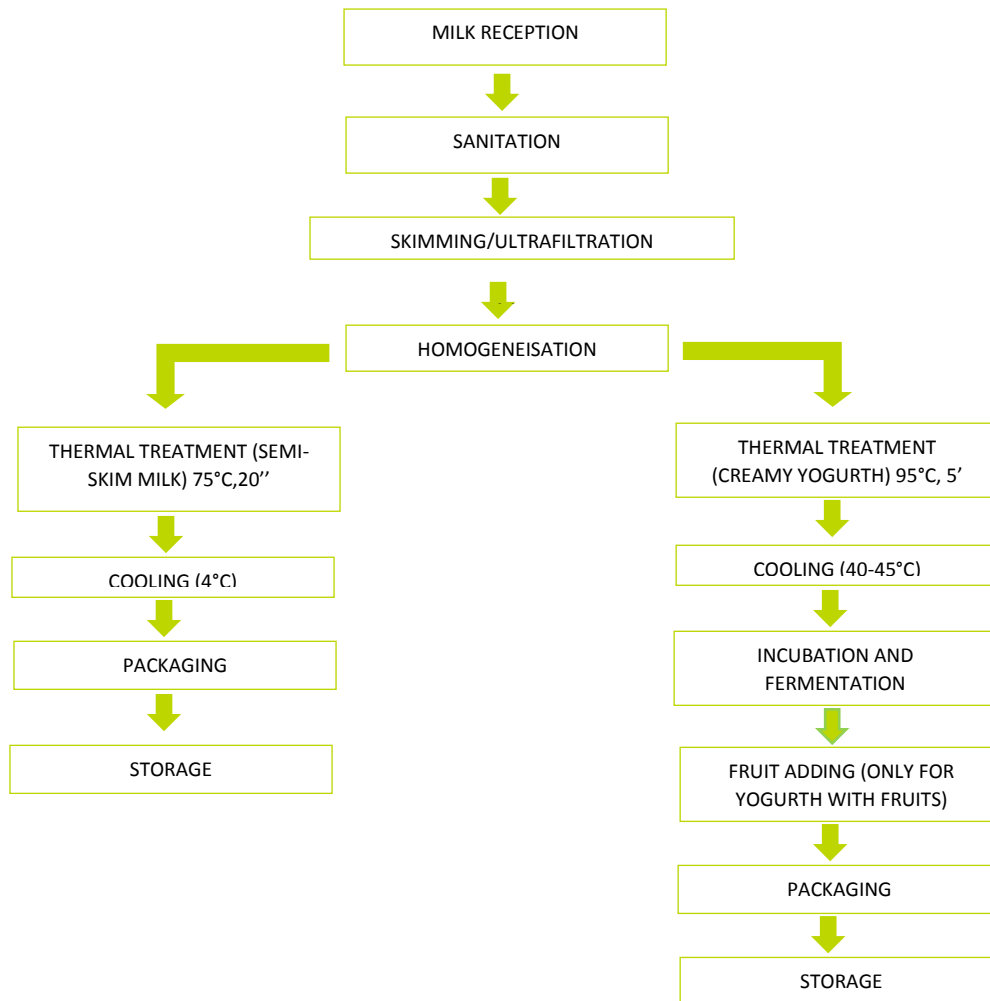


FIGURE 3: FLOW DIAGRAM FOR YOGURTH AND SEMI SKIMMED MIL INDUSTRY

## Milk Reception

The milk is transported from the farm or from the collection center to the industry by trucks with isotherm tanks. Milk has to be cooled below + 4 ° C immediately after milking and this temperature is maintained during its transportation and until its arrival to the industry. After its reception, milk will be discharged into the receiving silos located at the reception room after carrying out a rapid analysis of some key physicochemical, sanitary and microbiological parameters used to decide whether the track load is accepted or rejected.

During transportation, a slight temperature increase is inevitable over + 4 ° C. Therefore, the milk will be cooled below + 4 ° C in a plate heat exchanger before being stored in storage vertical tanks. The technical characteristics of the heat exchanger will be the following ones:

### Technical Characteristics

Namely Capacity	2000 l / h
Installed Power	2.24 kW

Untreated raw milk (whole milk) is stored in isotherm vertical tanks (silo tanks) located within the production plant. Deposits will be of stainless steel. Silo tanks will have a system of agitation to prevent cream separation by gravity. Agitation should be very smooth because of the otherwise it will lead to milk aeration and disintegration of the milk fat globules exposing milk fat to the action of lipase enzymes.



The technical characteristics of the silo tanks are:

### Technical Characteristics

Namely Capacity	5000 l
Installed Power	5.52 kW

FIGURE 1: RECEIVING ISOTHERMAL SILO

Source: Equiproin Catalogue, available in: <http://www.equiproin.pt/en/products/stainless-steel-isothermal-tanks>

## Sanitation

The final steps of this phase named bactofugation, consist in applying centrifugal forces of greater intensity in order to eliminate unwanted microorganisms present in milk. Fortunately, some of the microorganisms that are more resistant to heat treatment are also the heavier ones, and therefore the ones that is easiest to be removed by centrifugation.

### Technical Characteristics

Namely Capacity	2000 l / h
Installed Power	2.796 kW

## Skimming / Ultrafiltration

This phase consists in separating cream from milk for obtaining skimmed milk in order to further standardize it in the standardization stage. This step is carried out in a similar equipment to the one used for sanitizing milk by centrifugation. In this case the cream, i.e., fat globules, having a density less than skimmed milk is separated by centrifugal forces



FIGURE 2: SKIMMER

Source: SAA «Fábrica de construcción de maquinaria de Plavsk «Plava, available: <http://sp.plava.ru/catalog/32/9/>

### Skimmer

Technical Characteristics	
Namely Capacity	2000 l / h
Installed Power	0.93 kW

### Ultrafiltration

Technical Characteristics	
Namely Capacity	2000 l / h
Installed Power	4.85 kW

### Homogenisation

The homogenisation of milk is the formation of a homogeneous emulsion from two immiscible fluids: fat and water. Normally homogenization is applied in two phases. In the first phase, a pressure of 15 MPa is applied while 4 MPa are applied in the second one. For making all milk fat be in liquid state, homogenization should be performed at temperatures above 50 ° C.



FIGURE 3: HOMOGENEIZATER

Source: INMASA Ingeniería y Maquinaria para la Alimentación SA, available in: <http://www.inmasa.com/esp/homogeneitza dors.html>

Technical Characteristics	
Namely Capacity	2000 l / h
Installed Power	7.08 kW

### **Thermal Treatment (for the semi-skimmed production line)**

A pasteurization treatment is used to reduce the levels of pathogenic microorganisms in milk to obtain a product that not represented any risk for the consumer. The sporulated pathogens more thermoresistents, *Coxiella burnetti* and *Mycobacterium tuberculosis*, are also destroyed in the pasteurization. The treatment consists to apply and high temperature for short time (75 °C, 20 sec).



FIGURE 4: PASTEURIZER- HEAT EXCHANGER

INMASA Ingeniería y Maquinaria para la Alimentación SA, available in:  
<http://www.inmasa.com/esp/bescanviadors.html>

#### **Technical Charateristics**

Namely Capacity	2000 l / h
Installed Power	2.04 kW

### **Thermal Treatment (for the creamy yoghurt production line)**

For the production of the yoghurt, the homogenized milk is redirected to the pasteurization unit, where is heated up to 90 °C, and then pasteurized at 95 °C for 5 minutes.

#### **Technical Charateristics**

Namely Capacity	2000 l / h
Installed Power	2.04 kW

### **Cooling (for the semi-skimmed milk production line)**

Cooling is the process that immediately follows the pasteurisation. Milk is cooled to shield it from the area of thermal hazard and therefore it need to be refrigerated at temperatures considerably lower than the ones reached in the heating. In this case, temperatures less than or equal to 4 ° C are reached, increasing in this way the ability to preserve the product.

The cooling will be performed by a plate heat exchanger.

#### **Technical Charateristics**

Namely Capacity	2000 l / h
Installed Power	2.04 kW

### Cooling (for the creamy yoghurt production line)

After pasteurization, the milk is cooled to the inoculation temperature, which is around 40 °C. Cooling is carried out in the regenerative section of the heat exchanger and then by water up to the inoculation temperature between 40 and 45°C.

For simplifying, we will assume that the cooling will be also performed by a plate heat exchanger.

#### Technical Characteristics

Namely Capacity	2000 l / h
Installed Power	2.04 kW

### Incubation and Fermentation (for the creamy yoghurt production line)

Milk that has been previously cooled to the temperature of incubation is pumped into the fermentation tank. Once the tank has been filled, the milk is inoculated with a bulk starter containing the lactic acid bacteria *Lactobacillus delbrueckii* ssp. *Bulgaricus* and *Streptococcus thermophilus*, which have been previously added to a ferment maker in the form of a commercial frozen concentrate.

During the incubation period, the milk is kept at rest. The clot of yoghurt begins to form when lactic acid is produced and the pH of the milk approaches to the isoelectric point of casein (pH 4.6 - 4.7). When the pH drops to a value of 5.6 can already be seen the formation of a gel with a certain consistency. The incubation period is between 2.5 and 3 hours until a pH between 4.6 and 4,7 is reached, or what is the same, a concentration of 0.9% lactic acid.

After fermentation, the yogurt is gently agitated to break the coagulum. This shaking allows to break the hot clot and to reinstate the whey for getting the creamy texture of a yogurt smoothie. Generally, to obtain a homogeneous gel is enough a very gentle stirring (with speed of pallets of 2-4 r.p.m.) for about 5-10 minutes. In addition the agitation has an inhibitory effect on culture activity and reduces the production of lactic acid.

When preparing creamy, in the final phase of incubation, when a 4.2 - 4.5 pH is reached, the temperature should be lowered to 12-15°C quickly. This retards the subsequent rise of acidity and stops the activity of starter culture microorganisms. Cooling is performed in a plate heat exchanger. The clot is driven to this exchanger through a pump. The pump capacity will be dimensioned so that the fermentation tank is empty in a time of 20-30 minutes in order to maintain a uniform product quality.

#### Technical Characteristics

Namely Capacity	2000 l (3 hours)
Installed Power	14 kW



FIGURE 5: INCUBATION TANK

Source: INMASA Ingeniería y Maquinaria para la Alimentación SA available in: <http://www.inmasa.com/esp/fermentacio.html>.

### **Fruit Adding (only for creamy yoghurt with fruit)**

In the case of yoghurt with fruit, the stage subsequent to the incubation and fermentation (cooling included) is the addition of the fruit. Because a bilayer yogurt is being manufactured, in which the base layer is composed of fruit and yogurt is incorporated above the base layer, the addition method in the container will consist of dropping the desired dose of fruit on the container through distributor head and then the corresponding dose of yoghurt on it through a second distributor head.

#### **Technical Charateristics**

Namely Capacity	2000 l / h
Installed Power	2.796 kW

### **Packaging**



FIGURE 6: PACKER

Source: INMASA Ingeniería y Maquinaria para la Alimentación SA available in: <http://www.inmasa.com/esp/liniesenvasat.html>

## Milk Packaging

Once pasteurized, the milk is packaged in hermetically sealed containers for protecting it from contamination during marketing. Packaging consists of filling the containers with the product. The essential condition for preservation of the product for a long period of time is maintain proper hygienic conditions during packaging.

### Technical Characteristics

Namely Capacity	2000 l / h
Installed Power	2.98 kW

## Yoghurt Packaging

Once deposited the product inside of the container will be placed an aluminum lid for sealing. The containers will be made of polyethylene of high density with a capacity of 125 g. Then yoghurt containers will be in arranged in packs of two through a cardboard that will encompass both yoghurts.

### Technical Characteristics

Namely Capacity	1500 units / h
Installed Power	3.356 kW

## Storage

Products will remain in the refrigerated storage chamber until their removal for sale and distribution. In the case of semi-skimmed milk, from its heat treatment up to its consumption must be kept on a chain of no more than 6 °C cold, therefore after the packaging and until it is distributed to the sales points should be kept in refrigerated storage conditions. For yoghurts, the temperature should be 5 °C at a maximum. Yoghurts should stay 48 hours in the refrigerated chamber before being delivered to the distribution channel in order to allow the yoghurt clot to reach its stability.



FIGURE 7: REFRIGERATED CHAMBER FOR STORING

Source: Frigopack Catalogue, available in:  
[HTTP://WWW.FRIGOPACK.COM/SECCION~X~CAMARAS~FRIGORIFICAS~IDSECCIONARTICULO~286.HTML](http://www.frigopack.com/seccion~X~CAMARAS~FRIGORIFICAS~IDSECCIONARTICULO~286.HTML)



### Technical Characteristics

Namely Capacity	48 hours final production (a maximum of 20.000 kg)
Installed Power	6 kW

### Centrifugal Pump

Stainless steel centrifugal pumps, which can be entirely disassembled for cleaning, will be used for transporting milk from a stage to the next one. Pumps will have an electronic speed control that allows a flow of constant milk.

### Technical Characteristics

Namely Capacity	3000 litros/h
Installed Power	2,796 Kw

## 2.2 Overview list of the processes and equipment

PROCESS	EQUIPMENT	ELECTRIC AND/OR THERMAL	SOURCE OF ENERGY
MILK RECEPTION	PUMPING FROM THE MILK TRANSPORTING TRACKS	ELECTRIC	ELECTRICITY
	PLATE HEAT EXCHANGER	ELECTRIC	ELECTRICITY
	ISOTHERMAL STORAGE TANK	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS	ELECTRIC	ELECTRICITY
SANITATION AND BACTIFUGATION	SANITATIZER / BACTIFUGATION	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS	ELECTRIC	ELECTRICITY
SKIIMMING AND ULTRAFILTRATION	SKIMMER	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS	ELECTRIC	ELECTRICITY
	ULTRAFILTRATION EQUIPMENT <sup>1</sup>	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS <sup>1</sup>	ELECTRIC	ELECTRICITY
HOMOGENIZATION	HOMOGENIZER	ELECTRIC / THERMAL	GAS / ELECTRICITY
	PUMPING TO NEXT PROCESS	ELECTRIC	ELECTRICITY
THERMAL TREATMENT	PASTEURIZER	ELECTRIC / THERMAL	GAS / ELECTRICITY
	PUMPING TO NEXT PROCESS	ELECTRIC	ELECTRICITY



COOLING	PLATE HEAT EXCHANGER	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS <sup>2</sup>	ELECTRIC	ELECTRICITY
INCUBATION AND FERMENTATION	FERMENTATION TANK WITH PLATE HEAT EXCHANGER <sup>1</sup>	ELECTRIC	ELECTRICITY
	PUMPING TO NEXT PROCESS <sup>1</sup>	ELECTRIC	ELECTRICITY
FRUIT ADDING	DOSING PUMP <sup>1</sup>	ELECTRIC	ELECTRICITY
YOGHURT PACKAGING AND LABELLING	PACKER <sup>1</sup>	ELECTRIC	ELECTRICITY
	ELECTRICAL LIFT <sup>1</sup>	ELECTRIC	ELECTRICITY
SEMI-SKIMMED MILK PACKAGING AND LABELLING	PACKER <sup>2</sup>	ELECTRIC	ELECTRICITY
	ELECTRICAL LIFT <sup>2</sup>	ELECTRIC	ELECTRICITY
STORING	REFRIGERATED CHAMBER	ELECTRIC	ELECTRICITY
CLEANING & DISINFECTION	CIP EQUIPMENT: CLEANING TANK.	ELECTRIC/THERMAL	GAS/ELECTRICITY

<sup>1</sup>This equipment is only used for the production line of creamy yoghurts

<sup>2</sup>This equipment is only used for the production line of semi-skimmed milk



## 2.3 Current Value Stream Mapping

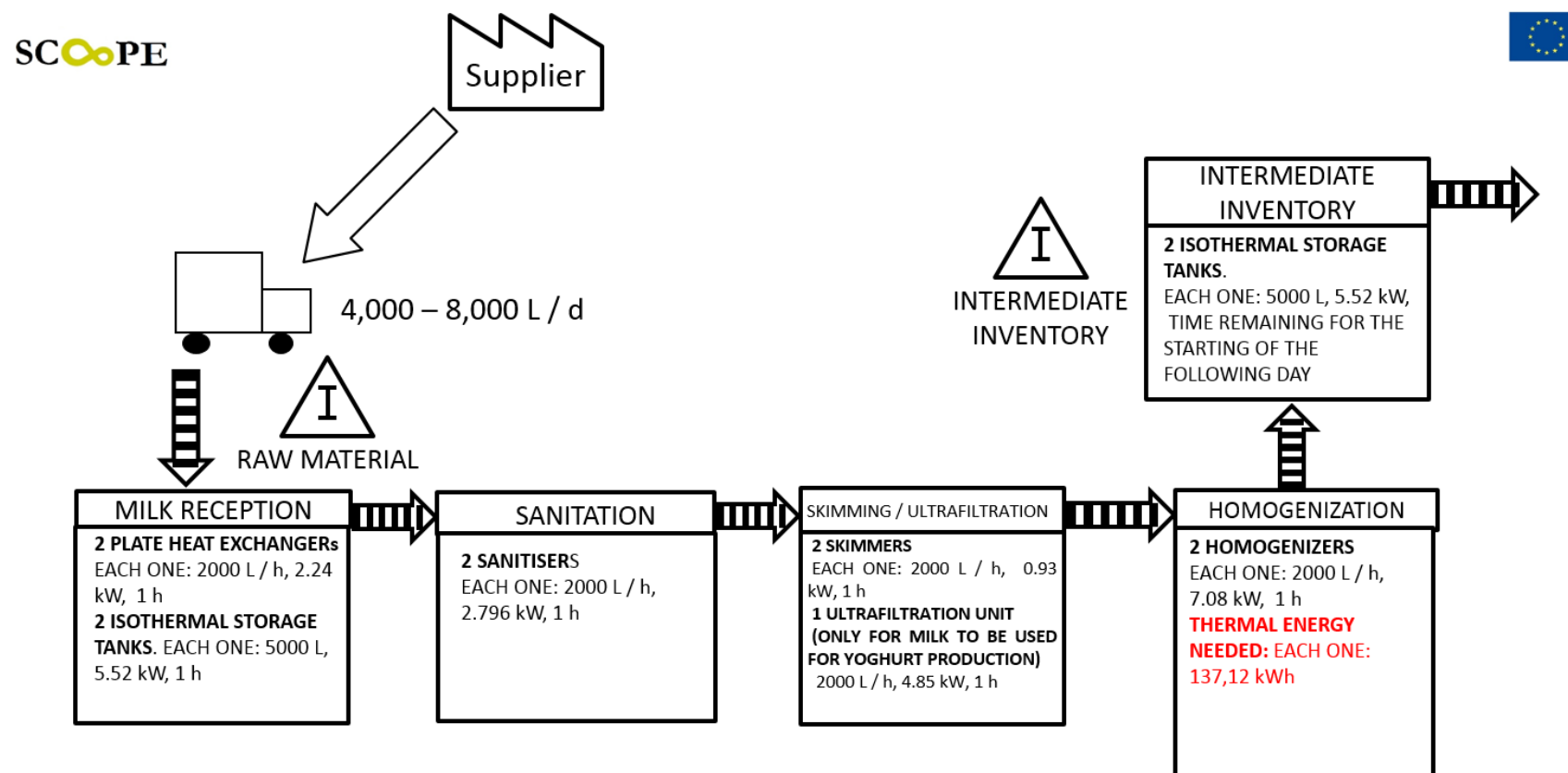


FIGURE 8: CURRENT VALUE STREAM MAPPING FOR YOGHOURT AND MILK INDUSTRY. FROM MILK RECEPTION TO HOMOGENIZATION

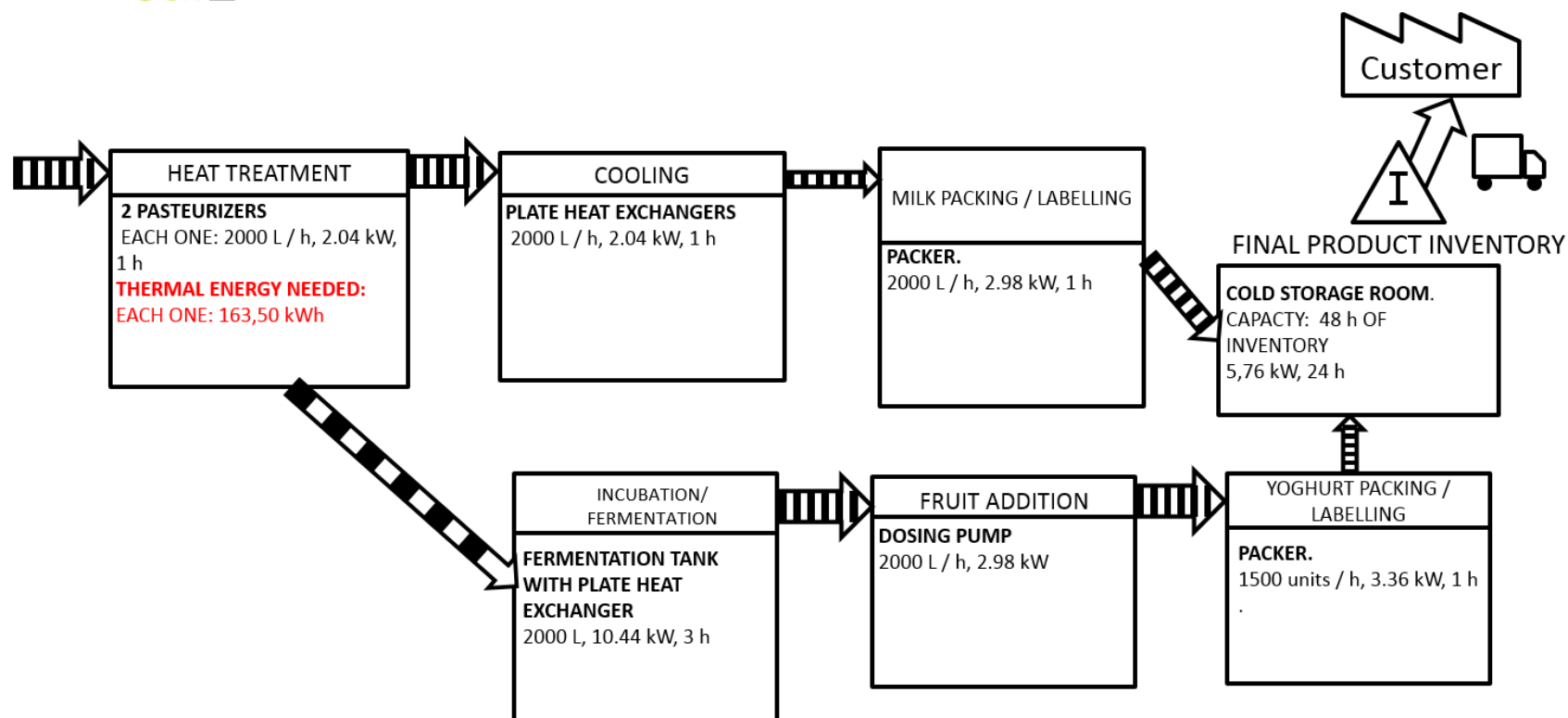


FIGURE 9: CURRENT VALUE STREAM MAPPING FOR YOGURTH AND MILK INDUSTRY. FROM HEAT TREATMENT TO FINAL PRODUCT INVENTORY



By using as a reference an engineering project for a new factory producing fruit creamy yoghurt and semi-skimmed milk, two virtual production lines have been designed, one for semi-skimmed milk and another one for fruit creamy yoghurt. For two operational scenarios, it has been estimated the time available for production in each one and how many batches could be produced for each type of product. It was assumed that each batch was the amount of final product obtained from transforming 2000 liters of homogenized milk. Every day it was transformed as many batches of 2000 liters of crude milk in homogenized milk as possible, taking into account the time available for completing the whole process in the same day. The homogenized milk produced in a day is transformed in final products next day. An intermediate inventory is only consider for homogenized milk.

In an Excel file has been calculated the productions and the energy consumptions for each scenario, the average one and the optimistic one. In the average operational scenario, it was possible to produce only a batch of semi-skimmed milk and a batch of fruit creamy yoghurts. However, in the optimistic operational scenario, it was possible to produce two batches for each final product. This improvement in the operational performance of the plant has a significant impact in the energy efficiency for the final products elaborated in the virtual production plant. These are the results obtained for the energy efficiency estimates:



DAILY PRODUCTION (OPTIMISTIC SCENARIO)								
	PRODUCTION	DEFECTS (1%)	REAL PRODUCTION (KG/L)	TOTAL DAILY ENERGY CONSUMPTION (kWh)	ENERGY EFFICIENCY (KWH PER KG)	TOTAL DAILY ENERGY CONSUMPTION (GJ)	ENERGY EFFICIENCY (GJ PER t)	ENERGY EFFICIENCY IMPROVEMENT (%)
YOGHURTS (KG)	3750,00	37,5	3712,00	1384,26	0,37	4,98	1,34	25,45%
SKIMMED MILK (L)	4000,00	40	3960,00	1301,42	0,33	4,69	1,18	26,52%

DAILY PRODUCTION (AVERAGE SCENARIO)							
	PRODUCTION	DEFECTS (5%)	REAL PRODUCTION (KG/L)	TOTAL DAILY ENERGY CONSUMPTION (kWh)	ENERGY EFFICIENCY (KWH PER L)	TOTAL DAILY ENERGY CONSUMPTION (GJ)	ENERGY EFFICIENCY (GJ PER t)
YOGHURTS (KG)	1875,00	93,75	1781,00	890,88	0,50	3,21	1,80
SKIMMED MILK (L)	2000,00	100	1900,00	849,75	0,45	3,06	1,61

The values of energy efficiency or energy utilization in GJ per tonne are relatively high in the case of average scenario. As we commented above, in recent review (Rad and Lewis, 2014), the following values of energy utilization (GJ / t) were reported:

- 1) Fluid milk: 0.7 (UNIDO, 2010), 0.24 – 0.7<sup>3</sup> (UK Environmental Energy, 2009), 1.43 (Klemes *et al.*, 2008), 0.66 (Foster *et al.*, 2006), 0.5 – 1.2 (UNEP Working Group, 2004).
- 2) Milk & yoghurt: 0.31 – 3.9 (FDM BREF, 2006), 0.25 -1.58<sup>1</sup> (Nordic Council of Ministers *et al.*, 2001).
- 3) Yoghurt: 0.96 (Bartholomai, 1987).

<sup>3</sup> The conversion from kWh / kg to GJ / t has been calculated by the authors (Rad and Lewis, 2014)



According to these values, energy utilization values obtained for skimmed milk and for yoghurt in the “average” operational scenario seems to be relatively high. However, the data for the “optimal” scenario are quite consistent with the reported values. In this first modelling exercise, maybe the more interesting result is the quantification of the impact of a substantial improvement in operational performance in energy efficiency. Despite a 25,45 % for yoghurt and a 26,52 % for skimmed milk could seem very high, experts in developing Lean & Green initiatives in the food industry has also reported high energy efficiency improvement values in a recent seminar celebrated in the Technical University of Madrid (Zokaei, 2016).

The result obtained for the calculations of the value-added energy and the non-value added energy are also very interesting and suggest that there is a large potential for reducing excessive energy consumption, a Green waste, in the dairy industry. The results obtained are the following ones:

#### ENERGY LINE (OPTIMISTIC SCENARIO)

Value adding energy (kwh)	1540,27
Non-value added energy	1145,40
Ratio (value adding energy / total energy consumption)	<b>57,35%</b>

#### ENERGY LINE (AVERAGE SCENARIO)

Value adding energy	861,96
Non-value added energy	878,68
Ratio (value adding energy / total energy consumption)	<b>49,52%</b>

## 2.4 Sankey diagram

### Optimistic Scenario

#### Yoghurt Production Line



FIGURE 10: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR YOGURT PRODUCTION LINE. OPTIMISTIC SCENARIO

SOURCE: CALCULATIONS FOR THE VIRTUAL PRODUCTION LINE

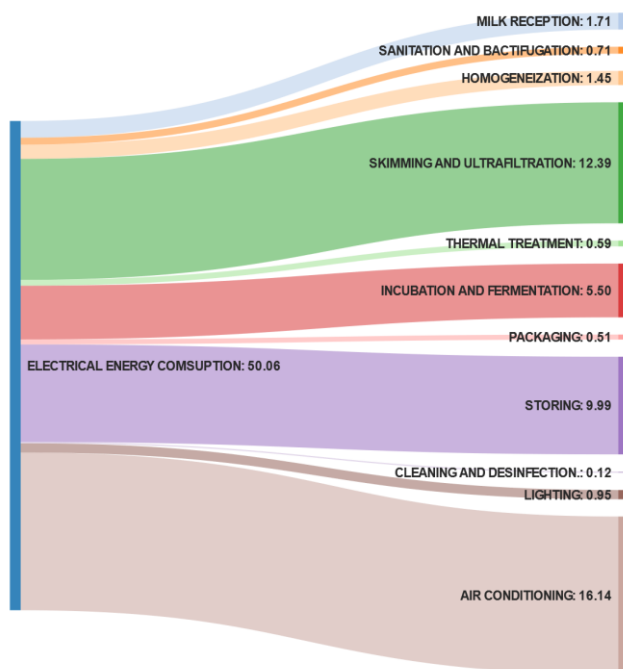


FIGURE 16: SANKEY DIAGRAM. ELECTRIC ENERGY CONSUMPTION. YOGURT PRODUCTION LINE. OPTIMISTIC SCENARIO

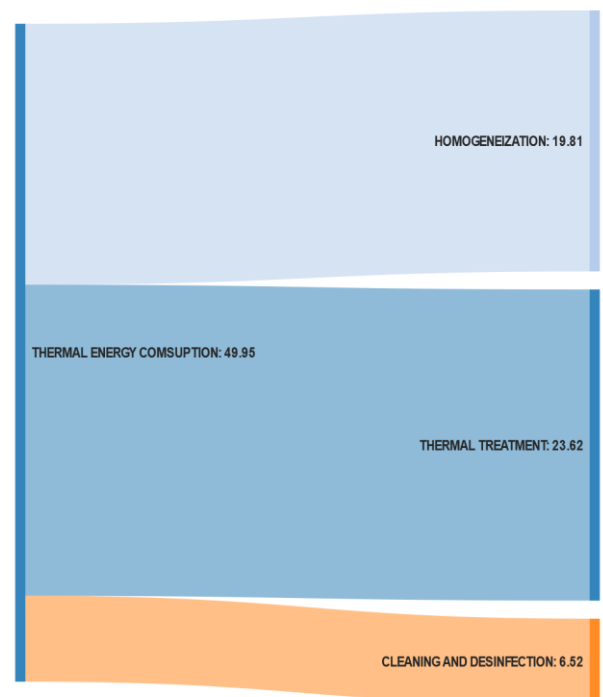


FIGURE 15: SANKEY DIAGRAM. THERMAL ENERGY CONSUMPTION. YOGURT PRODUCTION LINE. OPTIMISTIC SCENARIO

## Semi Skimmed Milk Production Line

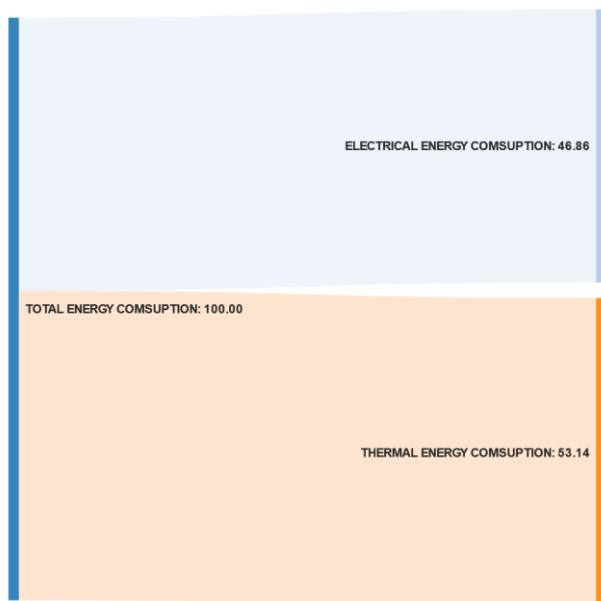


FIGURE 17: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR SEMI SKIMMED MILK PRODUCTION LINE. OPTIMISTIC SCENARIO

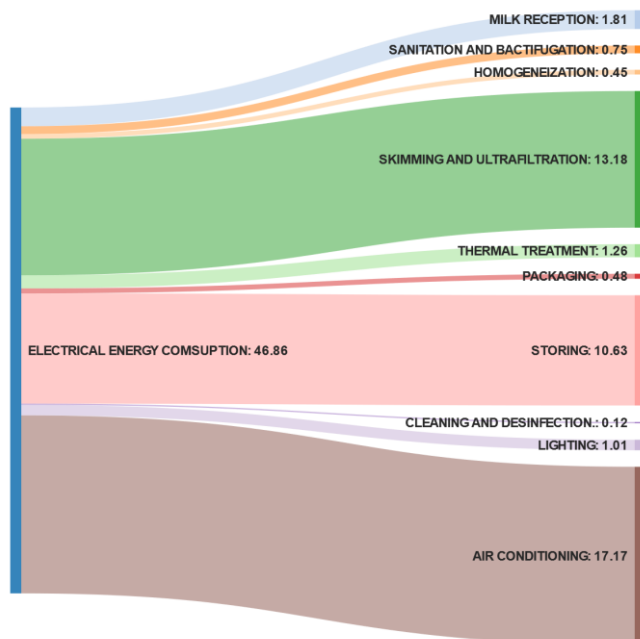


FIGURE 19: SANKEY DIAGRAM. ELECTRIC ENERGY CONSUMPTION. SEMI SKIMMED MILK PRODUCTION LINE. OPTIMISTIC SCENARIO

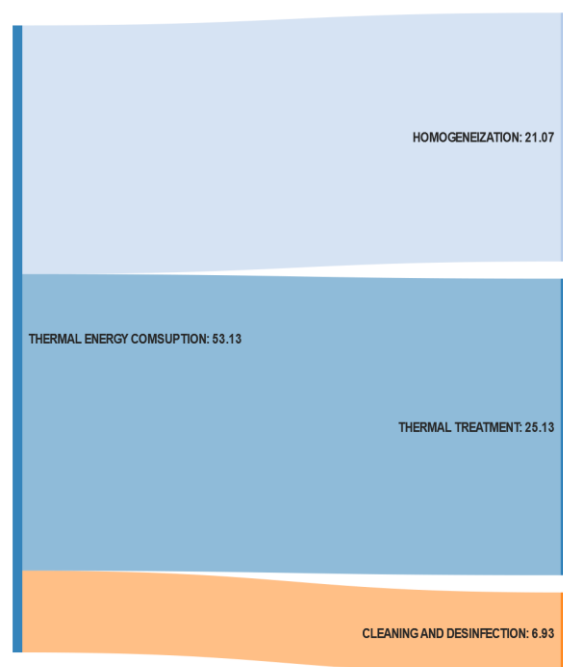


FIGURE 18: SANKEY DIAGRAM. THERMAL ENERGY CONSUMPTION. SEMI SKIMMED MILK PRODUCTION LINE. OPTIMISTIC SCENARIO

## Average Scenario

### Yogurt Production Line

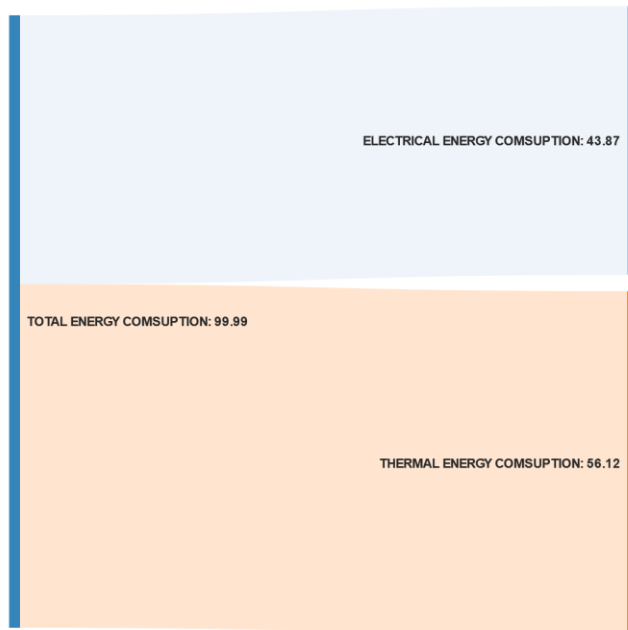


FIGURE 20: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR YOGURT PRODUCTION LINE. AVERAGE SCENARIO

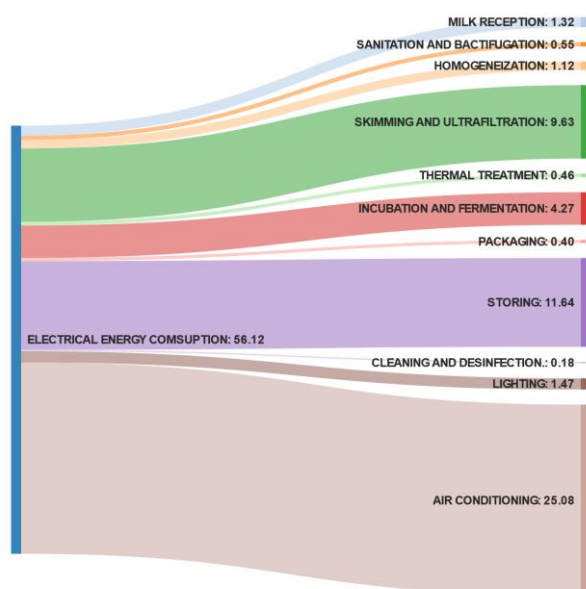


FIGURE 21: SANKEY DIAGRAM. ELECTRIC ENERGY CONSUMPTION FOR YOGURT PRODUCTION LINE. AVERAGE SCENARIO

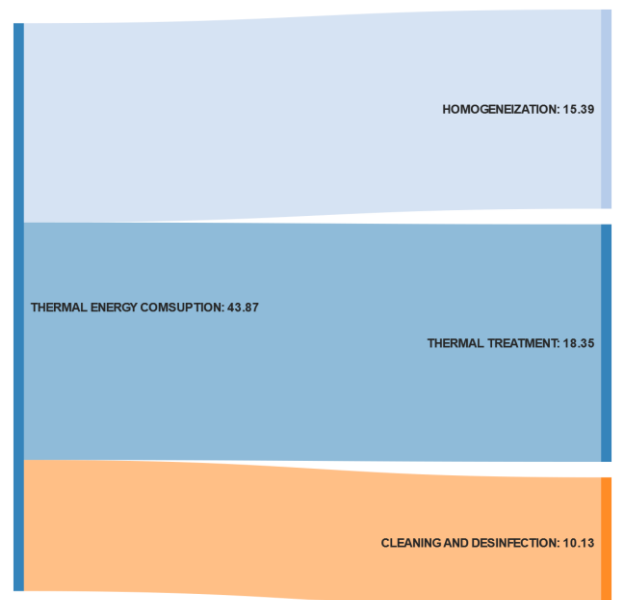


FIGURE 22: SANKEY DIAGRAM. THERMAL ENERGY CONSUMPTION FOR YOGURT PRODUCTION LINE. AVERAGE SCENARIO

### Semi Skimmed Milk Production Line

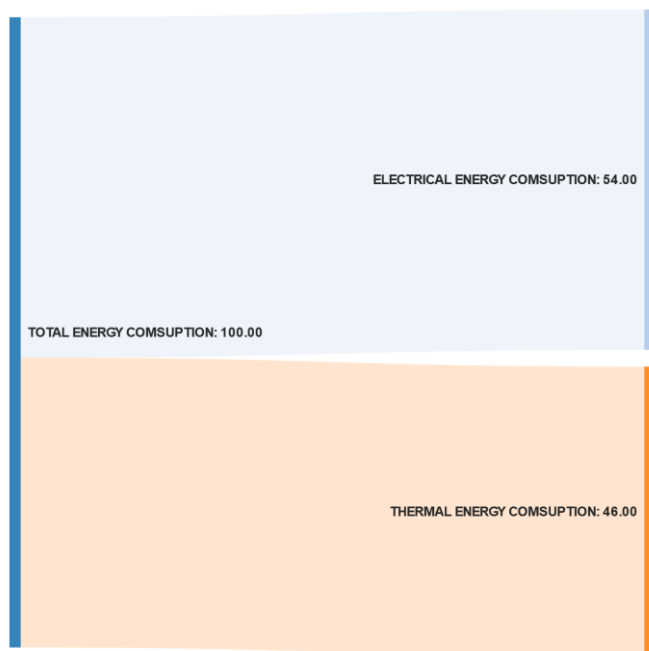


FIGURE 23: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR SEMI SKIMMED PRODUCTION LINE. AVERAGE SCENARIO

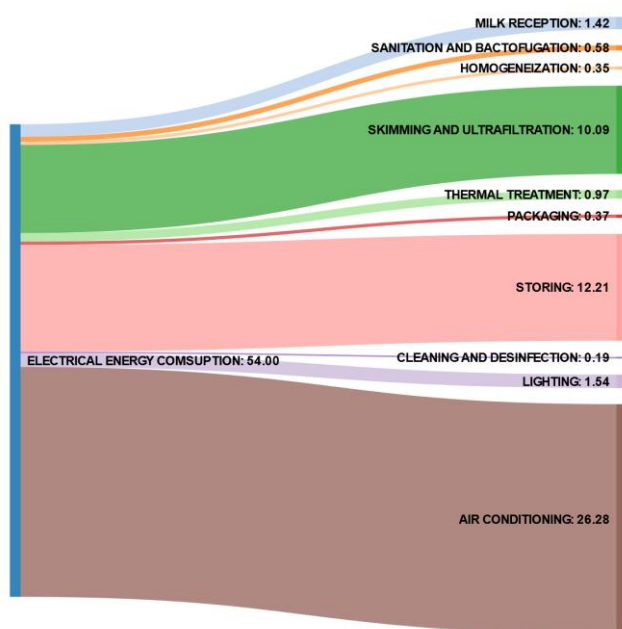


FIGURE 25: SANKEY DIAGRAM. ELECTRICAL ENERGY CONSUMPTION. SEMI SKIMMED MILK PRODUCTION LINE. AVERAGE SCENARIO

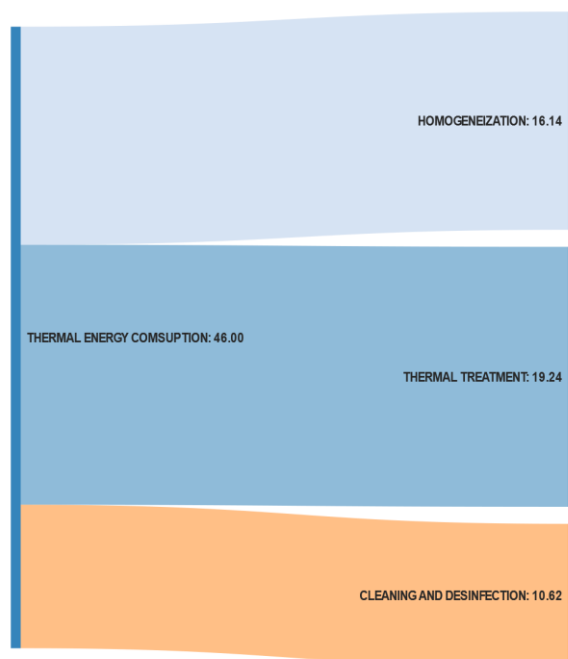


FIGURE 24: SANKEY DIAGRAM. THERMAL ENERGY CONSUMPTION. SEMI SKIMMED MILK PRODUCTION LINE. AVERAGE SCENARIO



## 2.5 Identification of the key points for setting up the baselines in electric and thermal processes

From the Sankey Diagrams, we can conclude that in skimmed milk production some processes where it is especially important to have KPIs to be used as benchmarks or baselines are the following ones:

- 🌀 Thermal treatment for pasteurization
- 🌀 Homogenization
- 🌀 Storing
- 🌀 Cleaning and disinfection
- 🌀 Skimming

Because, in the dairy industry, storing is usually carried out under refrigerated conditions, reducing unnecessary inventories is very important for improving energy efficiency. Energy consumption for storing has been overestimated in the calculations carried out for the virtual plant, since no assumptions have been introduced for taking into account that automated systems for temperature control will reduce energy consumption with respect to estimating energy consumption as installed power multiplied by twenty four hours (in the case of the optimistic scenario) or by twenty four hours and by 0.75 (in the case of the “average” scenario). 0.75 is used as a very simple adjustment factor for taking into account that the inventory inside the refrigerated chamber for the “average” scenario is half of the one for the optimistic scenario.

Air conditioning for cooling and heating could be a large component of total energy consumption in a dairy industry, particularly when the production areas has to be kept refrigerated at a certain temperature. In this case, we have applied a simplified methodology for maintaining a temperature of 21° C in a plant with a known dimensions (length, width, and height), with an isolation condition considered to be good, and for an average increase or decrease of temperature estimated by having into account the average maximum temperatures and the average minimum temperatures in the location where the virtual plant was planned to be built. More refined methodologies could be made for calculating the energy consumption of the compact air conditioning equipment. In any case, the methodology applied for estimating energy consumption for air conditioning will also result in its overestimation, but it has been considered admissible for a first approximation.

## 2.6 Possible inefficiencies in the performance of the processes

Inefficiencies in the performance of the processes could be due both to the operational performance and to the technical performance of equipment used for carrying out the different processes. In this first modelling of a virtual plant, we have only considered two operational performance scenarios for evaluating the impact of the operational performance improvements on energy efficiency. Nevertheless, the same approach could be used for evaluating the impact of technical performance improvements by substituting some equipment in virtual production lines by a more energy-efficient equipment, that consume less energy for getting the same throughput.



It is also important to understand that the approach adopted does not allow substituting a equipment in a virtual production line for another equipment with a greater maximum production capacity or greater reliability without doing the same with the other work stations in the production line. If we do not upgrade the whole production line, we will have some “bottlenecks” in the production line that will restrict the effective capacity of the production line to the effective capacity of the work station with the lowest one. This is just a basic application of the Theory of Restrictions, which establishes that “the output of the entire process is defined by the output of its weakest link” (Ernst & Young Global Limited, 2013).

When analyzing the operational performance of a particular production process in a virtual production line, it is not possible to identify where the bottleneck is. However, in a real production plant, if actual data of the average effective throughputs for each work station in a production line are available, the bottleneck for this production line could be easily identified. Lean methodologies & tools could be applied to eliminate the bottleneck or maximize their exploitation (Ernst & Young Global Limited, 2013). For the benchmarking activities to be carried out in the SCOoPE project, it could be advisable to conduct a “bottleneck” identification always that effective throughput data are available for each work station in a production line. The operational performance constraint linked to a “bottleneck” has also an impact on the energy efficiency for the product or family of products being produced in a particular production line.

It is also important to try to understand the links existing between preventive maintenance programmes and unscheduled downtime, because breakdowns and time to repair them could be important components of the unscheduled downtime. More time for preventive maintenance could contribute to reduce unscheduled downtime because of breakdowns.

Cleaning time is a restriction that cannot be eliminated in the food industry because it is a very important prerequisite for food safety. Despite CIP systems are widely used, cleaning time could also be reduced by applying good operational practices.

### 3. Cured Cheese

For designing a production line for a virtual factory, we have used as a reference an engineering project for a new factory producing cow milk cured cheese (Marín, 2012). This Engineering Degree Final Project include all the technical calculation for the construction and the operation of a plant designed for producing daily 900 kilograms of cured cheese in wedges of 250 grams each one. For the design of the production line, no assumptions on operational performance were considered because the production overcapacity of the plant should allow to cope with unscheduled downtimes.

The approach used for modeling the operational performance and the energy consumption of the virtual plant was based on assuming two operations scenarios for the Uptime or OEE (Overall Equipment Efficiency) of the production lines. For a daily working time of 24 hours, 7 days per week, once we have set up two “reasonable” operational scenarios, the “average” one and the “optimistic” one. On the basis of the



operational assumptions we will make below for each scenario, the daily uptime can be calculated for each scenario and the daily expected productions of cured cheese can be estimated. Then the daily energy consumptions associated with the production line, with each production process and with each workstation or equipment unit can also be calculated for each scenario. From these data, it is also possible to develop the Current Value Stream Map and the Sankey Diagrams for each scenario. Because, in this type of engineering project, not only the energy installed for each machine or equipment in the production lines is established but also the energy installed that is required for other auxiliary equipment as refrigerated chambers as well as the energy required for lighting and for heating and air conditioning has to be calculated, it is also possible to estimate the energy consumption for the whole plant. From the expected daily outputs of final products and the expected energy consumptions for production lines and for the plant as a whole, it is possible to estimate different measures of energy utilization or energy efficiency for each scenario.

For developing the Current Value Stream Map for each scenario, we have adopted the following operational assumptions:

- ⌚ DAILY WORKING TIME: 24 hours (3 shifts of 8 hours), 7 days per week
- ⌚ RELIABILITY: A 0.95 (95 %) value is assumed.
- ⌚ PRODUCTION CAPACITY FOR WORK STATIONS: It will be assumed that the production capacity when the equipment is up and running will be equal to the adjusted maximum capacity (maximum capacity multiplied by reliability). The machine cycle time will be the adjusted minimum cycle time (the minimum cycle time divided by reliability)
- ⌚ ESTIMATION OF CHANGEOVER TIME: 15 minutes (optimistic) or 60 minutes (average)
- ⌚ ESTIMATION OF CLEANING AND DESINFECTION (AT THE END OF DAY): 2 hours (optimistic) or 4 hours (average)
- ⌚ ESTIMATION OF PREVENTIVE MAINTENANCE TIME PER DAY: 30 minutes (optimistic) or 60 minutes (average). We are assigning a preventive maintenance time per day when, in a real setting, the total weekly preventive maintenance time could be concentrated and scheduled for a particular day of the week
- ⌚ ESTIMATION OF LINE DOWNTIME PER DAY: 1 hour (optimistic) and 4 hours (average)
- ⌚ ESTIMATION OF PORCENTAGE OF DEFECTS (AT THE END OF THE PRODUCTION LINE): 1% (optimistic) and 5% (average)

### 3.1 Processes description and equipment

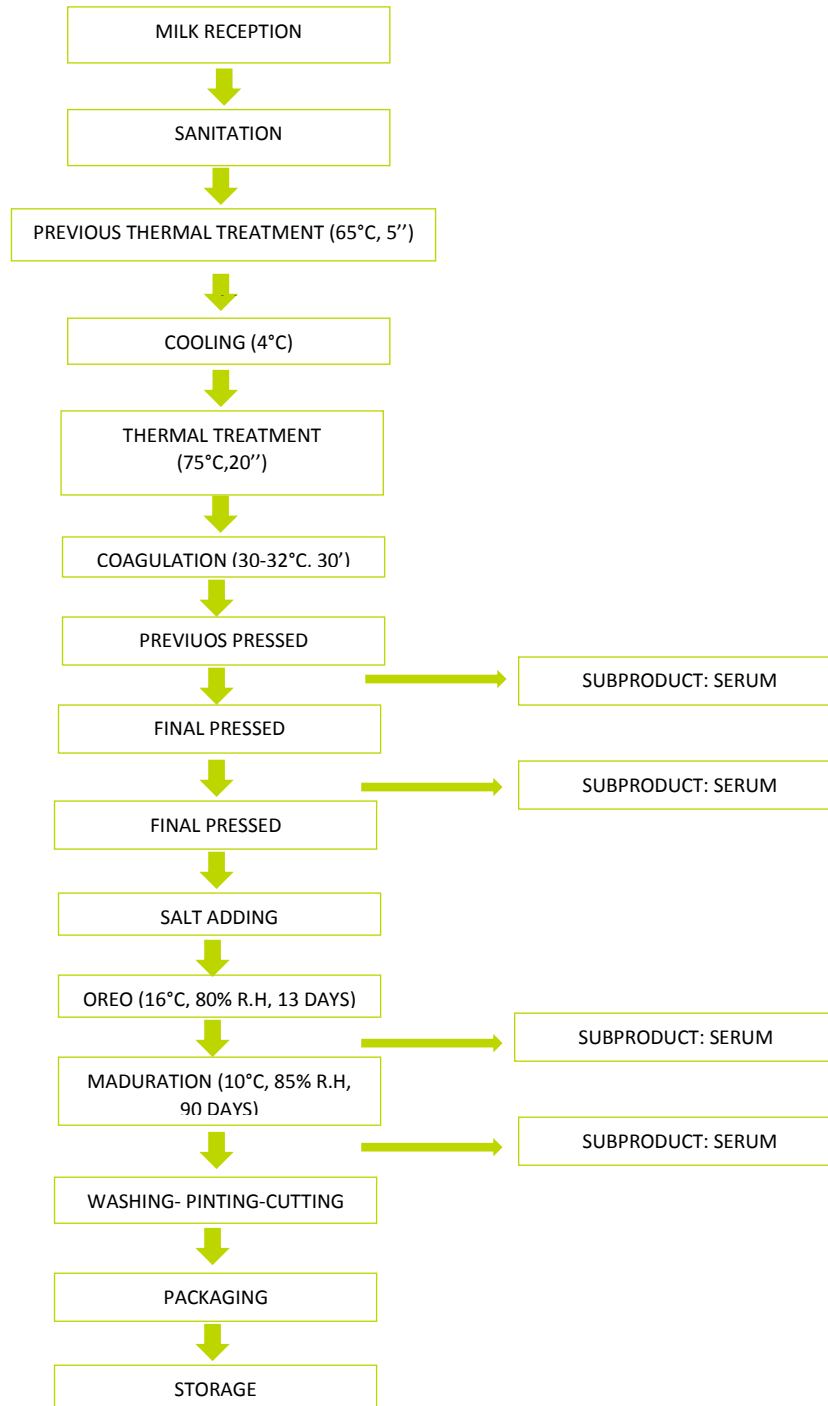


FIGURE 11: FLOW DIAGRAM FOR CURED CHEESE INDUSTRY

## Milk Reception

The milk is transported from the farm or from the collection center to the industry by trucks with isotherm tanks. Milk has to be cooled underneath + 4 ° C and keeping the same temperature until its arrival to the industry. After its reception, milk will be discharged into the receiving silos located at the reception room after carrying out a rapid analysis of some key physicochemical, sanitary and microbiological parameters used to decide whether the track load is accepted or rejected.



FIGURE 27: RECEIVING TANK SILO

Source: Equiproin Catalogue, available in: <http://www.equiproin.pt/en/products/stainless-steel-isothermal-tanks>

### Technical Characteristics

#### Isothermal storage tank

Namely Capacity	10000 litros
Installed Power	1,28 KW

### Technical Charateristics

#### Flow meter

Namely Capacity	10000-60000 l /h
Installed Power	4,20 KW

## Sanitation

This process involves two steps, the first one consist in the application of forces (centrifugal or gravitational) for the removal of organic and inorganic particles, agglomerates of protein and other dirt particles. It will be hold in a milk centrifuge clarifier to reduce times.

The final steps of this phase named bactofugation, consist in applying centrifugal forces of greater intensity in order to eliminate unwanted microorganisms present in milk. Fortunately, some of the microorganisms that are more resistant to heat treatment are also the heavier ones, and therefore the easiest ones to be removed by centrifugation.

#### Technical Characteristics

Namely Capacity	60000 - 80000 l/h
Installed Power	8 kW

#### Previous Thermal Treatment

This process is necessary to avoid proteins and minerals are damaged affecting the quality of cheese. Consists in the heating of the milk to 65° C by 15 seconds through an heat exchanger for its later reduction of temperature until them 4 ° C

#### Technical Characteristics

Namely Capacity	3000-20000 litros/h
Installed Power	10.40 KW

#### Storing

Storing is the process that immediately follows the pasteurisation. Milk is cooled to shield it from the area of thermal hazard and therefore it needs to be refrigerated at temperatures considerably lower than the ones reached in the heating. In this case, temperatures less than or equal to 4 ° C are reached, increasing in this way the ability to preserve the product.



FIGURE 12: ISOTHERMAL TANK

The storing will be performed in an isothermal tank.

#### Technical Characteristics

Namely Capacity	10000 litros/h
Installed Power	1.20 KW

## Thermal Treatment

A pasteurization treatment is used to reduce the levels of pathogenic microorganisms in milk to obtain a product that not represented any risk for the consumer. The sporulated pathogens more thermoresistents, *Coxiella burnetti* and *Mycobacterium tuberculosis*, are also destroyed in the pasteurization. The treatment consists to apply and high temperature for short time (75 °C, 20 sec).



FIGURE 29: PASTEURIZER- HEAT EXCHANGER

Source: INMASA Ingeniería y Maquinaria para la Alimentación SA, available in: <http://www.inmasa.com/esp/bescanviadors.html>

### **Technical Charateristics**

Namely Capacity	3000-20000 litros/h
Installed Power	10.40 KW

## Curding Vat Filling

Milk from pasteurizer cooled at 32°C will be pumped into the curding vat. During its filling, operators will proceed to the addition of lactic ferments in such a way that there is a good distribution in the vat. The lactic ferments to be used are *Lactococcus lactis* and *Lactococcus lactis cremoris* and will add at 30°C a dose of 0.01 g per liter of milk treated.

The phenomenon of coagulation consists of the flocculation of the casein micelles which join together to form a compact gel that imprison the dispersion liquid known as whey. For producing the gel formation, it is necessary to add an aqueous solution of curd at 32 °C and to shake for 5 minutes constantly for mix uniformly. The time of curding vat filling process is 30 min.



FIGURE 13: COAGULATION TANK

Source: Grupo ACER Catalogue, available:

[HTTP://WWW.GRUPACER.COM/TIENDA/TAXONOMY/TERM/669/0?PAGE=5](http://www.grupacer.com/tienda/taxonomy/term/669/0?page=5)

#### Technical Characteristics

Namely Capacity	10000 litros/h
Installed Power	6.0 KW

#### Previous Pressing and Molding

After the removal of the whey from the curdling vat, the curd is pumped through a paste impulsion pump to the draining and guillotine. The previous pressing of the curd is performed for squeezing some additional whey. The guillotine is used for cutting the curd in blocks through a system of blades adjustable to different dimensions depending on the format.

#### Technical Characteristics

##### Paste impulsion pump

Namely Capacity	80,000 L / h
Installed Power	2 kW

#### Technical Characteristics

##### Previous pressing, draining and guillotine

Namely Capacity	9,000 kg/ cycle
Installed Power	6.30 kW

#### Final Pressing

Once the curd is placed in molds, it is necessary a final pressing for forcing to the loose particles of the curd to adopt a shape sufficiently compact for handling it and squeezing the remaining whey. At the end of this process, the surface of the cheese must be closed, smooth and without cracks or fissures that favor the penetration of molds. Finally, the cheese will be unmolded.



FIGURE 14: PNEUMATIC PRESS

Source: <http://www.agro2607.com/lire-une-actu/items/idec-lutte-contre-les-tms.html>

#### Technical Characteristics

##### Neumatic press

Namely Capacity	4,200 cheeses
Installed Power	18.40 KW

#### Technical Characteristics

##### Unmolder

Namely Capacity	4,000 molds / h
Installed Power	9.10 KW

### Salt Adding

The pressed cheeses are loaded in special container called baskets and are immersed in brine (water with a 20-24 % of salt) at 12-14 °C. Cheeses should be kept in the baskets during the immersion for ensuring a maximum contact of the brine with the surface of the cheese and for using brine circulation to promote a more uniform salt uptake and distribution.



FIGURE 15: SALT ADDING PICTURE

### Technical Characteristics

#### Salting tub

Namely Capacity	4,500 kg
Installed Power	7.30 kW

### Technical Characteristics

#### Transporting to airing chamber

Namely Capacity	9,600 cheeses / h
Installed Power	2.60 kW

### Airing

The goal of this process is reducing cheese humidity. The conditions of the airing chamber are 16° C and 80% relative humidity. Cheeses should be rotated to get a uniform drying. The stay time in the airing chamber is 13 days and then cheeses are transferred to the maturation chamber.

### Technical Characteristics

#### Airing chamber

Namely Capacity	11,700 KG
Installed Power	2.80 kW

### Maturation

During the maturation period, the cheese will continue losing humidity. The maturation lasts around 90 days, the conditions at the maturation chamber are 10° C and 85% relative humidity. The loss of humidity produces an increase of the proportion of the dry extract.



FIGURE 16: MATURATION CHAMBER

Source: [HTTP://WWW.C3-BOVES.IT/SPAGNOLO/FORMAGGI.HTML](http://www.c3-boves.it/spagnoLO/formaggi.html)



#### Technical Characteristics

Namely Capacity	81,000 kg
Installed Power	13.62 kW

#### Washing – Brushing – Cutting - Painting

Once the cheese has matured will be led to the area of conditioning where will be washed, brushed, painted and finally cutted in wedges of 250 g.

#### Technical Characteristics

##### Washing - brushing

Namely Capacity	5,000 cheeses / h
Installed Power	2.60 KW

#### Technical Characteristics

##### Cutting

Namely Capacity	6,000 Cheese/h
Installed Power	3.60 KW

#### Technical Characteristics

##### Painting

Namely Capacity	16,000 units / h
Installed Power	2.60 KW

#### Packaging

The wedges will be vacuum packed in their respective containers. Then will be labelled and placed in cardboard boxes to be palletized.

#### Technical Characteristics

Namely Capacity	160000 unid/h
Installed Power	12.50 KW

#### Storing

Products will remain in the refrigerated storage chamber until they withdraw for sale and distribution Temperature: Not more 5 ° C and 5% of humidity.



FIGURE 17: REFRIGERATED CHAMBER FOR STORING

Source: Frigopack Catalogue, available in:  
<http://www.frigopack.com/Seccion~x~Camaras-frigorificas~IDSeccionArticulo~286.html>

#### Technical Characteristics

Namely Capacity	100,800 kg
Installed Power	7.82 kW

#### Centrifugal Pump

Stainless steel centrifugal pumps, which can be entirely dissembled for cleaning, will be used for transporting milk from a stage to the next one. Pumps will have an electronic speed control that allows a flow of constant milk.

#### Technical Characteristics

Namely Capacity	120,000 liters / h
Installed Power	2 kW

### 3.2 Overview list of the processes and equipment

PROCESS	EQUIPMENT	ELECTRICAL AND/OR THERMAL	ENERGY SOURCE
MILK RECEPTION	ISOTHERMAL STORAGE TANK	ELECTRICAL	ELECTRICITY
	FLOW METER	ELECTRICAL	ELECTRICITY
	CENTRIFUGAL PUMP	ELECTRICAL	ELECTRICITY
	ISOTHERMAL STORAGE TANK	ELECTRICAL	ELECTRICITY
SANITATION	SANITATION	ELECTRICAL	ELECTRICITY
	CENTRIFUGAL PUMP	ELECTRICAL	ELECTRICITY

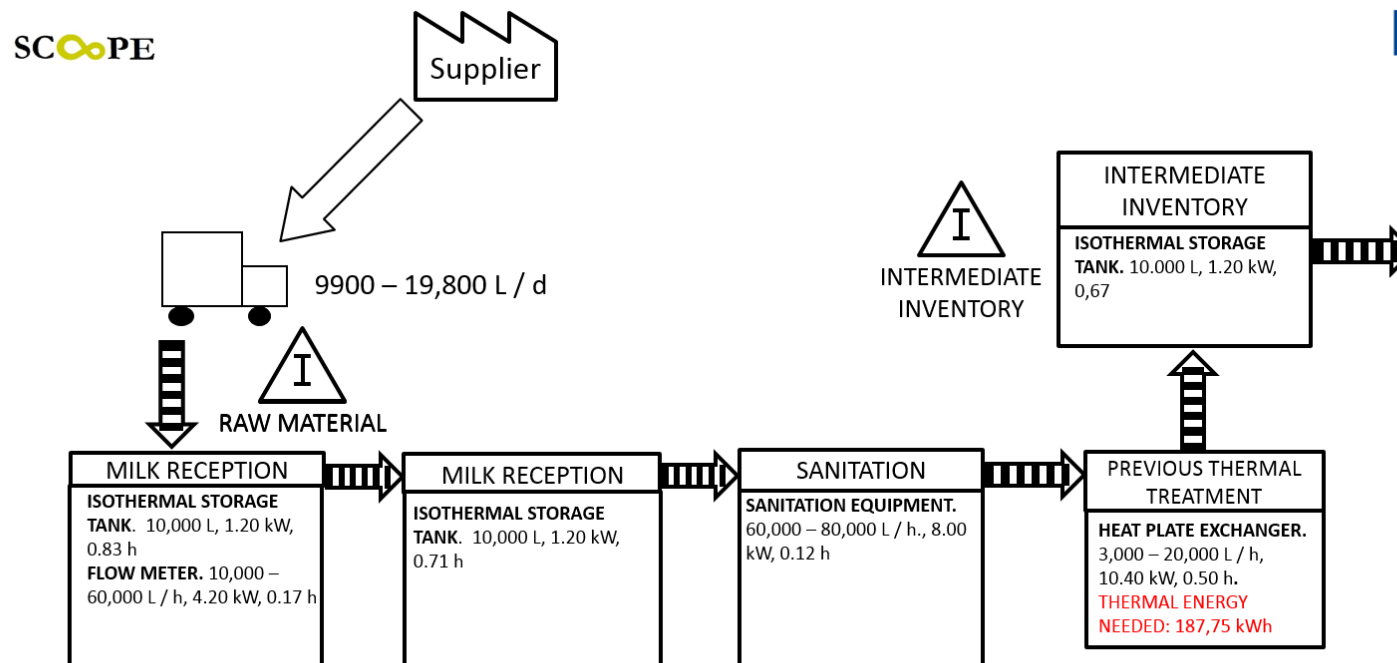
PREVIOUS THERMAL TREATMENT	HEAT PLATE EXCHANGER	ELECTRICAL/ THERMAL	GAS/ ELECTRICITY
	CENTRIFUGAL PUMP	ELECTRICAL	ELECTRICITY
STORING	ISOTHERMAL TANK	ELECTRICAL	ELECTRICITY
	CENTRIFUGAL PUMP	ELECTRICAL	ELECTRICITY
THERMAL TREATMENT	PASTEURIZER	ELECTRICAL/ THERMAL	GAS/ ELECTRICITY
	CENTRIFUGAL PUMP	ELECTRICAL	ELECTRICITY
CURDING VAT FILLING		ELECTRICAL /	GAS / ELECTRICITY
	CURDING VAT	THERMAL	
ADDING INGREDIENTS		ELECTRICAL /	GAS / ELECTRICITY
	CURDING VAT	THERMAL	
CURDING, CUTTING AND WHEY DRAINING	CURDING VAT	ELECTRICAL /	GAS / ELECTRICITY
	CENTRIFUGAL PUMP (WHEY)	THERMAL	
PREVIOUS PRESSING AND MOLDING		ELECTRICAL	ELECTRICITY
	PASTE IMPULSION PUMP		
	PREVIOUS PRESSING, DRAINING AND GUILLOTINE	ELECTRICAL	ELECTRICITY
	CENTRIFUGAL PUMP (WHEY)	ELECTRICAL	ELECTRICITY
FINAL PRESSING AND UNMOLDING	NEUMATIC PRESS	ELECTRICAL	ELECTRICITY
	UNMOLDER	ELECTRICAL	ELECTRICITY
SALT ADDING	SALTING TUB	ELECTRICAL	ELECTRICITY
	PIMARICIN TREATMENT	ELECTRICAL	ELECTRICITY
	TRANSPORTING TO AIRING CHAMBER	ELECTRICAL	ELECTRICITY
AIRING	AIRING CHAMBER	ELECTRICAL	ELECTRICITY
MADURATION	MADURATION CHAMBER	ELECTRICAL	ELECTRICITY
WASHING-BRUSHING-PAINTING	WASHING-BRUSHING	ELECTRICAL	ELECTRICITY
	PAINTING	ELECTRICAL	ELECTRICITY
CUTTING	CUTTING MACHINE	ELECTRICAL	ELECTRICITY
PACKAGING AND LABELLING	PACKAGER - LABELLER	ELECTRICAL	ELECTRICITY
WHEY STORAGE	WHEY TANK	ELECTRICAL	ELECTRICITY
CLEANING AND	CIP EQUIPMENT: 3 CLEANING SOLUTION	ELECTRICAL /	GAS/ ELECTRICITY

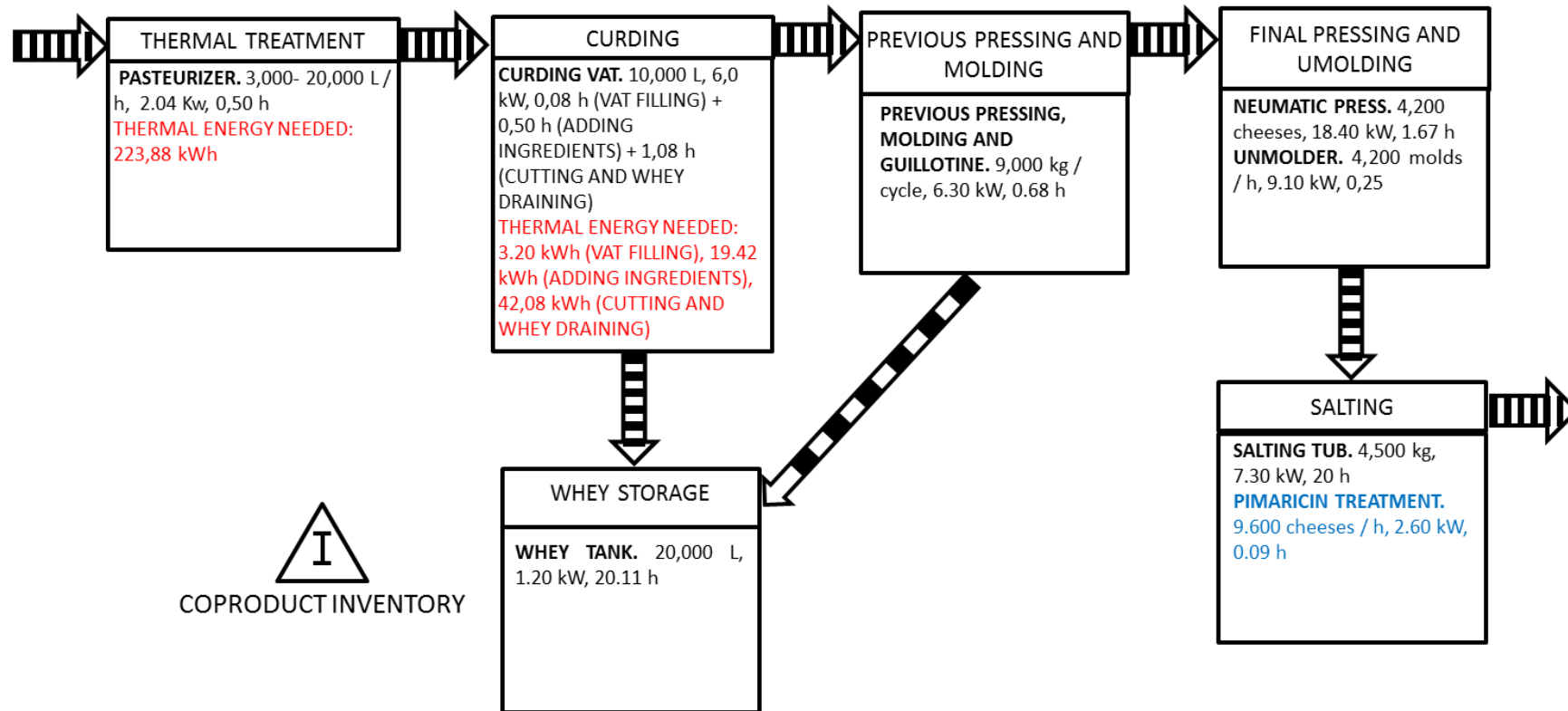


DESINFECTION.	TANKS	THERMAL	
MOLD WASHING	MOLD WASHING	ELECTRICAL / THERMAL	GAS / ELECTRICITY
FINAL PRODUCT STORAGE	REFRIGERATED CHAMBER	ELECTRICAL	ELECTRICITY
INGREDIENTS STORAGE	REFRIGERATED CHAMBER	ELECTRICAL	ELECTRICITY



### 3.3 Current Value Stream Mapping





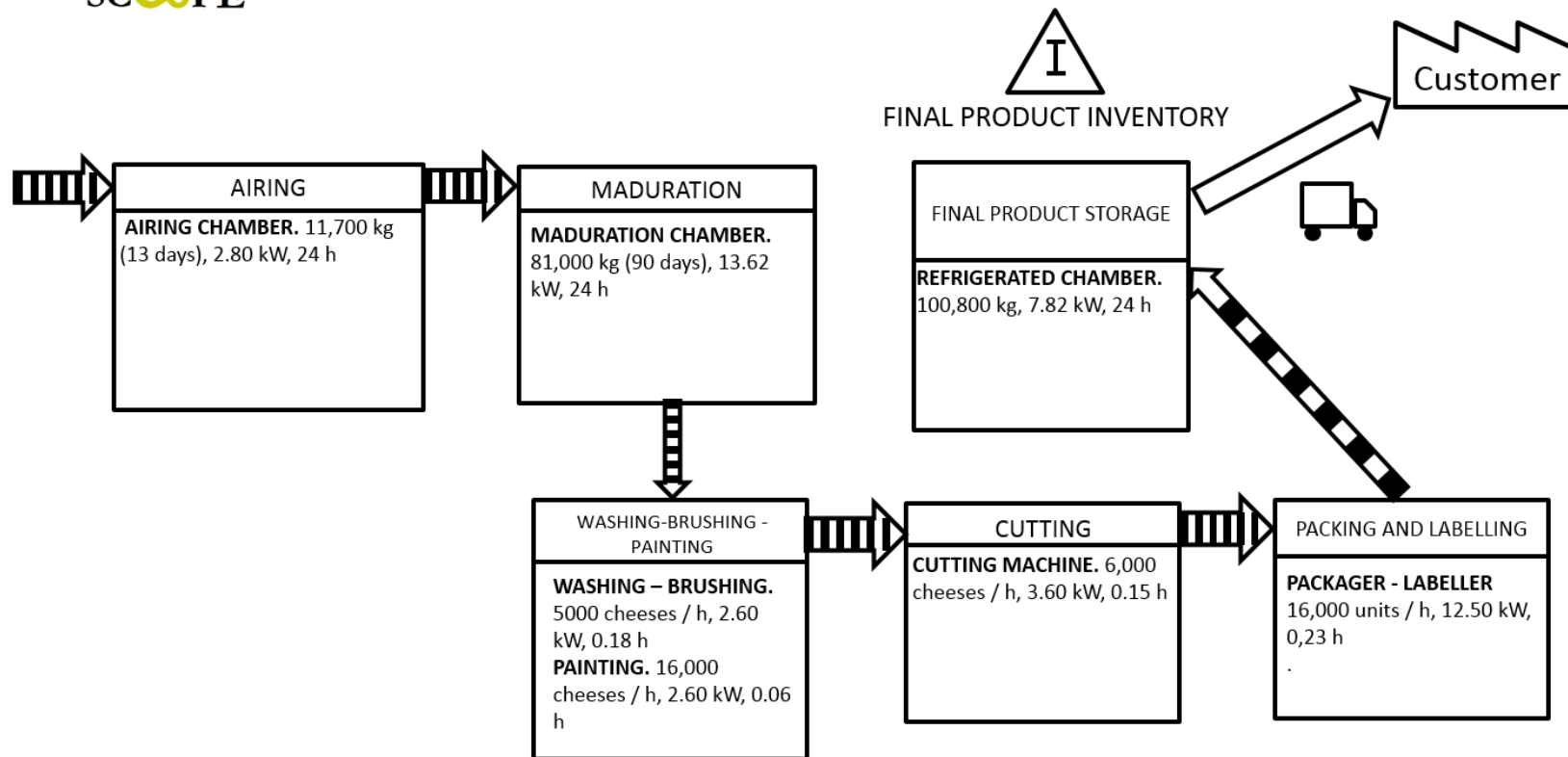


FIGURE 35: CURRENT VALUE STREAM MAPPING FOR CURED CHEESE INDUSTRY



By using as a reference an engineering project for a new factory producing cured cheese, a virtual production line has been designed. For two operational scenarios, it has been estimated the time available for production and how many batches of 900 cheeses could be produced per day.

In an Excel file has been calculated the productions and the energy consumptions for each scenario, the average one and the optimistic one. In the average operational scenario, it was possible to produce only a batch of 900 cheeses while, in the optimistic operational scenario, it was possible to produce two batches of 900 cheeses. This improvement in the operational performance of the plant has a significant impact in the energy efficiency for the final products elaborated in the virtual production plant. These are the results obtained for the energy efficiency estimates:

DAY PRODUCTION (OPTIMISTIC SCENARIO)								
	PRODUCTION	DEFECTS (1%)	REAL PRODUCTION (KG)	TOTAL DAILY ENERGY CONSUMPTION	ENERGY EFFICIENCY (KWH PER KG)	TOTAL DAILY ENERGY CONSUMPTION (GJ)	ENERGY EFFICIENCY (GJ PER t)	ENERGY EFFICIENCY IMPROVEMENT (%)
CHEESSE (KG)	1,800	18	1,782	5,034.75	2,83	18.13	10.17	23.02%

DAY PRODUCTION (AVERAGE SCENARIO)							
	PRODUCTION	DEFECTS (5%)	REAL PRODUCTION (KG/L)	TOTAL DAILY ENERGY CONSUMPTION	ENERGY EFFICIENCY (KG PER KWH)	TOTAL DAILY ENERGY CONSUMPTION (GJ)	ENERGY EFFICIENCY (GJ PER t)
CHEESSE (KG)	900	45	855	3,138.09	3.67	11.30	13.21



The values of energy efficiency or energy utilization in GJ per tonne are relatively higher in the case of average scenario. We have to take into account that the virtual plant produces a cured cheese that requires a stay of 13 days in an airing chamber and a stay of 90 days in a maturation chamber, both consuming large amounts of electrical energy for maintaining temperature and humidity to the specified levels. As we commented above, in recent review (Rad and Lewis, 2014), the following values of energy utilization (GJ / t) were reported:

- Cheese: 3.3 (UNIDO, 2010), 0.21 – 7.2<sup>4</sup> (FDM BREF, 2006), 5.1 (Foster *et al.*, 2006), 0.39 – 0.95 (UNEP Working Group, 2004), 1.4 for Mozzarella production (Bartholomai, 1987).

According to these values, energy utilization values obtained for cheese in the two operational scenarios seem to be relatively high. However, the data for the “optimal” scenario are closer to the maximum value considered in the FDM BREF (2006). Due to the assumptions we are making for calculating the energy consumption by the airing, maturation and storing chambers as well as for air conditioning, we could be overestimating this components of the total daily energy consumption. This could also explain the high values obtained in this first modelling exercise. However, perhaps the more interesting result is the quantification of the impact of a substantial improvement in operational performance in energy efficiency. Despite a 23.02 % improvement could seem very high, experts in developing Lean & Green initiatives in the food industry has also reported high energy efficiency improvement values in a recent seminar celebrated in the Technical University of Madrid (Zokaei, 2016).

The result obtained for the calculations of the value-added energy and the non-value added energy are also very interesting and suggest that there is a relatively high potential for reducing excessive energy consumption, a Green waste, in this industry. It is worth to point out that the energy consumptions of the airing and maturation chambers have been considered as value added energy. The results obtained are the following ones:

#### ENERGY LINE (OPTIMISTIC SCENARIO)

Value adding energy (kwh)	4,227.60
Non-value added energy	807.15
Ratio (value adding energy / total energy)	<b>83.97%</b>

#### ENERGY LINE (AVERAGE SCENARIO)

Value adding eneergy	2,364.82
Non-value added energy	773.28
Ratio	<b>75.36%</b>

<sup>4</sup> The conversion from kWh / kg to GJ / t has been calculated by the authors (Rad and Lewis, 2014)



### 3.4 Sankey diagram

#### Cheese Producing Plant. Optimistic Scenario

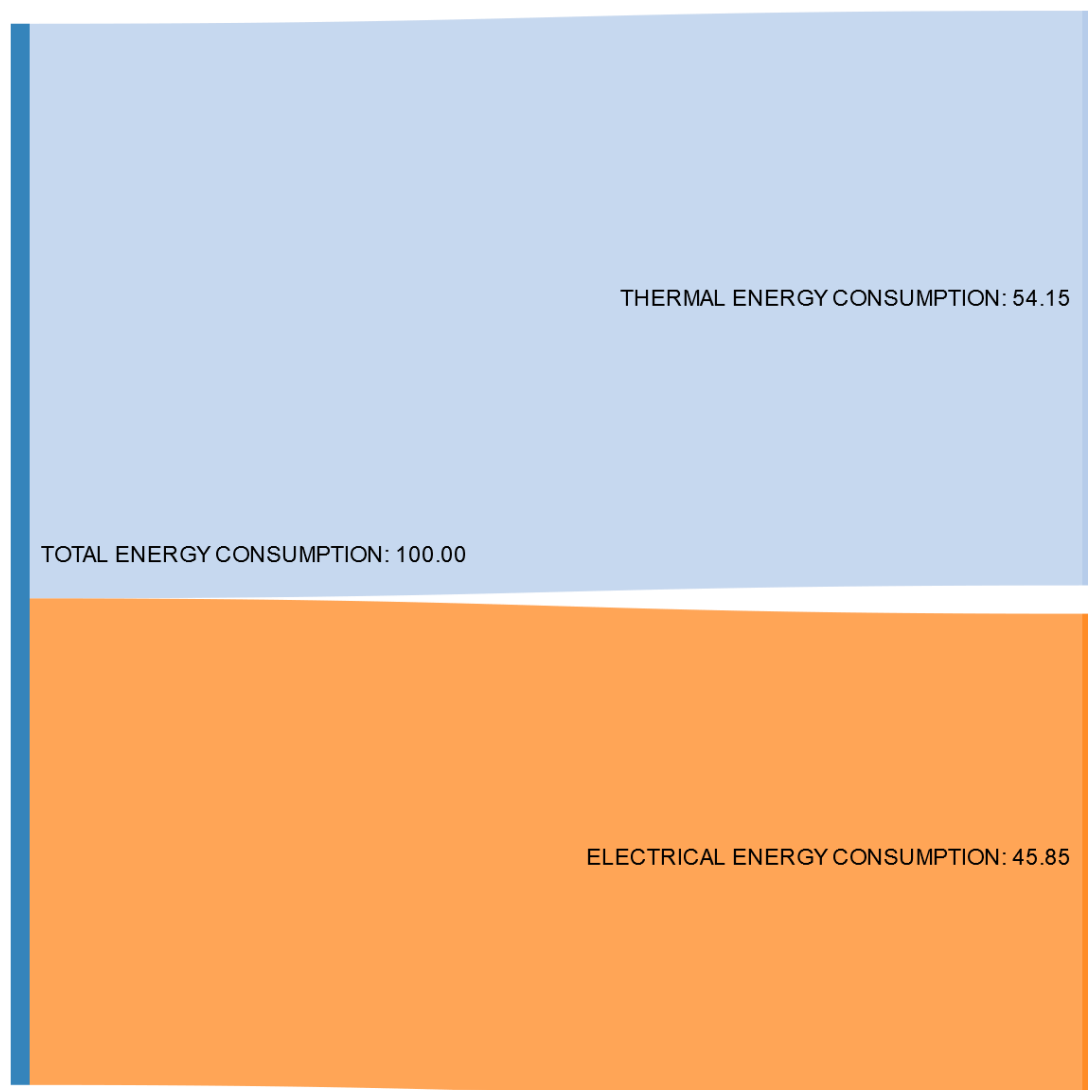


FIGURE 36: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. OPTIMISTIC SCENARIO

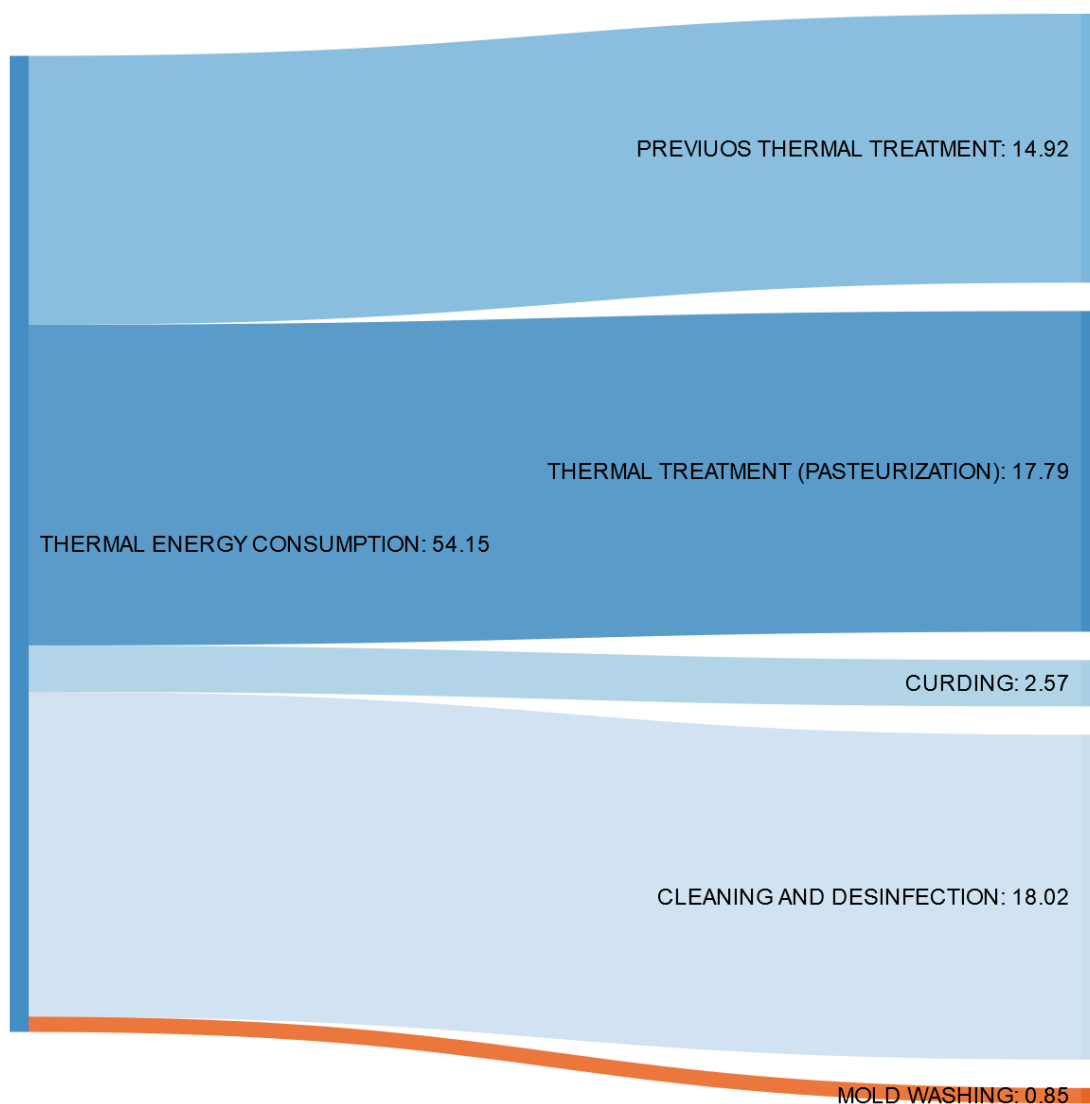


FIGURE 37: SANKEY DIAGRAM THERMAL ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. OPTIMISTIC SCENARIO.

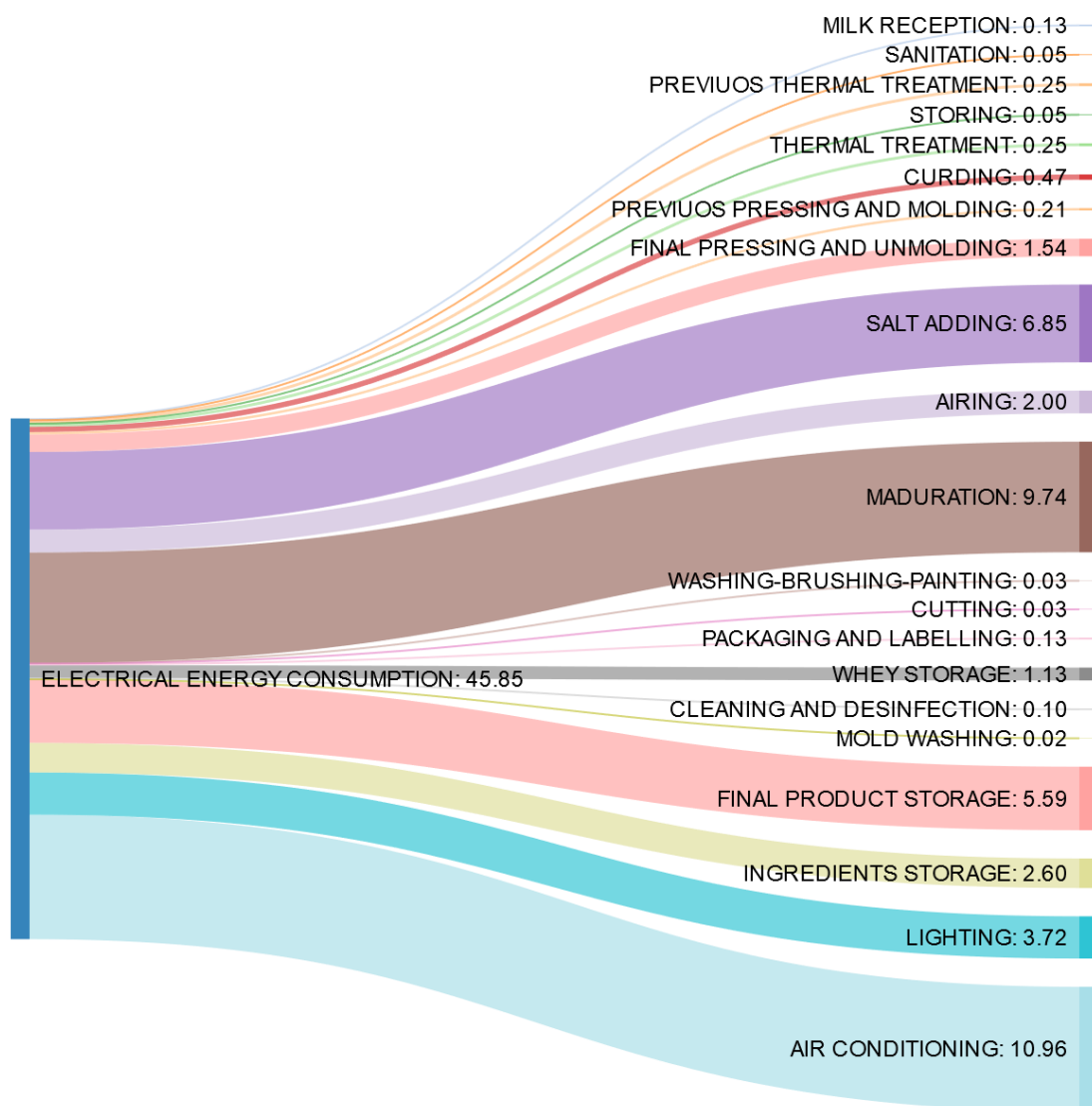


FIGURE 38: SANKEY DIAGRAM ELECTRICAL ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. OPTIMISTIC SCENARIO

## Cheese Producing Plant. Average Scenario

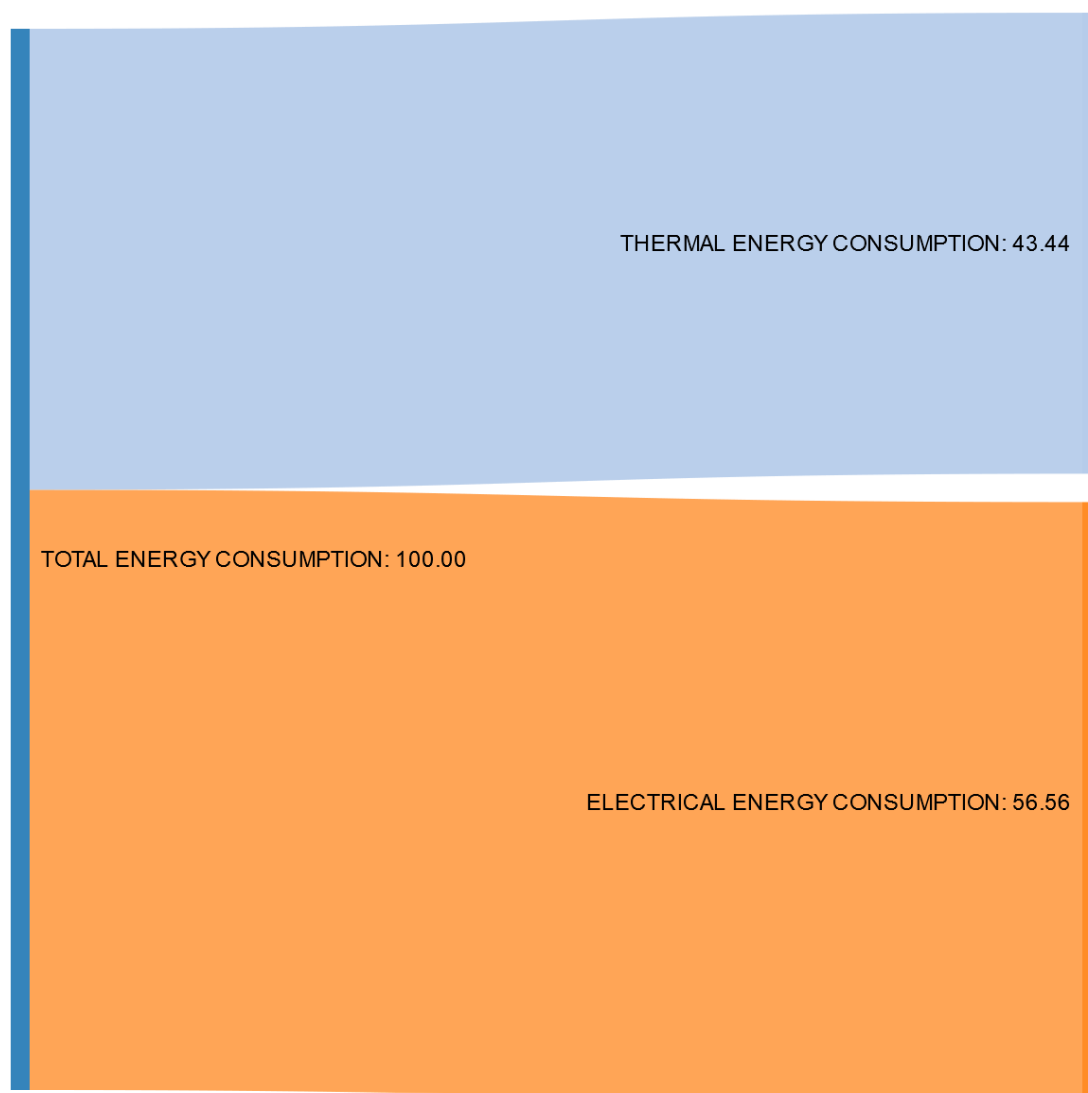


FIGURE 39: SANKEY DIAGRAM. DISTRIBUTION OF TOTAL ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. AVERAGE SCENARIO

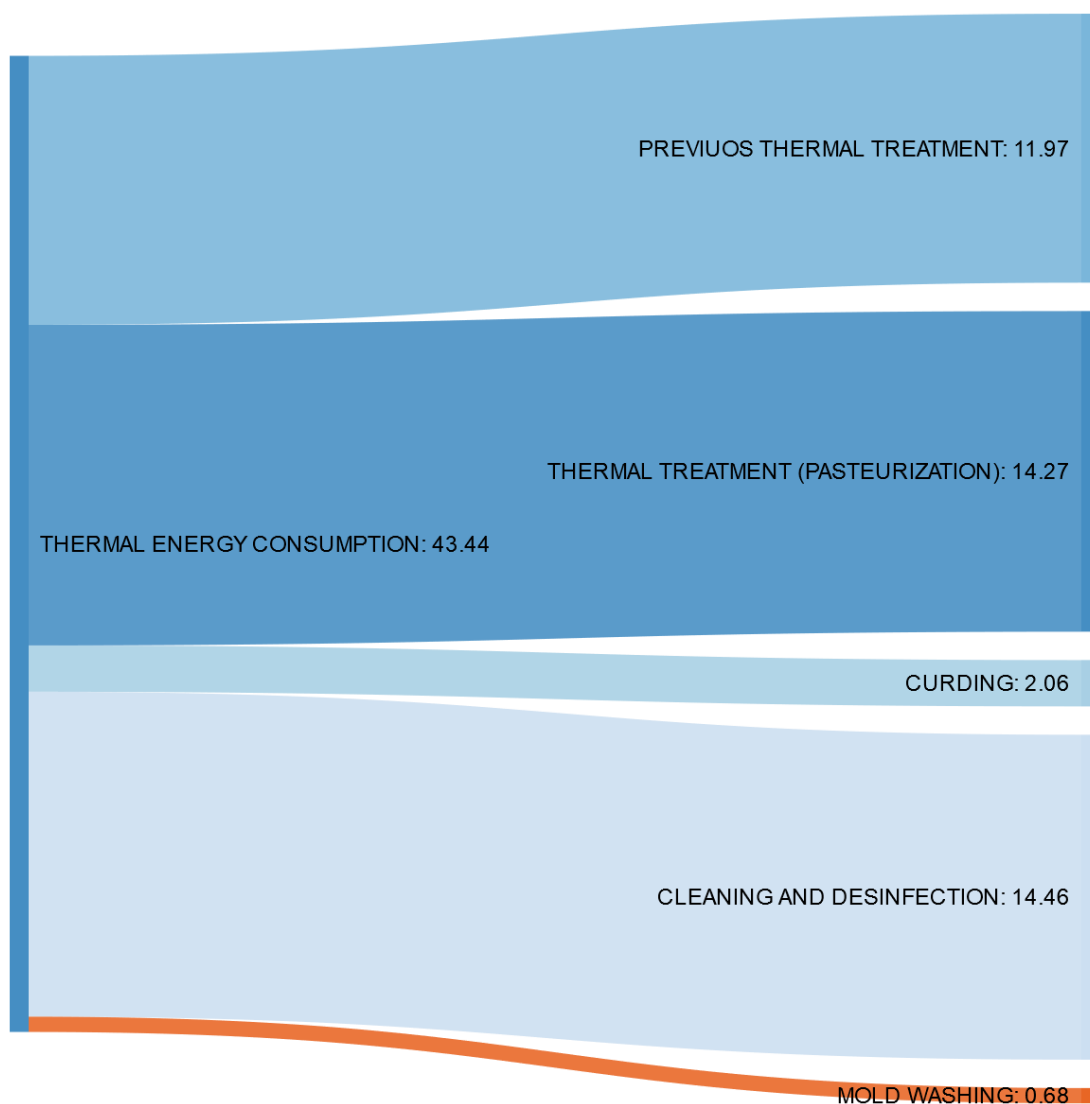


FIGURE 40: SANKEY DIAGRAM THERMAL ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. AVERAGE SCENARIO

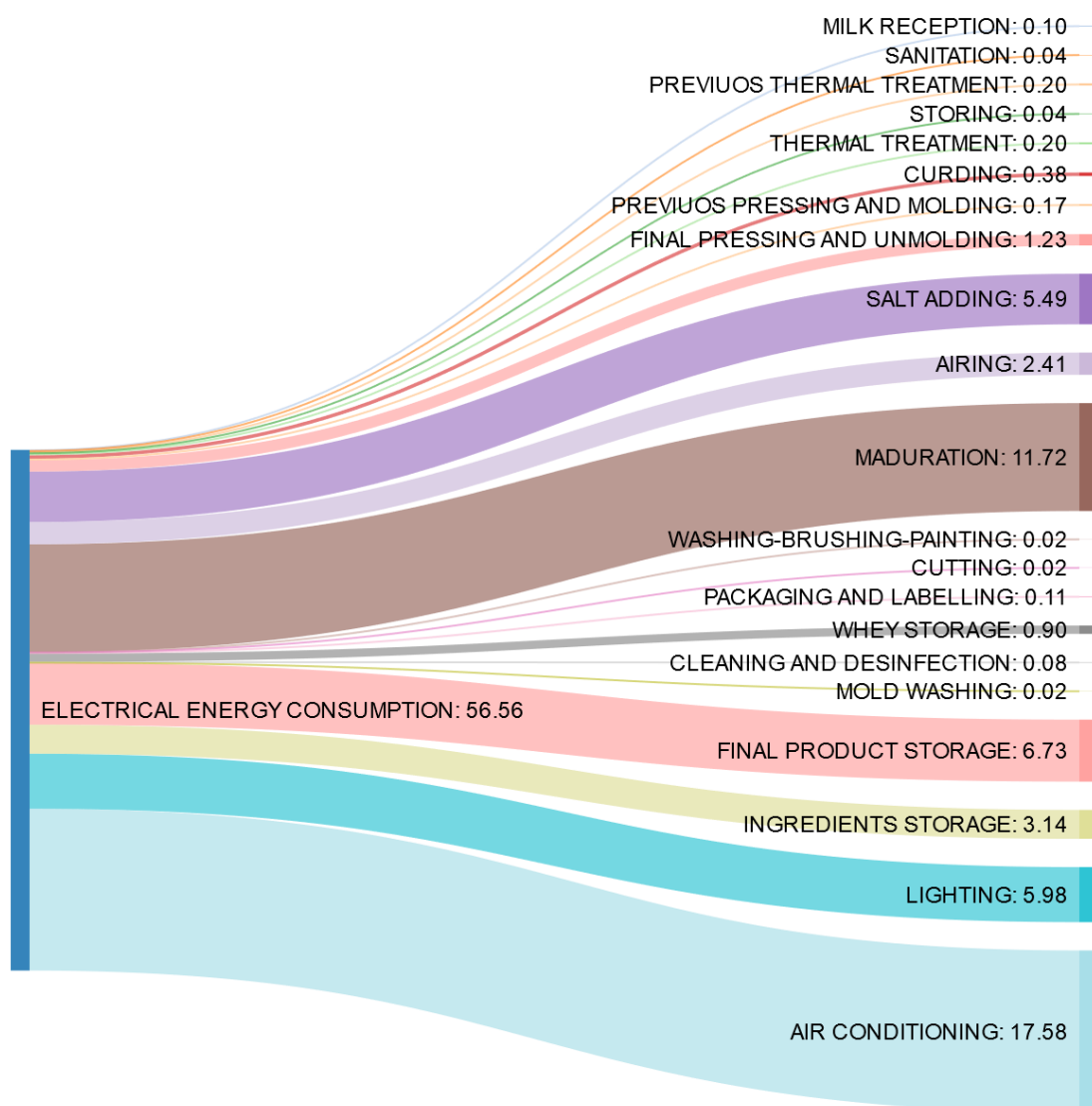









FIGURE 41: SANKEY DIAGRAM ELECTRIC ENERGY CONSUMPTION FOR A CHEESE PRODUCING PLANT. AVERAGE SCENARIO



### 3.5 Identification of the key points for setting up the baselines in electric and thermal processes

From the Sankey Diagrams, we can conclude that in cured cheese production some processes where it is especially important to have KPIs to be used as benchmarks or baselines are the following ones:

-  Cleaning and disinfection
-  Thermal treatment for pasteurization
-  Previous thermal treatment
-  Maturation
-  Final product storage
-  Salting
-  Airing

Because, in the cheese producing industry, airing, maturation and storing is usually carried out under controlled conditions of temperature and humidity, reducing unnecessary inventories as well as reducing airing and maturing periods without affecting cheese quality attributes could significantly contribute to improve energy efficiency. Energy consumptions for airing, maturation, and storing have been overestimated in the calculations carried out for the virtual plant, since no assumptions have been introduced for taking into account that automated systems for temperature and humidity control will reduce energy consumption with respect to estimating energy consumption as installed power multiplied by twenty four hours by 0.75 (in the case of the optimistic scenario) or by twenty four hours and by 0.5625 (in the case of the “average” scenario). 0.75 and 0.5625 are used as very simple adjustment factors for taking into account same energy savings due to the automated control systems as well as that the inventory inside the refrigerated chambers for the “average” scenario is half of the ones for the optimistic scenario.

Air conditioning for cooling and heating could be a large component of total energy consumption in a cheese producing industry, particularly when the production areas has to be kept refrigerated at a certain temperature. In this case, we have applied a simplified methodology for maintaining a temperature of 21° C in a plant with a known dimensions (length, width, and height), with an isolation condition considered to be good, and for an average increase or decrease of temperature estimated by having into account the average maximum temperatures and the average minimum temperatures in the location where the virtual plant was planned to be built. More refined methodologies could be made for calculating the energy consumption of the compact air conditioning equipment. In any case, the methodology applied for estimating energy consumption for air conditioning could also result in its overestimation, but it has been considered admissible for a first approximation.



### 3.6 Possible inefficiencies in the performance of the processes

Inefficiencies in the performance of the processes could be due both to the operational performance and to the technical performance of equipment used for carrying out the different processes. In this first modelling of a virtual plant for cured cheese production, we have only considered two operational performance scenarios for evaluating the impact of the operational performance improvements on energy efficiency. Nevertheless, the same approach could be used for evaluating the impact of technical performance improvements by substituting some equipment in virtual production lines by a more energy-efficient equipment, that consume less energy for getting the same throughput.

It is also important to understand that the approach adopted does not allow substituting an equipment in a virtual production line for another equipment with a greater maximum production capacity or greater reliability without doing the same with the other work stations in the production line. If we do not upgrade the whole production line, we will have some “bottlenecks” in the production line that will restrict the effective capacity of the production line to the effective capacity of the work station with the lowest one. This is just a basic application of the Theory of Restrictions, which establishes that “the output of the entire process is defined by the output of its weakest link” (Ernst & Young Global Limited, 2013).

When analyzing the operational performance of a particular production process in a virtual production line, it is not possible to identify where the bottleneck is. However, in a real production plant, if actual data of the average effective throughputs for each work station in a production line are available, the bottleneck for this production line could be easily identified. Lean methodologies & tools could be applied to eliminate the bottleneck or maximize their exploitation (Ernst & Young Global Limited, 2013). For the benchmarking activities to be carried out in the SCOoPE project, it could be advisable to conduct a “bottleneck” identification always that effective throughput data are available for each work station in a production line. The operational performance constraint linked to a “bottleneck” has also an impact on the energy efficiency for the product or family of products being produced in a particular production line.

It is also important to try to understand the links existing between preventive maintenance programmes and unscheduled downtime, because breakdowns and time to repair them could be important components of the unscheduled downtime. More time for preventive maintenance could contribute to reduce unscheduled downtime because of breakdowns.

Cleaning time is a restriction that cannot be eliminated in the food industry because it is a very important prerequisite for food safety. Despite CIP systems are widely used, cleaning time could also be reduced by applying good operational practices.

In the specific case of cured cheese production, the reliability of some processes could be much lower than 0.95 because some key processes such as curding have a manual component and they hardly can be automated. These processes could easily become a “bottleneck”, despite their weight on the total energy consumption seems to be low. As we have already commented, there are energy efficiency improvement opportunities linked to technological or organizational improvements in the processes of airing, maturation and storing.

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