Faculdade de Engenharia da Universidade do Porto

FEUP

ENERGY AUDIT OF AN INDUSTRIAL PLANT IN PORTUGAL

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"It's not the load that breaks you down, it's the way you carry it"

Lou Holtz

RESUME

This is a Master's dissertation carried out within the scope of the Computational Mechanics Masters Program of the Faculty of Engineering of the University of Porto.In this thesis we will go through the use of energy in a Coating installation in Portugal where our work would be based on the standards of the SGCIE. And the main goal would be to reduce the facility's global energy consumption through the energy rationalization plans that would be proposed based on the analysis carried out on the existent machinery in the installation.

Energy Audit of an Industrial Plant in Portugal

ABSTRACT

In order to reduce energy consumption for industrial plants, continuous energy auditing and process tracking of industrial machines is essential. Compared to other non-residential buildings that have been widely researched, industrial buildings are generally characterized by larger thermal loads, ventilation losses and pollution control requirements.

This report presents an analysis of the use of energy in a Coatings installation here in Portugal made under the standards of the **SGCIE ''Sistema de Gestao dos Consumos Intensivos de Energia''**. with regard to the detection of measures to save and rationalize energy consumption with a view to optimize the manufacturing process, combined with the most effective energy management process possible; and, at the same time, the collection of necessary data to enforce the legislation that applies to it, that will mainly be coming from energy bills and the measures that will be taking straight from the facility itself.

The analysis will be done basing on the measures that will be taken using the required equipments on the facility's machinery such as chillers, boilers, scrubbers etc… also the electric installation where the main objective will be the characterization of the energy sector, both in terms of global and sectoral energy consumption and to look and suggest measurements to be applied on the facility in order to generate added value whether on the economic side (in form of energy cost reduction) or on an environmental side since reaching lower consumption levels will consequently cause reductions in dioxide carbon emissions into the atmosphere.

APPRECIATION

I would like to express my gratitude to the faculty of engineering of Porto FEUP for letting me be part of this Master program where I have been growing ever since I joined this magnificent university. Also I would like to thank Mr Jose Lourenço, Rui Almeida and Thiago Figueiro and all the Colleagues that I've met during my time at EWEN and for the opportunity that I have been offered where I have well grown professionally and developed multiple skills.

I am also thankful for the guidance that I have been receiving from my supervisor throughout this internship. To conclude, I cannot forget to thank my family for the support that I have been receiving ever since I started this **'' without you this could ever be done ''**.

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LISTA OF ABREVIATIONS

IEA	International Energy Agency
UN	United nations
CO2	Carbon dioxide
PNEC	Plano nacional energia e clima
GHG	Greenhouse Gas Emissions
Toe	Tonne of oil equivalent
MT	Média Tensão
SGCIE	Sistema de Gestão dos Consumos Intensivos de Energia
SCE	Sistema de Certificação Energética dos Edifícios
PRE	Plano do rationalização da energia
EI	Energy Intensity
GAV	Gross Added Value
TEC	Total Energy Consumption
SEC	Specific Energy Consumption
TEC	Total Energy Consumption
EC	Energy Consumption not including
R_{FC}	Renewable Fuels Consumption
E_{WC}	Endogenous Waste Consumption
CI	Carbonic Intensity
CO2	Emissions- Greenhouse gas emissions
QGBT	Low Voltage General Boards
NG	Natural gas
GN	Gas Natural
UTA	Unidade de Tratamento da AR, Air Handling Unit
ERP	Energy Rationalization Plan
MRCE	Measures for Rationalization of Energy Consumption
AHU	Air Handling Unit
HR	Relative Humidity

Chapter I

INTRODUCTION

1.1 General Introduction:

Energy is the driving force of our society and the major source for covering the demand worldwide is fossil fuels since they contain high energy they´re easy to find, exploit and transport. The limited reserves and the uneven geographical distribution of this type of resources result in energy dependence on certain countries, a situation that limits the economic competitiveness and that characterizes Portugal. However, since the nineteen sexties huge environmental concerns have been raised about the contribution of fossil fuels in global pollution levels due to the emissions of greenhouse gases to the atmosphere, which is the main driver in climate change, through the enhancement of global warming, which consists of the increase in Earth's global surface temperature. It is estimated that the absence of the greenhouse effect produced by the Earth's atmosphere would make life as we know it impossible. The presence of GHGs in ideal (reduced) concentrations in the atmosphere is therefore essential for a balanced greenhouse effect, that is, for the maintenance of temperature in the Atmosphere-Earth system.

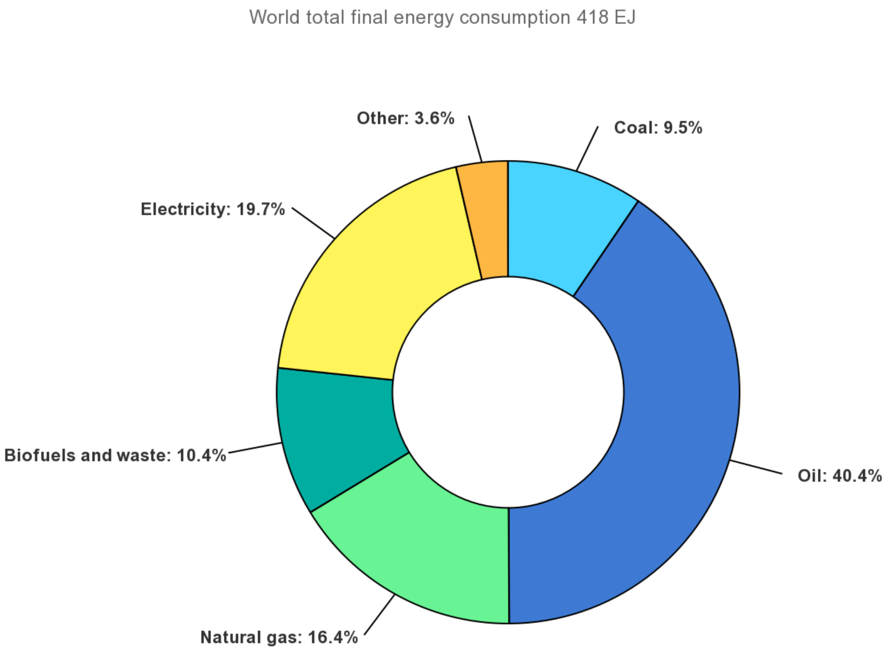


Figure 1: Share of world total final consumption by source, 2019 (IEA 2021)

In order to fight this phenomenon, it was implemented, more recently, on December the 12th, 2015 climate change from the United Nations (UN), the Paris Agreement.

This agreement translates into a plan to combat climate change, which aims to achieve decarbonisation of world economies and establishes as one of its long-term goals to limit the rise in global average temperature to levels well below 2°C above pre-industries and pursue efforts to limit the temperature rise to 1.5°C, recognizing that this will significantly reduce the risks and impacts of climate change.

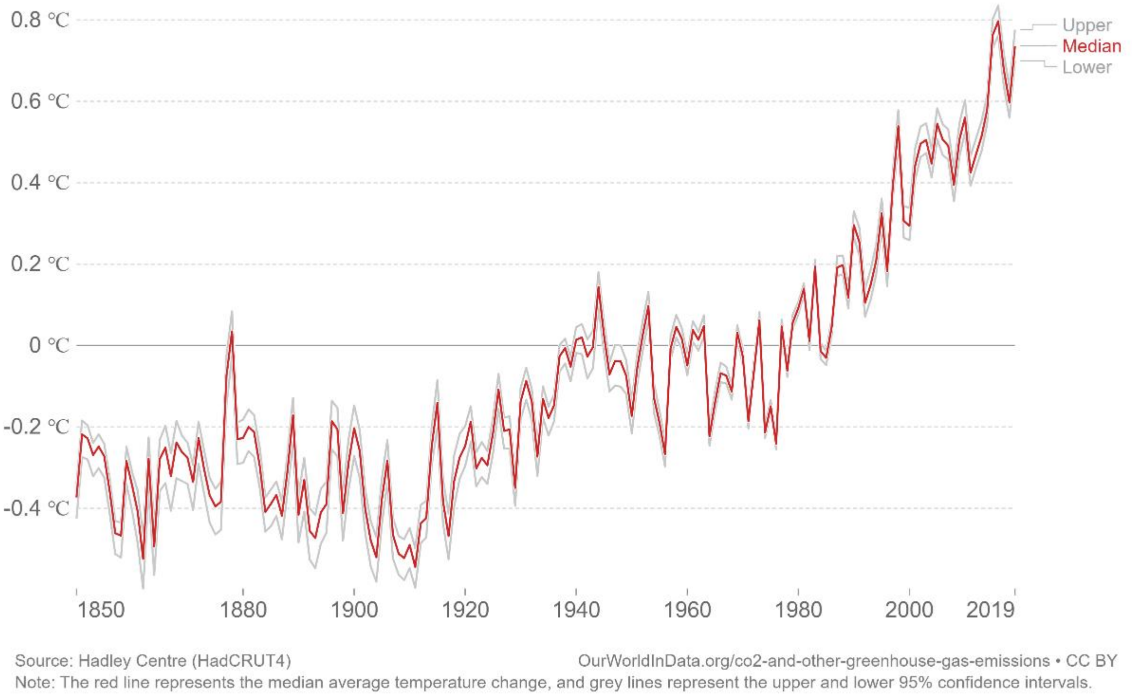


Figure 2: Average temperature anomaly, Global (2020 Our World in Data)

Instead of establishing the obligations that each country would have to fulfil, the agreement determines that each country must present, in every five years, national plans with the objectives that it intends to fulfil to mitigate the climate change.

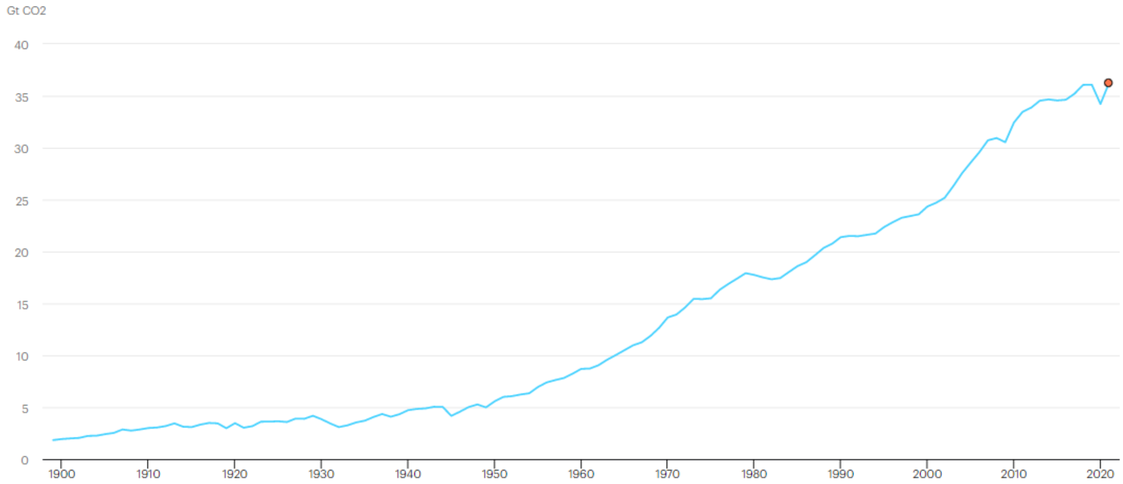


Figure 3 : CO2 emissions from energy combustion and industrial processes, 1900-2021 (IEA 2021)

Measures has been set up worldwide in order to reduce these emissions and especially in the European Union as climate goals under short & long term strategies.

The EU actions are divided into 3 sections:

<u>* 2020 climate & energy package:</u>

Where it aims for 3 key targets:

- 20% cut in greenhouse gas emissions (from 1990 levels)
- 20% of EU from renewable sources of energies
- 20% improvement in energy efficiency

<u>* 2030 climate & energy framework:</u>

This framework includes EU objectives for the period of 2021 to 2030

Greenhouse gas emissions:

In September 2020 the EU commission proposed to raise the 2030 greenhouse gas emission reduction target to at least 55% compared to 1990.

2030 climate and energy framework:

Key targets of 2030:

- At least 40% of cuts in greenhouse gas emissions comparing to 1990 levels
- At least 32 % share for renewable energy
- At least 35,5% improvement in energy efficiency

<u>* 2050 long-term strategy:</u>

For the long term strategy adopted by EU it is aiming to be climate-neutral by 2050 with net-zero greenhouse gas emissions economy. All part of the European society is involved in this objective; power sector, industry, mobility, buildings and agriculture and forestry.

EU submitted its long-term strategy to the UN framework convention on climate change. EU members are required to develop national long term strategies on how to plan to achieve these objectives and goals to meet their commitments to the "Paris agreement".

1.2 Framework:

- In case of Portugal, a national vision has been set **"Plano Nacional Energia e Clima" PNEC 2030** which is a policy instrument that Portugal has set for the decade 2021-2030, it contains a characterization of the existent situation of energy and climate in the country and it covers 5 major domains; decarbonizing energy efficiency, security of supply, internal energy market, research and innovation.

This plan defines the national contributions and main lines of actions planned to fulfill the different commitments of the Union, including in terms of reducing greenhouse gas emissions greenhouse effect, renewable energy, energy efficiency and interconnections.

One of the main objectives of the national energy policy is the reduction of the dependence of energy from abroad (by establishing "PNEC") to the value of 65% for 2030. The focus on renewable energies and on energy efficiency has allowed Portugal to reduce its energy dependence to levels below 80% with regard to the implementation of targets for renewable energies, the law 28/2009/EC, of the European Parliament and of the Council, of 23 April 2009, introduced the obligation for EU member countries to submit a plan to promote the use of energy from renewable sources.

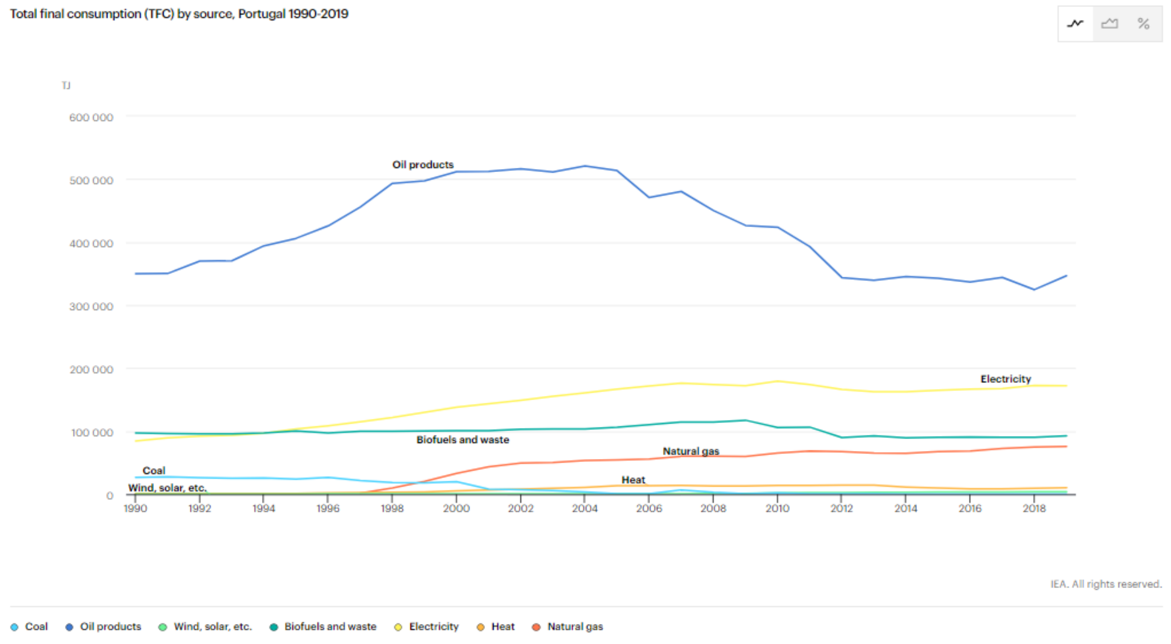


Figure 4: Total final consumption by source, Portugal 1990-2019 (IEA 2020)

PNEC 2030 targets:

- Reducing GHG emissions of 45% to 55% relative to 2005
- Incorporating renewable energy to 47%
- Energy efficiency 35%
- Interconnections 15%

- Also PNEC 2030 has sectoral targets for the reduction of GHG emission:

- 70% in the service sector
- 35% residential sector
- 40% transport sector
- 11% agriculture sector
- 30% waste and waste water sector

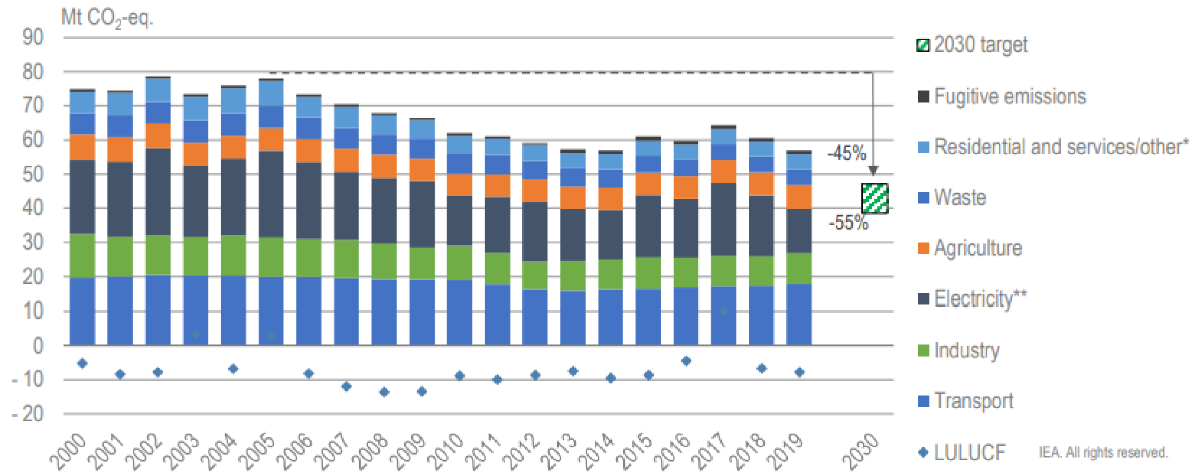


Figure 5: Portugal’s greenhouse gas emissions by sector, 2000-19 and 2030 target

- Between 2005 till 2014 Portugal’s GHG emissions dropped steadily but after that it has increased and became more variable. The main sources of these emissions are electricity, transport and industry.

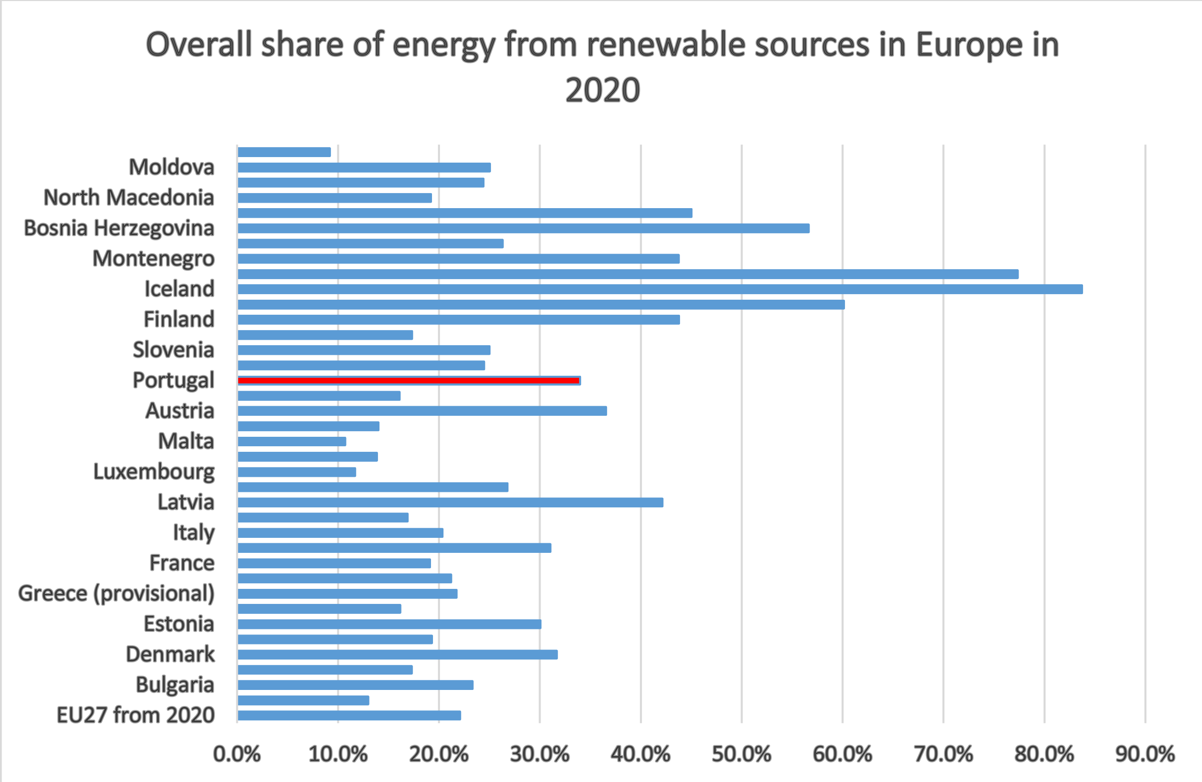


Figure 6: Overall share of energy from renewable sources in Europe in 2020 (Eurostats 2020) [17]

- As PNEC is aiming to incorporate renewable energy up to 47% by 2030 as we can see from the chart above in 2020 Portugal has reached 34%, it still didn't reach the targeted value yet but we believe that it will be achievable by that time.

1.3 Portugal Total Final Consumption by sector:

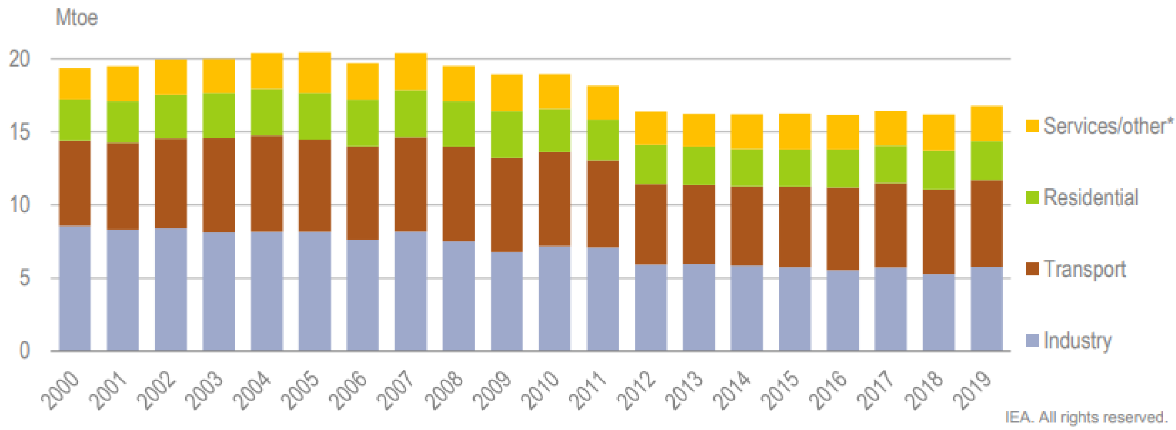


Figure 7: Total final consumption in Portugal by sector, 2000-19

- We can deduce from the chart above that the drop of the total final consumption in Portugal is due to the 2008 economic crisis, the recovery increased the demand in transport, residential and services/other sectors but industry demand kept declining.

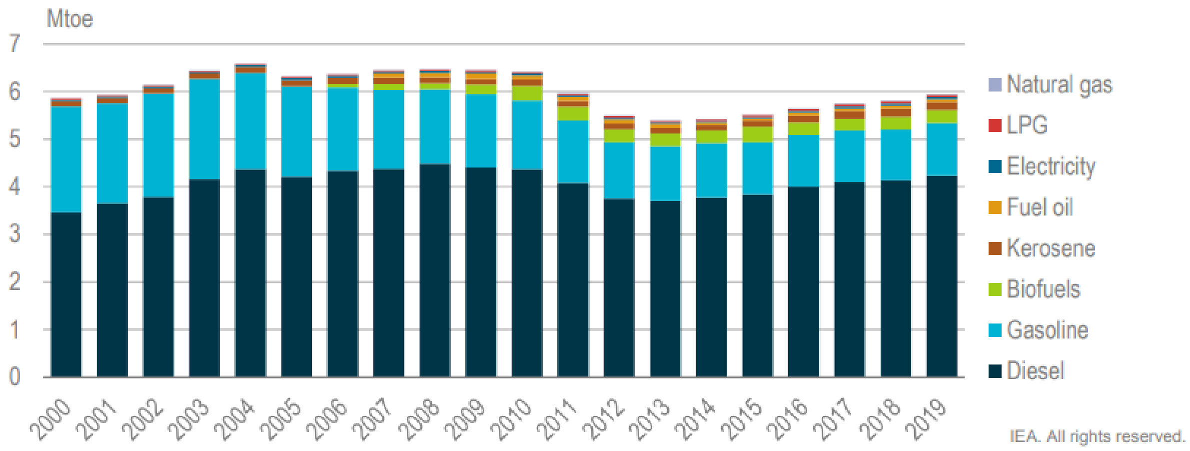


Figure 8: Transport total final consumption in Portugal by fuel, 2000-19

- Transport sector is considered as one of the major energy consumers in Portugal over the years as, in 2019, it had the highest energy demand 5,9 Mtoe and 35% of the total final consumption. The demand started to increase after 2008 due to the economic crisis.

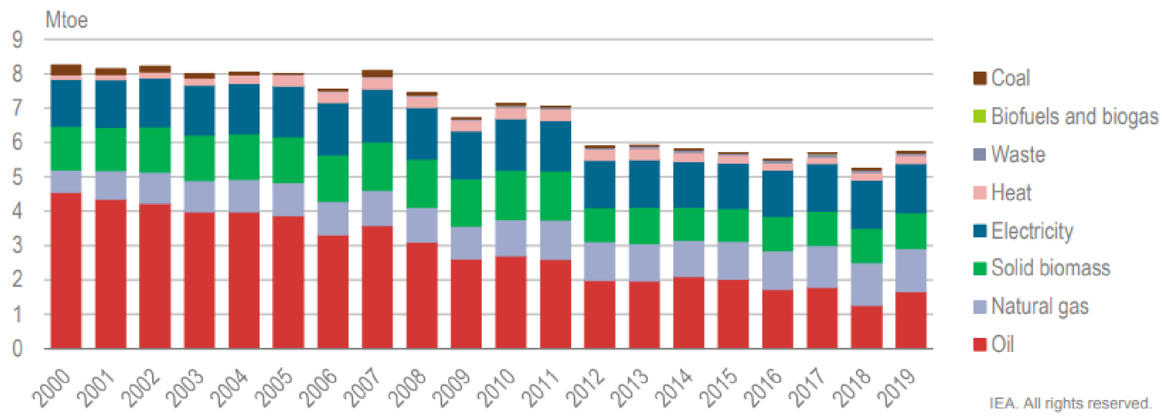


Figure 9: Industry total final consumption in Portugal by source, 2000-19

- The decrease of energy demand in industry sector started to be noticeable after 2008 same as the transport sector the economic crisis has impacted the demand as it fell by 20% between 2008 and 2012. It has also continued to decline due to the improved efficiency that the governmental body has adopted and to the change and the development that has occurred to energy structure.

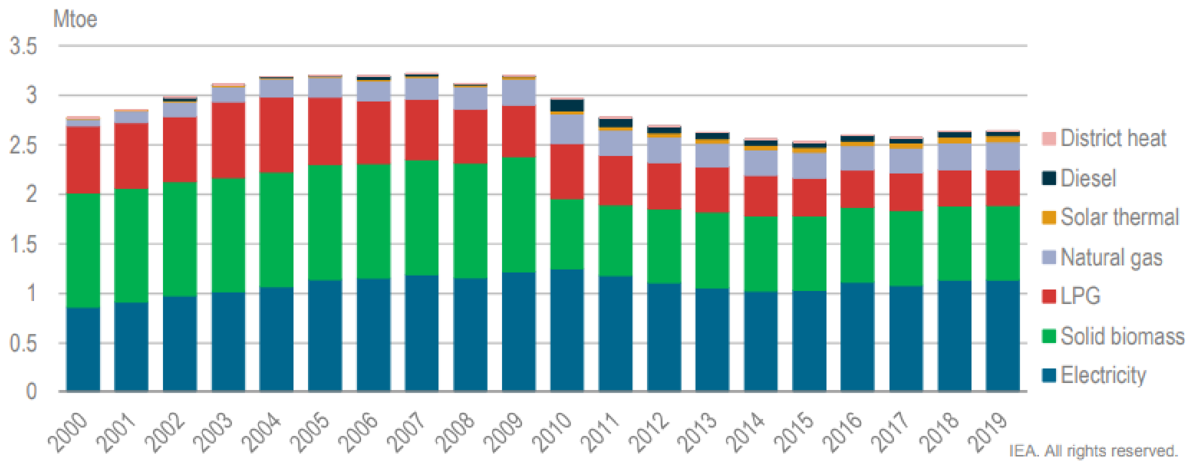


Figure 10: Residential total final consumption in Portugal by source, 2000-19

- The chart above represents the total final consumption for the residential sector in Portugal between 2000–2019, electricity and solid biomass represents the highest consumed source of energy by respectively 43% and 29%.

1.4 Electricity Transport, Distribution and Use in Portugal:

Electricity must be directed to consumption locations, In effect it circulates in transport lines constituents of the electric energy networks that are divided into the following classes:

- Very high voltage: Used for long transport distances, the tension between phases has an effective value greater than 110 KV;
- High voltage: Also used for long distances and sometimes direct supply for big companies, the tension between phases has an effective value greater than 45 KV and equal or less than 110 KV;
- Medium voltage: obtained through the passage of electricity through transformers, that allows it to pass from high voltage to low voltage, the tension between phases has an effective value greater than 1 KV and equal to or less than 45 KV;
- Low voltage: The voltage between phases has an effective value equal to or less than 1 KV;

As mentionned above the facility is supplied by medium voltage type of electricity during working time, the electricity consumption is classed by periods of the day which it is devided as the following:

- Peak: Corresponds to the time when both energy demand and price are the highest;
- Full: corresponds to the time when energy demand is intermediate, where its price is the second highest of the paid hours;

- Off Peak: corresponds to the time when energy demand is low. the price is the second lowest of the paid hours;
- Super Off Peak: corresponds to the time when both energy demand and price are the lowest;

Weekly cycle of electricity in Portugal			
Winter Time		**Summer Time**	
From Monday to Friday		From Monday to Friday	
Peak:	17:00/22:00 h	Peak:	14:00/17:00 h
Full:	00:00/00:30 h 07:30/17:00 h 22:00/24:00 h	Full:	00:00/00:30 h 07:30/14:00 h 17:00/24:00 h
Off Peak:	00:30/02:00 h 06:00/07:30 h	Off Peak:	00:30/02:00 h 06:00/07:30 h
Super Off Peak:	02:00/06:00 h	Super Off Peak:	02:00/06:00 h
Saturday		Saturday	
Full:	10:30/12:30 h 17:30/22:30 h	Full:	10:00/13:30 h 19:30/23:00 h
Off Peak:	00:00/03:00 h 07:00/10:30 h 12:30/17:30 h 22:30/24:00 h	Off Peak:	00:00/03:30 h 07:30/10:00 h 13:30/19:30 h 23:00/24:00 h
Super Off Peak:	03:00/07:00 h	Super Off Peak:	03:30/07:30 h
Sunday		Sunday	
Off Peak:	00:00/04:00 h 08:00/24:00 h	Off Peak:	00:00/04:00 h 08:00/24:00 h
Super Off Peak:	04:00/08:00 h	Super Off Peak:	04:00/08:00 h

Table 1: Weekly cycle of electricity in Portugal

MT Network access prices		**PRICES**
Power		**EUR/(kW.day)**
	Peak hour	0,2198
	Contracted	0,0161
Active energy		**EUR/kWh**
	Peak hours	-0,0799
	Full hours	0,0000
	Off Peak hours	0,0000
	Super Off Peak ours	0,0000
Reactive energy		**EUR/kvarh**
	Inductive	0,0015
	Capacitive	0,0011

Table 2: MT Network access prices in Portugal

With regard to reactive energy, this is a form of electrical energy that does not produce work, but which is necessary for the operation of most electrical equipment or electromechanical equipment installed in practically all energy utilization facilities, in n particular, in the facilities assigned to industrial units. Since this energy increases the losses in distribution networks, their consumption must be controlled.

1.5 Energy:

1.5.1 Definition of energy:

Energy is defined as the ability to do work, in general it can manifest itself in many ways such as kinetic energy, electrical, mechanical, nuclear, chemical, thermal etc. And it measured by Joule where Joule is the amount of work (work is the energy transferred to or from an object via the application of force along a displacement) done when a force of 1 newton displaces a mass through a distance of 1 meter in direction of the force applied [1].

Since the industrial revolution, the human being has always had a tendency towards high energy consumption, within the scope of its existence and evolution. Over time, several processes of transformation, transport and storage of energy.The transformation of energy allows obtaining new energy forms, more appropriate or convenient to use. Taking into account its transformation processes, we can classify it in:

Primary Energy:

It is the energy available in nature before being converted or transformed. It encompasses the renewable and non-renewable energy sources. For example like coal, oil, natural gas, solar radiation, water or wind. It is usually presented in terms of oil equivalent (tonnes of oil equivalent), which represents the amount of oil’s chemical energy content that would be necessary to generate a given quantity of final energy in standard conditions. It can also be presented in other units such as MMBtu (million british thermal units) [2].

Secondary Energy:

This type of energy results from processes of transformation of primary energy into other forms suited to different practical uses, naturally suffering losses inherent to these processes. Oil is an example of a primary energy source, which is transformed in refineries into secondary energy sources, such as gasoline, diesel or liquefied petroleum gas. Another example of secondary energy is the high voltage electricity produced in the plants, which use energy sources renewable or non-renewable [3].

Final Energy:

Corresponds to the energy that is received and used directly by the consumer or ordinary citizens. We have as examples, the diesel or gasoline with which we fill the car deposit and low-voltage electricity that reaches home appliances in our houses. Sometimes primary energy is converted directly into final energy. For example, solar radiation is converted, through solar thermal panels, into energy thermal energy, a final energy used in heating water. Already a forest residue (biomass) can be used by combustion in a fireplace, in the form of thermal energy [4].

From the extraction/collection of a particular form of primary energy to its use under the form of final energy, there are always going to be some losses or energy waste along the way. Such losses are the result of inefficiencies associated with the processes, carelessness on the part of the user or due to thermodynamic limitations. In addition to these, losses resulting from energy transport may also be relevant.

Thus, it becomes important to refer to the useful energy used in a process, which is directly related to its output or efficiency, constituting the amount of energy that actually serves a process or activity profitably.

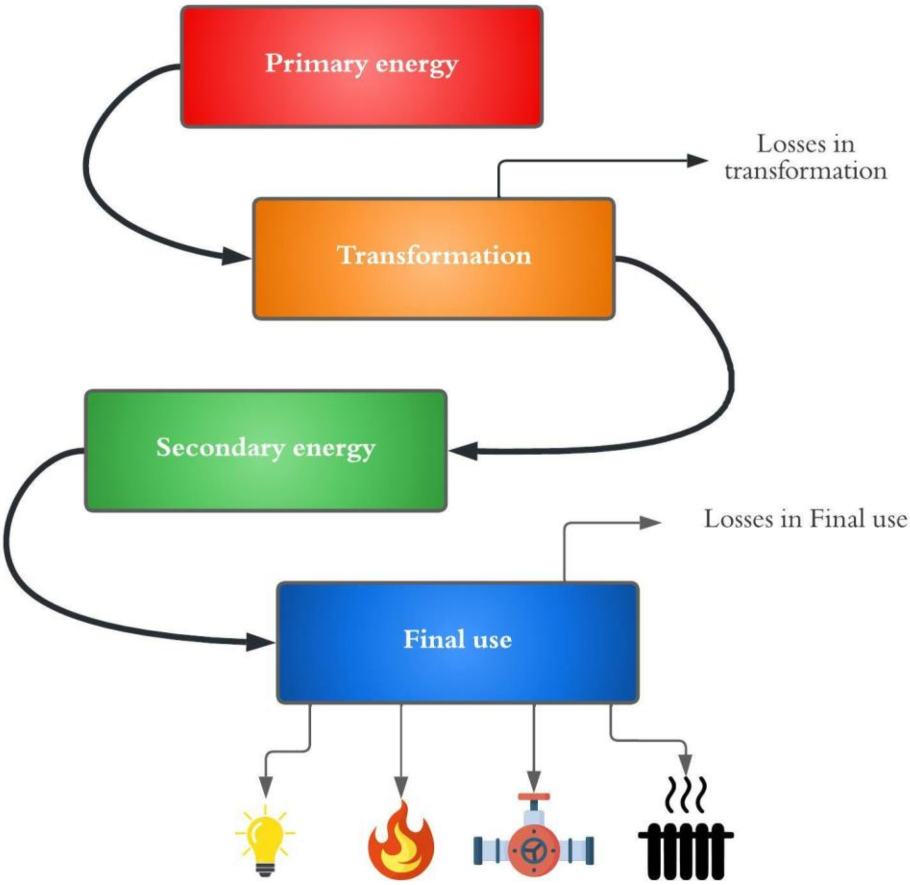


Figure 11: Energy Classification and Transformation

1.5.2 Energy Efficiency:

Energy efficiency simply means using less energy to perform the same task – that is, eliminating energy waste. Energy efficiency brings a variety of benefits: reducing greenhouse gas emissions, reducing demand for energy imports, and lowering our costs on a household and economy-wide level''. While renewable energy technologies also help accomplish these objectives, improving energy efficiency is the cheapest – and often the most immediate – that targets less energy consumption [5].

1.5.3 Entropy:

Entropy is an extensive property of a system and sometimes is referred to as total entropy.
So entropy is a scientific concept as well as a measurable physical property that is most commonly associated with a state of disorder, randomness, or uncertainty. The term and the concept are used in diverse fields, from classical thermodynamics, where it was first recognized, to the microscopic

description of nature in statistical physics, and to the principles of information theory. It has found far-ranging applications in chemistry and physics, in biological systems and their relation to life, in cosmology, economics, sociology, weather science, climate change, and information systems including the transmission of information in telecommunication [6].

1.5.4 Exergy:

The exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir, reaching maximum entropy. When the surroundings are the reservoir, exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy is zero. Determining exergy was also the first goal of thermodynamics [7].

1.5.5 Importance of Thermodynamics in energy auditing:

Thermodynamics laws are really important in realizing energy audits because basically energy auditing is simply an application of the law of conservation of energy. Which means that we can account for energy, since it is not created or can be destroyed in the facilities and the systems we are operating [16].

In practical terms, the law of conservation of energy is:

what comes in = what goes out

The first law of thermodynamics in general says that the heat is considered as a form of energy so the principle of conservation of energy can be applicable. That means that heat, which is a form of energy, cannot be created or destroyed. Yet it can be transferred from one place to another and also converted to other forms, such as work [15].

In simple words, the second law of thermodynamics states that entropy always increases. Since as energy in transferred or transformed, more of it is wasted. It also says that there is a natural tendency of any isolated system to degenerate into a more disordered state, according to Boston University.

The challenges of an audit requires:

- To particularly characterize the system being considered;
- To compute energy flows in and out of the studied system;

1.6 Energy Audits:

Audits can be carried out in different sectors, such as industrial audits, building audits and transport fleet audits. In this part we will concentrate on energy audits, what it consists of, its objectives and its methodology, with a deep emphasis on industrial energy audit, which is the case study type of audit [10].

1.6.1 Objectives of an energy Audit:

An energy audit is an inspection survey and an analysis of energy flows for energy conservation in a building. It may include a process or system to reduce the amount of energy input into the system without negatively affecting the output. In commercial and industrial real estate, an energy audit is the first step in identifying opportunities to reduce energy expense and carbon footprint.

Under the terms of Order nº 17449/2008, of 27 June (Diário da República, 2008), consists of a detailed survey of all aspects related to the energy use or that, in some way, contribute to the characterization of the energetic flow.

Energy audit has the following objectives, among others:

- Specify the forms of energy used;
- Examine how energy is used and how much it costs;
- Establish the energy consumption structure;
- Determining consumption by process, operation or equipment;
- Relate energy consumption to production;
- Identify possibilities for improving energy efficiency;
- Technically and economically analyze the founded solutions;
- Propose a program for actions and investments to be undertaken;
- Propose an operational energy management scheme in the Company;
- Propose the replacement of equipment linked to the process by more efficient ones;
- Propose the change of energy sources, if it is necessary [11].

1.6.2 Types of Audits:

The type of audit to be performed depends on the purpose for which it is designed. We can consider an audit as preliminary or detailed. Preliminary or simple industrial audits are intended to carry out a diagnosis of the energy situation of an installation, consisting of a simple visual observation that allows the identification of superficially perceptible flaws, and in the collection of data susceptible to provide information on specific energy consumptions. The most common sources of information are related to the analysis of energy consumption and billing of different types of energy.

Detailed industrial audits, on the other hand, consist of an in-depth survey of the state of the installation, analyzing the amounts of energy used in each step of the production process. Detailed energy audit includes an analysis of energy use of all major equipment of the facility, calculations of costs reduction, detailed energy costs and a technical-economic feasibility studies. Investments to implement the measures identified.

1.6.3 Methodology of an Energy Audit:

In regard of the execution of an industrial energy audit, there is no strict methodology that is applicable to all cases of energy audits. However, it is essential to establish the part of actions/steps to obtain the necessary knowledge of the analyzed installation, in order to detect, quantify and correct the existing the energy losses. ISO 50002 regulates and defines the methodology that used to perform an energy audit and it is presented in the next figure.

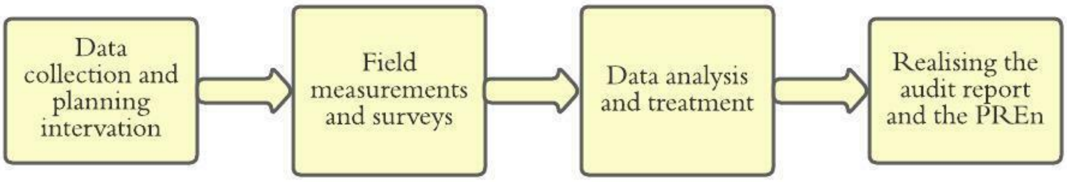


Figure 12: Energy Audit Methodology

1.6.3.1 Data collection and intervention planning:

Data collection and intervention planning are one of the most important steps in the process, because it will be an important factor in the quality of the work to be developed later on. To define a methodology structured to carry out the complete energy audit, an information request is sent to the installation, before visiting.

The request for information and data must contain at least the following information:

- General installation data;
- Description of the production process;
- Production data and working hours;
- Monthly invoices of energy consumption that are part of the scope of the audit;
- Technical characteristics of the main equipment (chillers, compressors, boilers, pumps, fans, among others);
- Thermal energy distribution network scheme.

1.6.3.2 Field measurements and surveys:

During this phase of work a first visit to the facility is needed, during this visit the audit team will establish objectives, collect the information previously requested, identify the main energy consuming sectors/equipment, define the monitoring period and identify the points to monitor.

At this point, special focus is given to the production process and auxiliary systems (central thermal, compressed air plant, lighting, among others), the energy flows are established (thermal and electrical), the main equipment is identified (characteristics, operating hours, hours of operation, etc.) and monitoring of the main energy consumers and production.

It is important to highlight the need to carry out a follow up at the same time, so that the values obtained can be analysed in a systematic way. Another aspect that should be taken into account is the definition of the system boundary, the purpose of the measurements and the measurement time and dates.

1.6.3.3 Data analysis and treatment:

After carrying out the fieldwork, the analysis and treatment of the collected data allow us to evaluate the energy performance of the facility.

At this phase of the audit, energy and mass balances are carried out, the energy efficiency, the overall load diagrams of the installation and the main energy consumers and the overall energy indicators of the installation are calculated.

Afterwards, the energy consumption rationalization measures that can be implemented are identified and the determination of the savings estimates is carried out

1.6.3.4 Realizing the audit report and the PREn:

The final step of an energy audit is to prepare the report that contains all information collected and analysed throughout the audit in an organized manner.

In the detailed analysis, it is important to determine the energy efficiency of the main energy-consuming equipment, which must be analysed from a critical point of view and compared to the equipment available on the market that present better energetic performances.

Likewise, a detailed analysis of the operating mode in the production process or other auxiliary activities, with the concern of correcting behavioural practices. With this analysis, possible changes are proposed that lead to an increase in energy efficiency.

When preparing the report, the auditor should bear in mind that the energy audit is the first step towards the implementation of a continuous energy management process, presenting in an Energy

Consumption Rationalization Plan (PREn) energy efficiency measures implementable, over a limited time frame, and that allow the achievement of improvements of the intended energy performance.

1.7 ''Sistema de Gestão dos Consumos Intensivos de Energia (SGCIE):

Portugal has established the SGCIE - Sistema de Gestão dos Consumos Intensivos de Energia. The SGCIE, regulated by Decree-Law nº 71/2008, of 15 April, and later amended by Law n.º 7/2013, of 22 January, and by Decree-Law n.º 68-A/2015, of 30 April, is one of the measures provided for in the National Action Plan in Energy Efficiency (PNAEE) aimed at improving energy efficiency in the area of industry, revoking the old Energy Consumption Management Regulation (RGCE), created by the Decree-Law No. 58/82, of February 26, and regulated by Ordinance No. 359/82, of April 7. Decree-Law n.º 68-A/2015 establish the following [14]:

-Formulas and conversion factor for calculating primary energy consumption (tons of oil equivalent) and greenhouse gas emissions (CO_2 equivalent) from bills of the different types of energy used in these facilities.

-The SGCIE's fundamental objectives are the promotion of energy efficiency and monitoring energy consumption of the ''intensive energy consumers'' installations, which are installations with annual consumption equal or greater than 500 tons of oil equivalent (toe).

-These installations must carry out energy audits periodically that will reduce energy use and promote increased energy efficiency, including the use of renewable energy sources. So the scope of SGCIE is the following:

-The obligation of the companies included in the SGCIE in terms of energy efficiency and the respective deadline (according to consumption, carrying out audits, presenting a rationalization plan of energy consumption and presenting execution and progress reports.

-The indicators to be followed and the goals to be achieved.

-Incentives for inclusion in the SGCIE

-The penalties to be applied in case of non-compliance

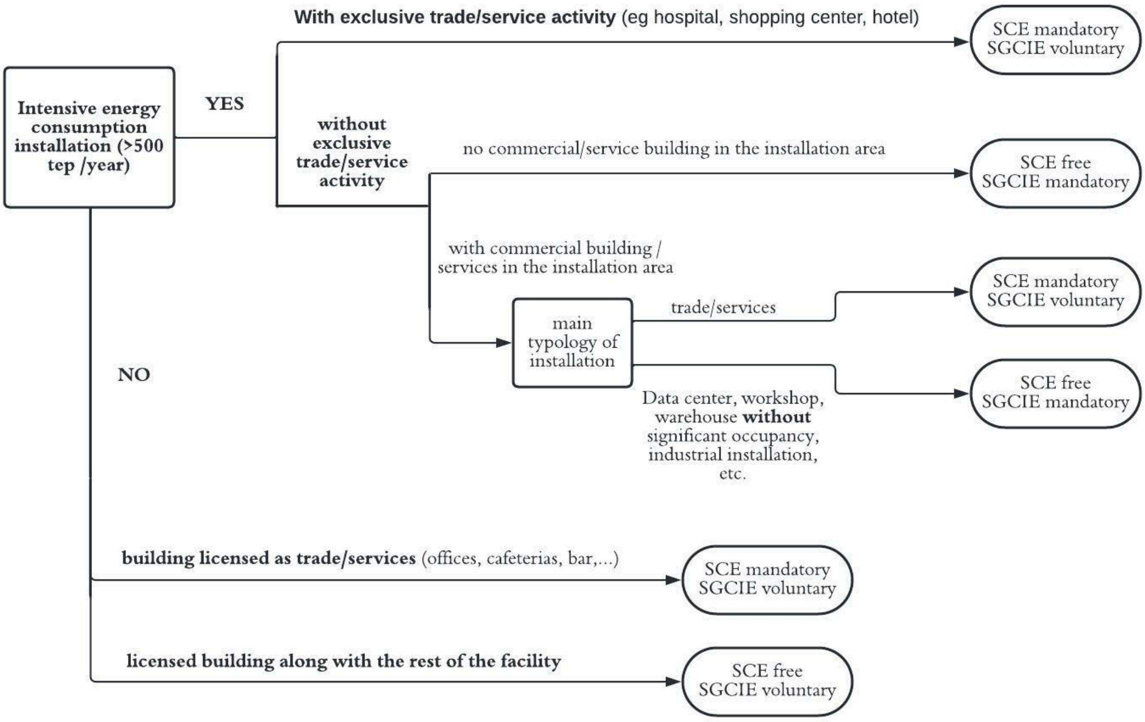


Figure 13: Flowchart illustrating the scope of application of the SGCIE and SCE (DGEG, 2020) [9]

A change was made for DL 71/2008 for a complementary regulation that concerns DL7/2013, which regulates the recognition of technicians, by the general directorate of energy, for acting as auditors within the scope of the SGCIE and which puts an end to the recognition of collective entities. DL 7/2013 establishes minimum requirements for access to the same functions reserved for recognized technicians (technical responsibility for services provided, within the scope of the SGCIE, to operators of energy intensive installations), their responsibilities and possible penalties [12].

- DL 68-A/2015, which transposes the European directive 2012/27/EU to Portugal, changes DL71/2008 in order to harmonize it with the European directive and establishes obligations, in terms of energy efficiency, for companies considered “non-SME".

Obligations include the implementation of an energy accounting system, the performance of independent and cost-effective audits which allow, with the implementation of the resulting measures, to recover in four years the investment in these measures, and in the audit itself and the performance of follow up reports.

DL 68-A/2015 also seeks to harmonize the objectives and obligations arising from the various regulations relating to energy efficiency: the regulation for the management of energy consumption in transport (RGCE), the energy certification system for buildings (SCE) and indirectly because it acts on costs attributed to greenhouse gas emissions, the European greenhouse gas emissions trading scheme (CELE).

The Energy Consumption Rationalization Plan is composed of a set of measures that aims to improving the energy efficiency of the audited facility, by reducing its energy consumption and, consequently, energy costs. These measures are defined on the energy audit and they help setting the targets to be achieved, at the end of the term of the respective plan, relative to the energy intensity indicators, specific energy consumption and carbon intensity.

The reference year of that plan will be the calendar year prior to the energy audit date. In the case of installations with energy consumption equal to or greater than 1,000 toe/year, the audit and PREn must be submitted to ADENE within 8 months after registration, with the PREn being prepared to a period of 8 years. In other cases, the audit and PREn must be submitted to ADENE until 16 months after registration, the PREn being also prepared for a period of 8 years [13].

As previously mentioned, the PREn must establish goals related to Energy Intensity, Carbon Intensity and Specific Energy Consumption, whenever applicable, taking into account the following these global energy indicators:

- **Energy Intensity :**

Energy Intensity is an economic indicator that measures the energy productivity of an industrial facility for the production of a particular product or products. It is translated by the quotient between global consumption and GAV.

$$EI = \frac{TEC}{GAV}$$

Where:

EI – Energy Intensity (tep/Eur or kgep/Eur);

GAV – Gross Added Value;

TEC – Total Energy Consumption (tep or kgep);

- Specific Energy Consumption:

Specific Consumption is an energy indicator that reflects energy consumption per unit of product produced.

$$SEC = \frac{TEC}{Production}$$

$$TEC = EC + 0.5 \times (R_{FC} + E_{WC})$$

Where:

SEC − Specific Energy Consumption (tep/production unit or kgep/ production unit);

TEC − Total Energy Consumption (tep or kgep);

Production − Total production of a given product or industrial facility;

EC − Energy Consumption not including R_{CC} or E_{WC} (Electricity, natural gas, etc.) (tep or kgep);

R_{FC} − *Renewable Fuels Consumption (tep or kgep);*

E_{WC} − Endogenous Waste Consumption (tep ou kgep);

- CO2 Emissions and Carbon Intensity

Carbon Intensity is the quotient between greenhouse gas emissions resulting from the use of different types of energy and the total consumption of primary energy:

$$CI = \frac{CO2\ Emissions}{TEC}$$

Where,

CI − Carbonic Intensity (kg CO2/tep or kg CO2/kgep)

CO2 Emissions − Greenhouse gas emissions (kg CO2)

As part of the application of the regulation, it is imperative to carry out audits and the elaboration of the PREn leading to an improvement of 6% both indicators ''Energy Intensity'' and ''Specific Energy Consumption'', in eight years, in the case of installations with intensive consumption of energy equal to or greater than 1 000 toe/year, or an improvement of 4% of the same indicators for the other installations, for the same period of time. With regard to Carbon Intensity, it is mandatory, at least, the maintenance of the old values of this indicator.

1.8 Presentation of EWEN:

EWEN – Global Solutions in Energy and Environment, Lda. is a company founded in 2004 and headquartered in Ramalde, Porto. It currently has 19 employees and it is present in Portugal, Spain and Saudi Arabia. While also providing project management consulting services, EWEN is primarily an energy services company.

It provides consulting services and develops engineering projects in the area of energy efficiency in steam, industrial cooling, compressed air, water networks and other fluids, air conditioning and manufacturing processes.

Based on the experience accumulated by its engineers, EWEN has developed several products related to energy efficiency, with emphasis on the e+Jackets, flexible insulation for valves and other equipment, custom-designed and manufactured in its own workshop, and for the e+ Monitor, a remote monitoring system for energy consumption based on a computer platform developed in-house and adaptable to the reality of each installation and the objectives of its operator.

A significant part of EWEN's activity takes place within the scope of the SGCIE, with its most recent portfolio carrying out energy audits and monitoring energy plans. Rationalization plan of energy consumption (PREn) of some of the most important industrial facilities in Portugal, such as the factories of IKEA, Sociedade Central de Cervejas, Continental and Corticeira Amorim, for example. In this market, EWEN as it is a part of Helexia, Voltalia Group stands out in Portugal for its specific skills in the area of Mechanical Engineering, having 6 engineers with academic specialization in the area of thermal energy.

This contributes to a clear differentiation with regard to the ability to obtain a fundamental understanding of the production processes that allows it to intervene on their energy efficiency, in contrast to approaches that are limited to the efficiency of auxiliary systems.

Chapter 2

Presentation of the Case Study:

- This chapter presents the energy audit carried out on an industrial painting and surface treatment facility in Portugal, which constitutes the case study of this dissertation, for confidential reasons, the name of the installation and the specification of certain parameters were not mentioned in the developed study. Henceforth we will refer to it by either a ‘’facility’’ or ‘’installation’’

- Under the conditions set out in Decree-Law 71/2008, of April 15th, an energy audit is obligatory, given that it is verified during the preceding calendar year the annual consumption of primary energy obligates the facility to realize and energy audit. So, initially the general elements and equipments of the facility are presented, as well as the annual values of energy production and consumption. And briefly describing the type of energy used and the auxiliary services. Then, we will go through an analysis of consumption by type of energy and each production line.

2.1

2.1 Installation Overview:

- The targeted company in this energy audit is located in Portugal and their main field of work is dedicated to the execution of surface treatments and finishing on various types of parts, being particularly dedicated, in the last few years, to automotive components.

- The facility works mainly on:

- Lacquering (Lines 1 and 2);
- Cataphoresis painting (Line 5);
- Liquid paint (Lines 6 and 8);
- Anodizing (Line 7)

2.2 Description of Production Process on the studied facility:

The production process is divided into 6 sections of painting and one for cleaning the pieces.

2.2.1 Lacquering (Line 1 and 2):

It is a polyester powder paint coating and a polyester powder varnish. These lines work separately, and the pre-treatment of the parts in both is specific to each batch, which is the main difference between them.

In Line 1, the parts undergo pre-degreasing, degreasing, washing with industrial water, deoxidation followed by a new washing with industrial water, washing with demineralized water, passivation using Silanes, which serves to improve the corrosion resistance of the paint and, finally, a new wash using hot water. In line 2, the pre-treatment is similar but there is no deoxidation step.

After pre-treatment, the painting phase is the same on both lines. The piece initially goes through a drying and cooling phase, after which it is painted with polyester powder paint. After this phase, the piece is transferred to an oven where the paint polymerization phase takes place, being then cooled, before taking the second coating layer (polyester powder varnish). Finally, the piece goes through an oven again to cure the varnish layer, and is finally packaged.

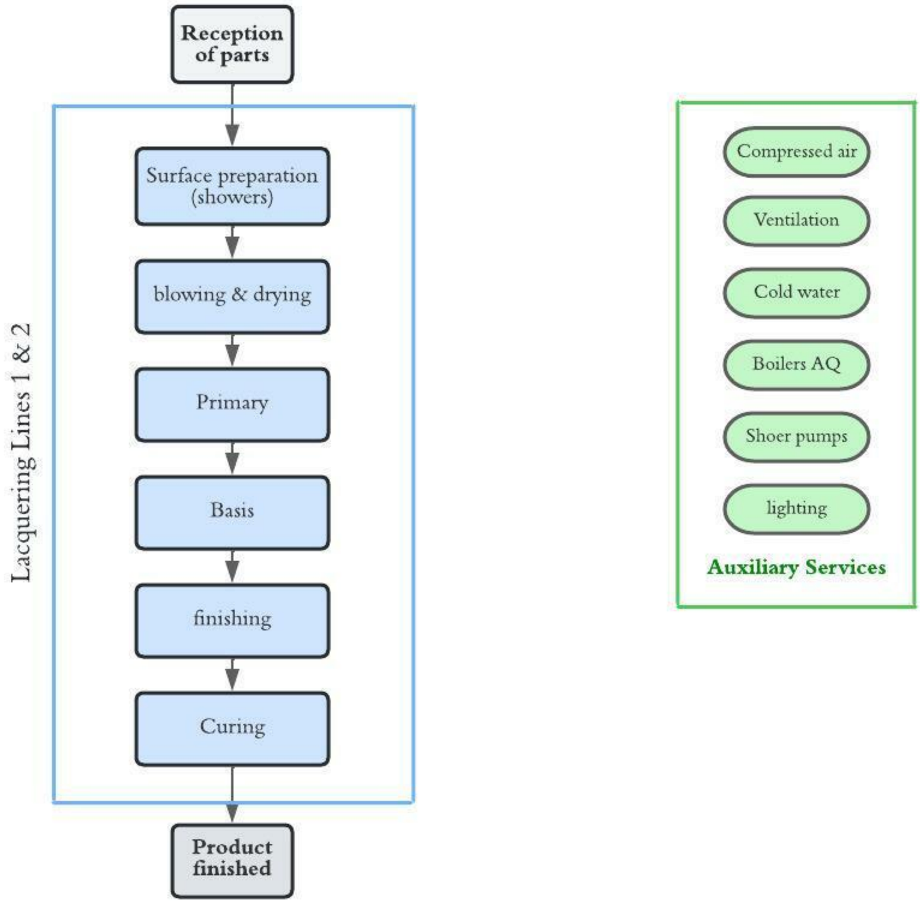


Figure 14: Schematic and simplified diagram of the production process for the lacquering lines

2.2.2 Cataphoresis (Line 5):

In this line, painting is done through the application of an electric field that will make the paint adhere to the piece. As in lines 1 and 2, the parts to be painted first undergo a pre-treatment process, which consists of a pre-degreasing and degreasing phase, followed by washing with industrial water. Then, the part goes through the activation, phosphating, and passivation phases, treatments that facilitate the adhesion of the paint to the part and improve corrosion resistance.

After this pre-treatment, the painting proceeds by Cataphoresis, where the various pieces are submerged in a bath that contains the paint to be used. The paint adheres because a potential difference is imposed between the part and the bath.

After painting, the pieces are washed where excess paint is removed, and this excess is reused through an ultrafiltration system. After this washing, the piece passes through an oven where the paint polymerization takes place, being then cooled and collected to be packaged.

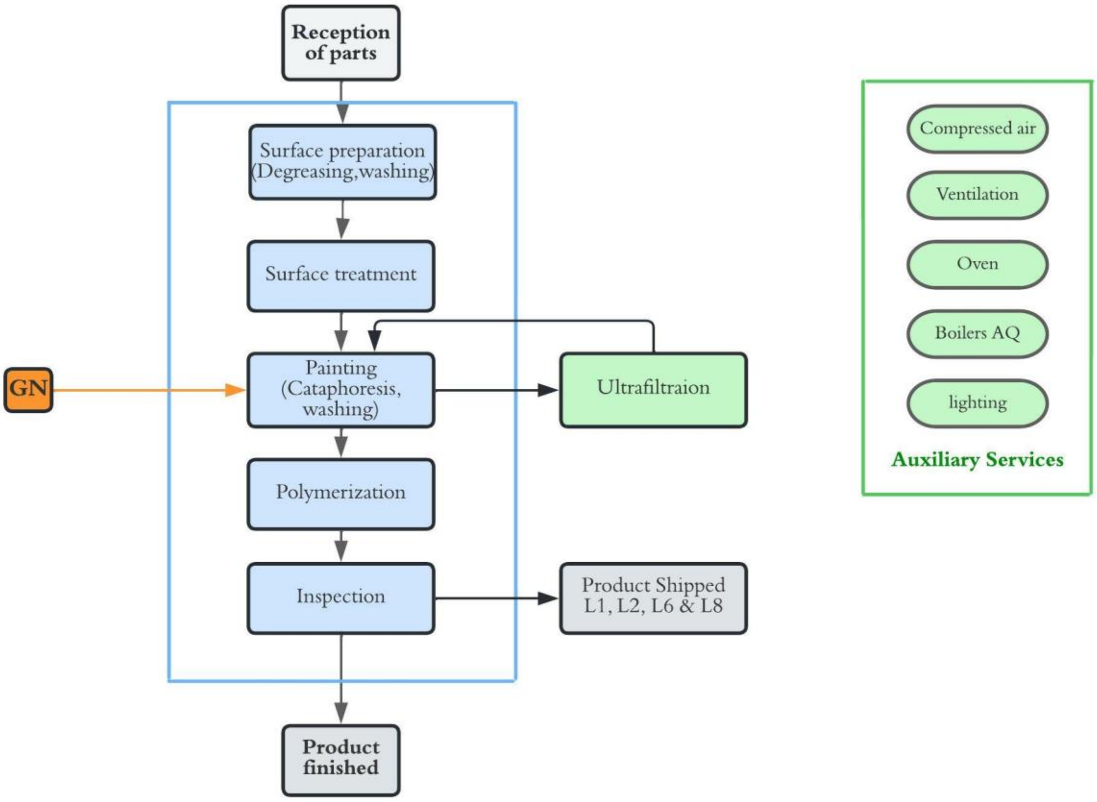


Figure 15: Schematic and simplified diagram of the production process of Line 5

2.2.3 Liquid Paint (Line 6):

In line 6, the pieces also undergo a pre-treatment process, where the piece goes through the phases of degreasing, washing with industrial and demineralized water, blowing and drying. Then, it goes to the first painting booth, where the primer is applied, then it goes through an oven where the curing (drying process) of this layer takes place.

After applying the primer, the piece is then painted with the desired colour, followed by a varnish application. After this application, the piece goes through an oven again where the varnish cures and, after this phase, it is ready to be collected and packaged.

This process ends with the drying of the parts and packaging.

2.2.4 Liquid Paint (Line 8):

This line is very similar to line 6, but has a much larger dimension. Being the most recent line in the company, it also presents greater sophistication in the various processes, visible in a greater automation of the processes, where there are already programs capable of controlling the entire course of the piece, from pre-treatment to the last stage of painting, defined which pre-treatment stages the part has to go through, as well as all paint specifications.

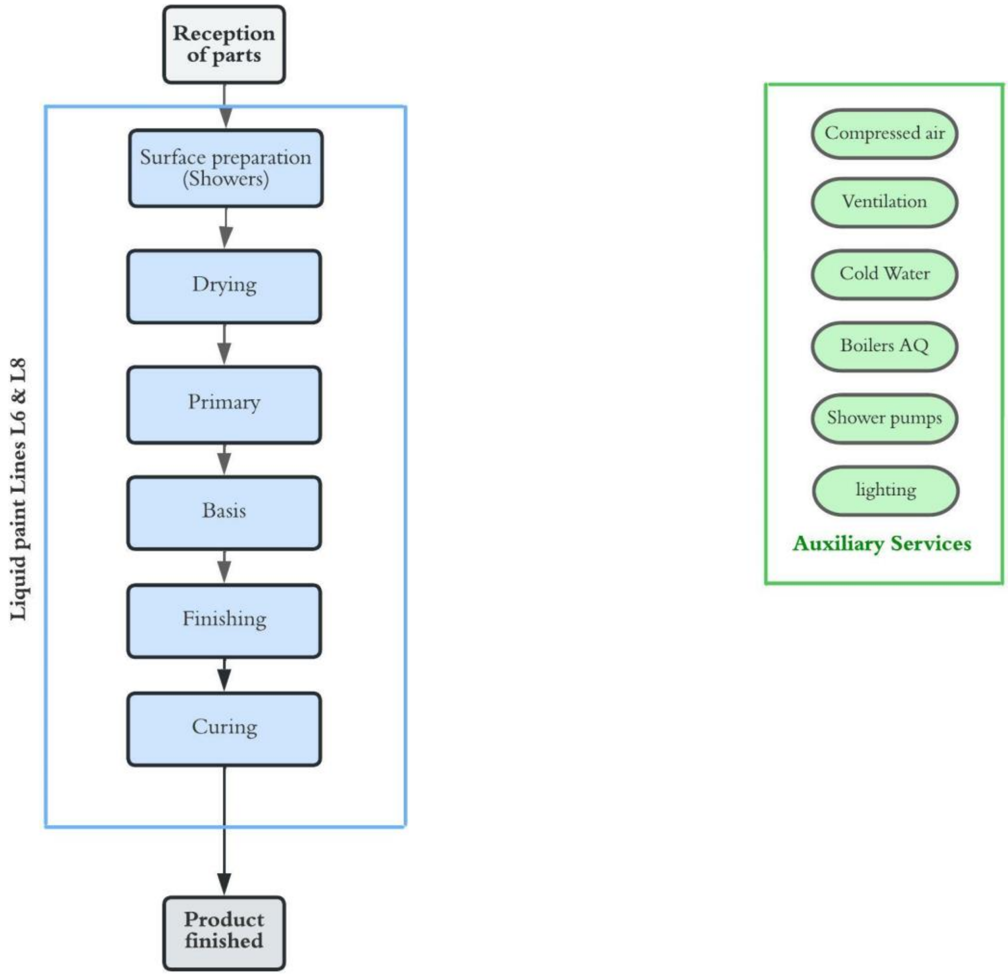


Figure 16: Schematic and simplified diagram of the production process of Lines 6 & 8

2.2.5 Anodizing (Line 7):

Anodizing is a process that consists of the formation of an oxide on the surface of the part that will guarantee greater protection to the paint layer. As in all lines, the piece starts by going through a pre-treatment process, which contains the phases of pre-degreasing, degreasing, cascading washing, deoxidation, acid and alkaline desmuting (elimination of a film that forms on the piece during pre-treatment, and electro-polishing).

Then, the piece passes to the anodizing phase itself, where the oxide formation takes place, and through an electro-colouring or organic colouring phase. Finally, there is sealing – hot or cold –, depending on the type of piece. All these phases consist of immersion of the part in specific baths for each objective, which may or may not be heated and/or electrically charged.

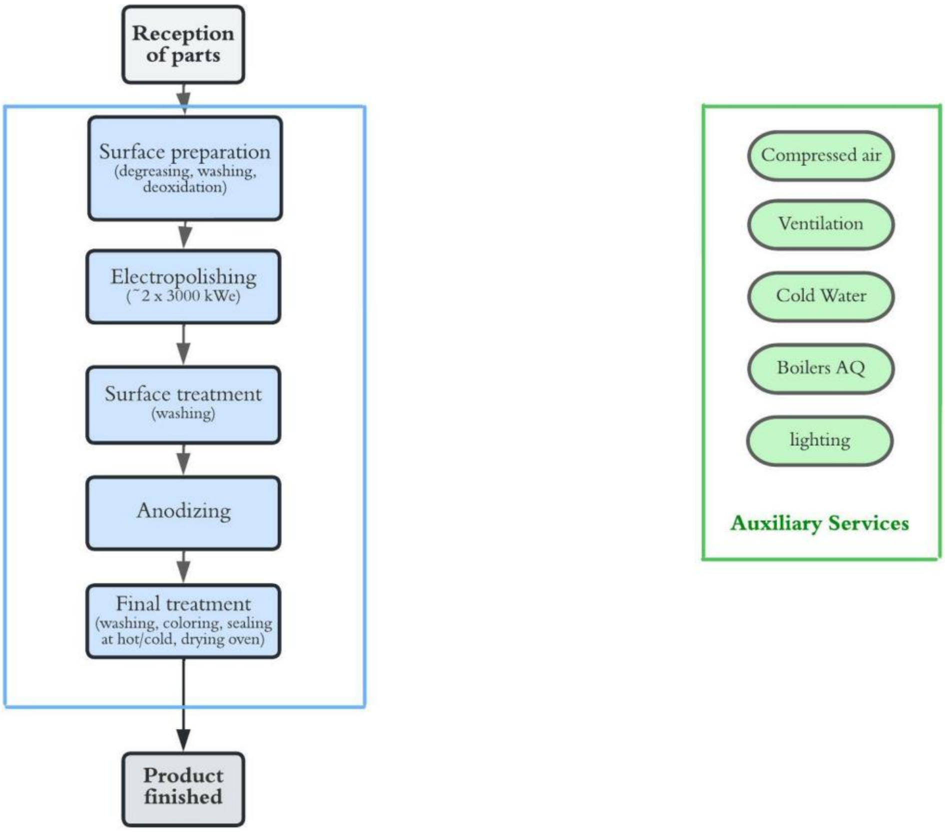


Figure 17: Schematic and simplified diagram of the production process of Line 7

2.2.6 Pickling:

There is also an area dedicated only to cleaning and stripping the parts. This area contains two pyrolysis pickling ovens that are used to clean the supports where the pieces are painted, and that end up accumulating a significant layer of paint over time.

In addition, it also contains a chemical pickling area, consisting of three tanks with specific baths and an area with parts washing machines.

2.3 Energy Utilities at the Facility:

- The targeted facility in this energy audit uses three different forms of energy; electricity, natural gas and diesel.

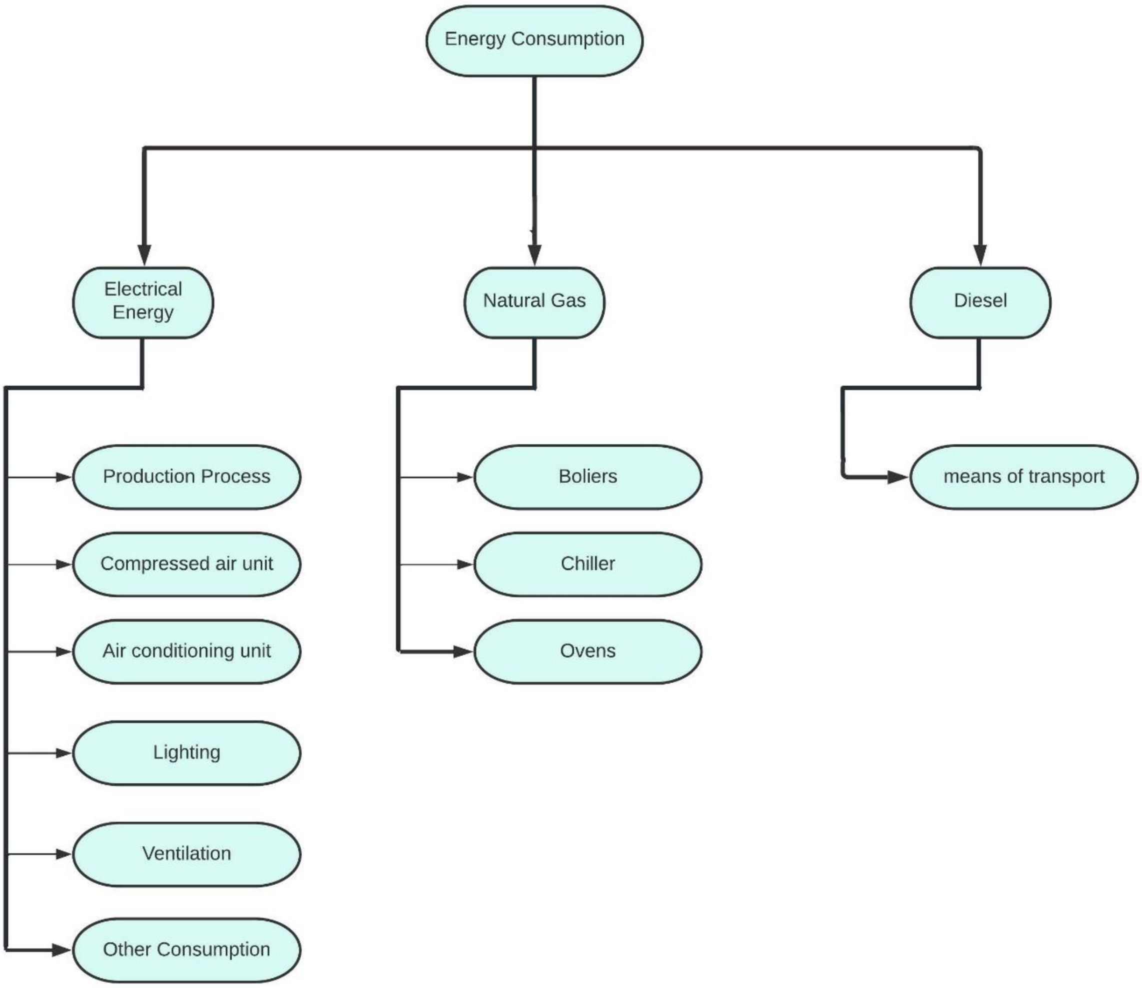


Figure 18: Schematic diagram of energy utilities in the facility

2.4 Description of the Electricity Supply and Distribution of the Studied Facility:

The facility receives through two lines of 15kV provided by ‘’E-Redes’’. The reception is done at the sectioning stations, being equipped with protective cells.

The facility poses four transformation stations called (PT) where they supply it by 4.244kW contracted power. From the Transformer Substations, there is a set of cables in a gutter for the respective Low Voltage General Boards which are called here QGBT. From the QGBT the power supply is branched out to the general line boards or partial boards.

The QGBTs are equipped with capacitor banks to compensate for the installation's reactive energy consumption.

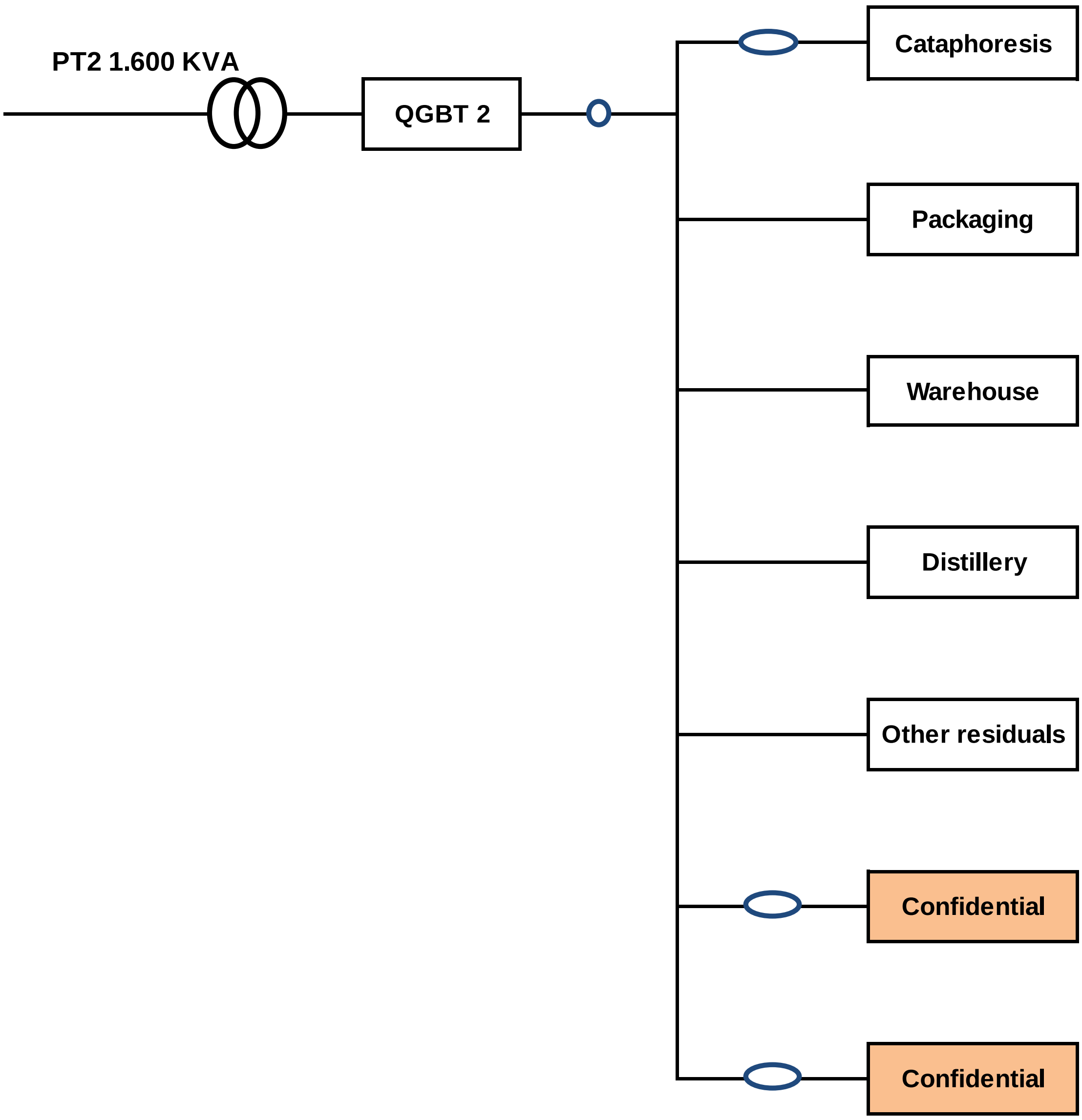
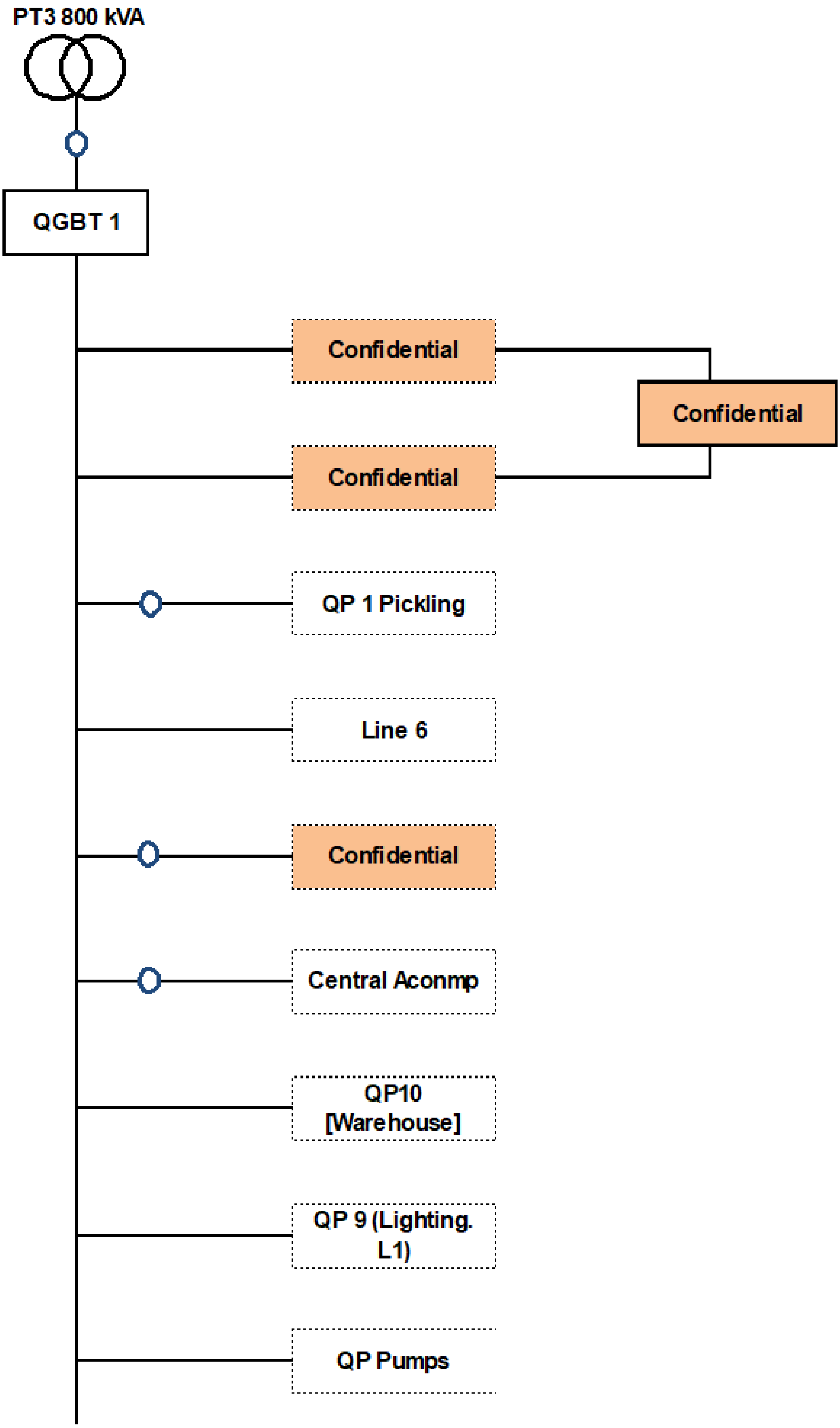


Figure 19: Simplified diagram of PT2 outputs


PT3 800 kVA
QGBT 1
Confidential
Confidential
Confidential
QP 1 Pickling
Line 6
Confidential
Central Aconmp
QP10 [Warehouse]
QP 9 (Lighting. L1)
QP Pumps

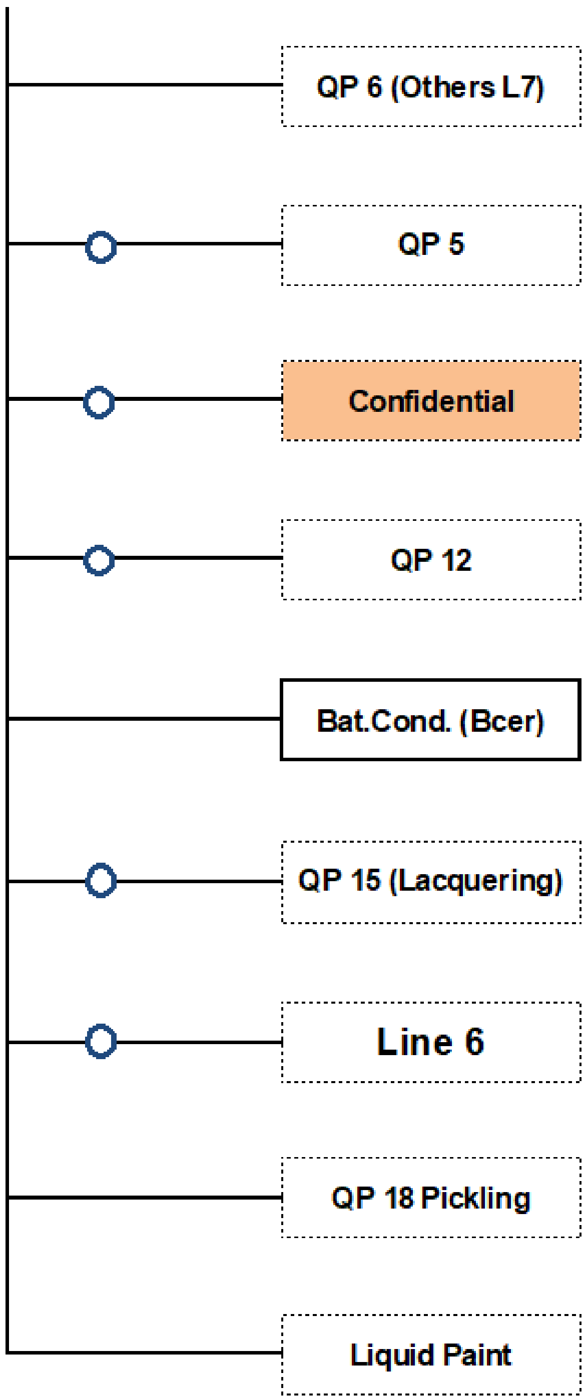


Figure 20: Simplified diagram of PT3 outputs

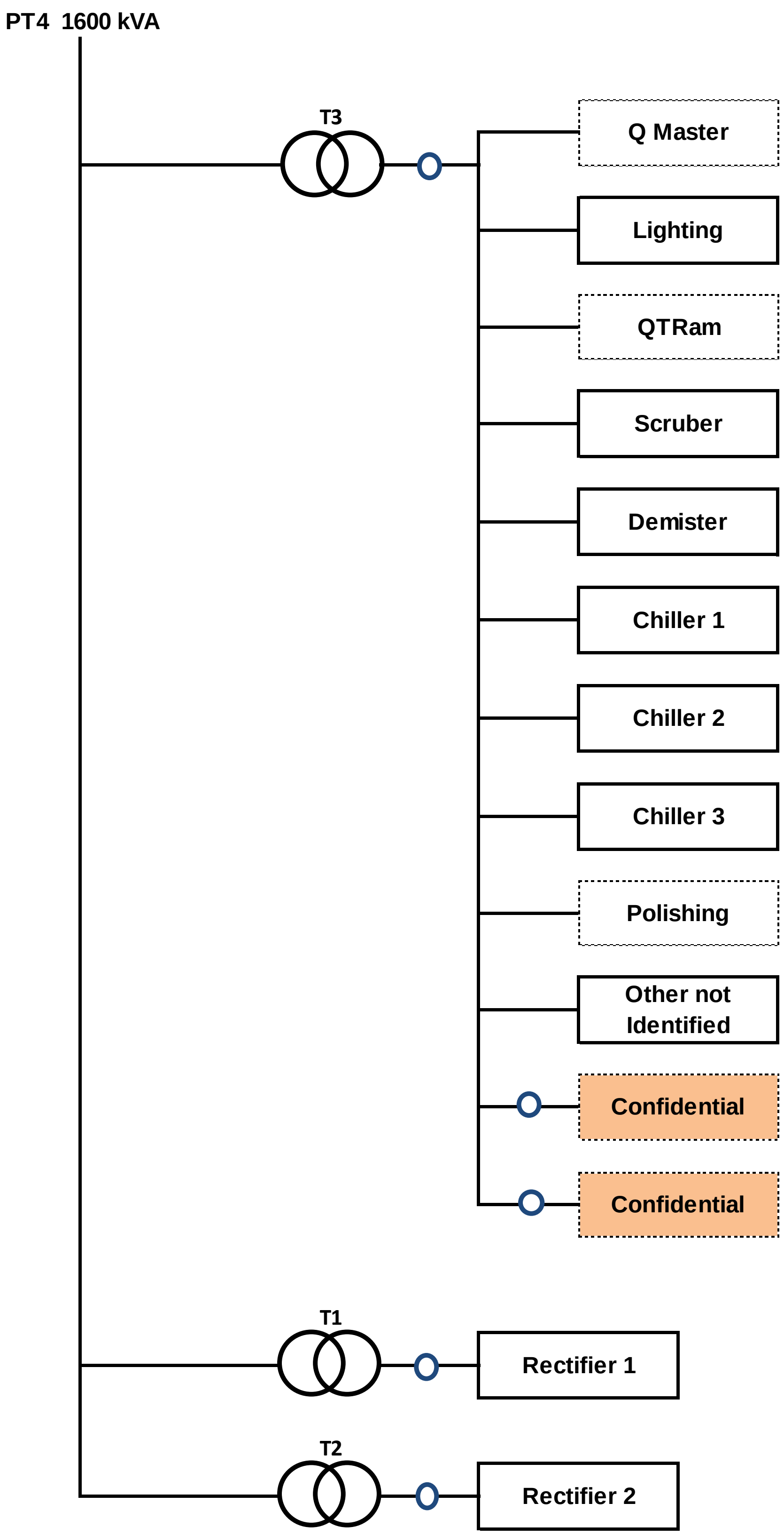


Figure 21: Simplified diagram of PT4 outputs

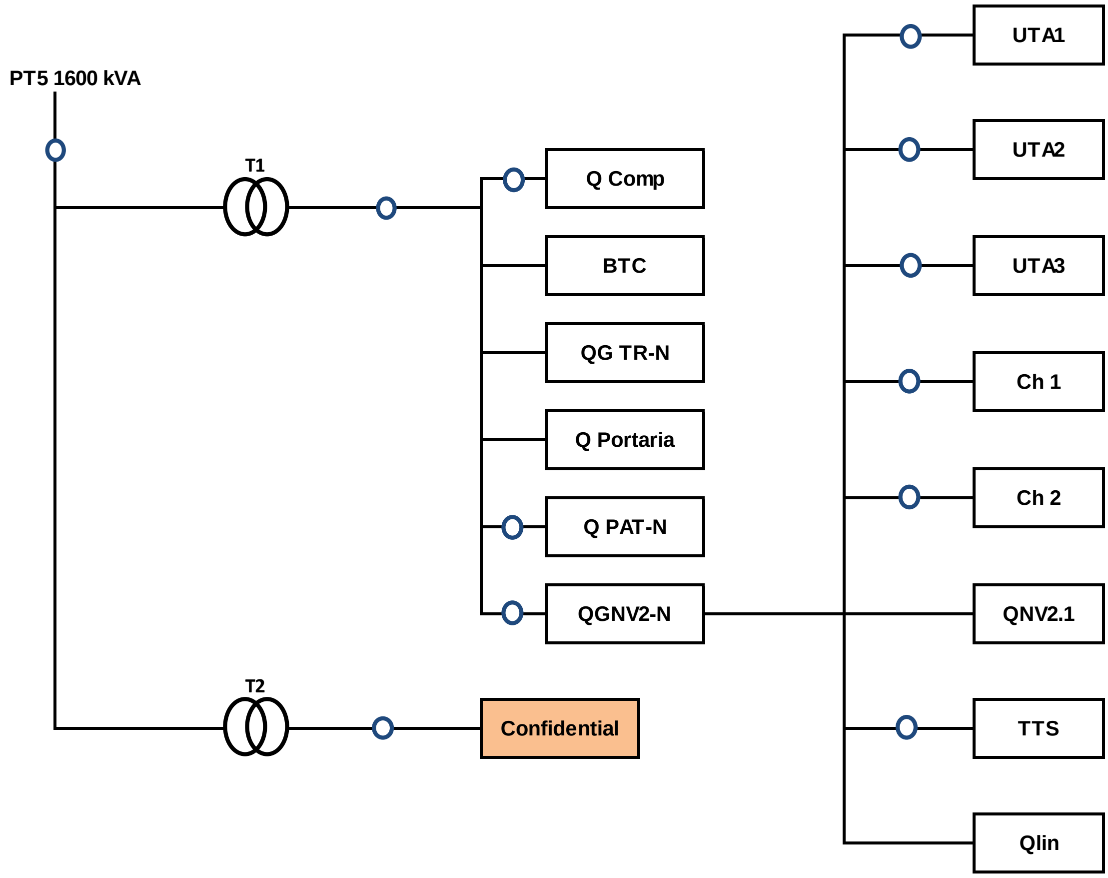


Figure 22: Simplified diagram of PT5 outputs

There are six other companies that are present along with the studied facily (one of them is no longer on the premises, so the consumptions are from the studied facility, and another one is cureently with no activity and without consumptio) are continuously monitored and they are referred here as ‘’Confidential’’. The consumption of two other companies (QP3 and QP4 of the PT3 and part of the consumption of the QP5) were estimated based on punctual measurements, being residual compared to the consumption of the studied facility.

- Sectioning Station;
- Transformation Stations;
- Low Voltage General Boards (QGBT);
- Partial frames.

Natural gas:

The natural gas consumed in the facility is used essentially in the boilers for the steam production and in the chillers.

Diesel:

The installation's consumption of diesel is associated with service cars, this type of energy has the lowest energy consumption and the least financial charges to the facility.

2.5 Auxiliary Services:

Auxiliary Services represent auxiliary and indispensable commodities for the development and execution of various operations of the production process. In this manufacturing unit, considered auxiliary services are the following:

- Compressed Air
- Hot Water
- Thermal Oil
- Cold Water
- Ventilation
- Lighting
- Water Collection and Treatment

Below, a detailed description and characterization of the auxiliary services is presented.

2.5.1 Compressed Air Unit:

In order to produce compressed air in the facility, we have two centrals (one is dedicated to line 8 and one is for the rest of the lines) with the following equipments:

Central	Brand	Model	Control	Set-points [bar]	Nominal Power [kW]
1	BOGE	SLF 125-3	VSD	7	90
	BOGE	S 90-4LF	VSD	7	90
2	BOGE	S 160-4LF	VSD	7,5	160
	BOGE	S 150-3	VSD	7,6	110
	Atlas Copco	GA250	C-V	7,7	250

Table 3: Main characteristics of compressors

Both plants also have compressed air tanks (4x3m3) and dryers (adsorption with PDP control and air regeneration in 1 and cooling in 2.

Figure 23: Production of Compressed Air

As for the Line 7 blowers, there are two 37 kW and one 3 kW equipments that blow into the electro-polishing baths (discharge pressure is around 300 mbar).

2.5.2 Hot Water Sub-unit:

The hot water production equipment of the studied facility is characterized by natural gas boilers for line 1 and burners and smoke pipes for line 2. The produced hot water heats the baths for the surface treatment of the parts and also serves to acclimatize the greenhouses of some production lines. The production of hot water is divided as follows by the production lines:

Line	**#Boiler**	**Nominal Power [kWt]**
5	1 (Pre-degreasing bath)	740
	2 (Phosphating bath)	1.200
6	1 (Classified company)	1.160
7	1+2 (Baths)	2x930
8	1 (Classified Company)	~1.500 (est.)
	2 (showers)	525

Table 4: Main characteristics of hot water boilers

Figure 24: Boilers of hot water

2.5.3 Thermal Oil:

Thermal oil by definition qualifies a material causing a sticking or welding effect under the effect of heat. This thermal oil heats the chemical pickling baths which are normally around 120°C.

Line	Brand/Model	Nominal Power [kWt]
5	Babcock Wanson	116

Table 5: Main characteristics of thermal oil boilers

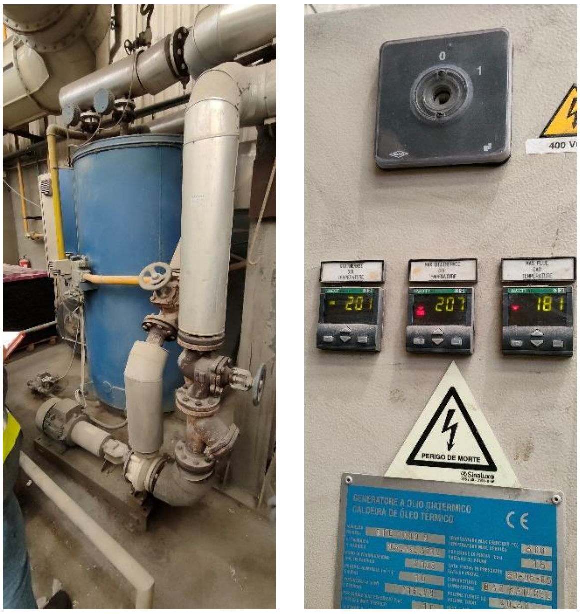


Figure 25: Thermal oil Boiler

2.5.4 Cold Water:

On Line 7 there are three chillers dedicated to the cooling of some anodizing baths, through indirect exchange with the respective bath in plate exchangers. On Line 8, on the other hand, these machines are only used for air conditioning the painting lines, by cooling and dehumidifying the supply air of the UTA. Similar to Line 8, on Lines 6 and 1 there are dedicated equipment for air conditioning the painting/lacquering lines.

Central	Brand	Model	Nominal Potential [kWe]	Nominal Power [kWt]
1 (L7)	Climaveneta	NECS/B 2015	3x184	3x525
2 (L8)	Climaveneta	NECS/B 1715	2x160	2x435
3 (L6)	Climaveneta	FOCS/B 2432	179	466
4 (L1)				

Table 6: Main characteristics of chillers

Figure 26: Cold Water Central

2.5.5 Ventilation System:

Ventilation is the mechanical system in a building that brings in "fresh" outdoor air and removes the "contaminated" indoor air. In a workplace, ventilation is used to control exposure to airborne contaminants. It is commonly used to remove contaminants such as fumes, dusts, and vapours, in order to provide a healthy and safe working environment. The Ventilation equipment in the facility are assigned to the lines of the production of ‘’ the classified company’’ and the extraction and insufflation fans from line 7.

Figure 27: Ventilation equipment (L8, Scrubber L7)

2.5.6 Lighting:

The facility is equipped by LED Lightning in most of its area and a specific power per unit of area and operating hours was estimated (also depending on whether or not there is natural lighting) to measure the consumption of this sub-unit.

2.5.7 Water Collection and Treatment:

Water treatment involves a series of procedures to ensure a seamless flow of treated water for use at an industrial facility. Industrial water treatment performs a critical role in protecting against risks and rising operating costs, as well as the sustainability of the business. Poorly managed water treatment can lead to corrosion of costly equipment, as well as result in a lackluster product and countless other (expensive) issues. For this process, the facility is equipped by ‘’water bore’’ for the collection of water and a ‘’reverse osmosis’’ for the treatment of the water and effluents.

Chapter 3

Energy Analysis of the Facility:

- This chapter presents the evolution of the installation's energy consumption in the year 2021 and the respective associated costs, determining the possible consumption trend and the evolution of costs per unit of energy considered.

The following table indicates which conversion factors are considered for the calculation, as stipulated in DL 71/2008 and subsidiary ordinances.

	Conversion factors considered				
Type of energy	**MJ/kg**	**tep/kg**	**tep/kWh**	**Kg CO_2/tep**	**Kg CO_2/kWh**
Electricity	-	-	0,000215	-	0,47
Natural gas	45,1	0,001077	-	2683,7	-
Diesel/Gasoline	42,8	0,001022	-	3098,2	-

Table 7: Conversion Factors

3.1 Energy consumption and the associated costs:

The consumed types of energy in the facility are electricity, natural gas (referred here as NG) and diesel. The following figures display the facility's global final energy consumption during 2021.

	Primary Energy						
	Electricity				Fossil		
	Consumed	Purchased	Produced	Shared	NG		Diesel
	kWh	kWh	kWh	kWh	m3	kg	kg
jan/21	912,242	1,221,142	11,417	-320,317	165,558	139,135	2,505
fev/21	856,682	1,134,676	13,403	-291,397	136,568	114,772	0
mar/21	987,421	1,311,800	26,014	-350,393	175,409	147,414	0
abr/21	931,670	1,224,147	26,937	-319,414	150,750	126,690	2,505
mai/21	922,003	1,175,448	37,807	-291,252	142,559	119,807	0
jun/21	897,401	1,132,247	37,481	-272,327	126,848	106,603	0
jul/21	969,739	1,104,395	38,667	-173,323	114,954	96,607	0
ago/21	688,445	839,554	30,609	-181,718	70,228	59,020	2,505
set/21	932,192	1,176,320	26,368	-270,496	121,700	102,277	0
out/21	756,217	983,594	19,593	-246,970	108,257	90,979	0
nov/21	818,770	1,057,735	14,871	-253,836	52,334	43,981	0
dez/21	783,845	872,463	9,231	-97,849	115,453	97,027	2,505
TOTAL	**10,456,628**	**13,233,521**	**292,398**	**-3,069,291**	**1,480,618**	**1,244,311**	**10,020**

Table 8: Global primary energy consumption

Methodological note: "purchased" electricity refers to what is actually billed to the company, although part of this consumption "Shared" refers to consumption by other companies within the factory. The electrical energy consumed by the studied facility is shown in the "Consumed" column, which results from the sum between what is produced by the photovoltaic system and the difference of this "Shared" portion to the billed consumption:

"Consumed" = "Purchased" + "Produced" + "Shared''

Also NG refers to natural gas.

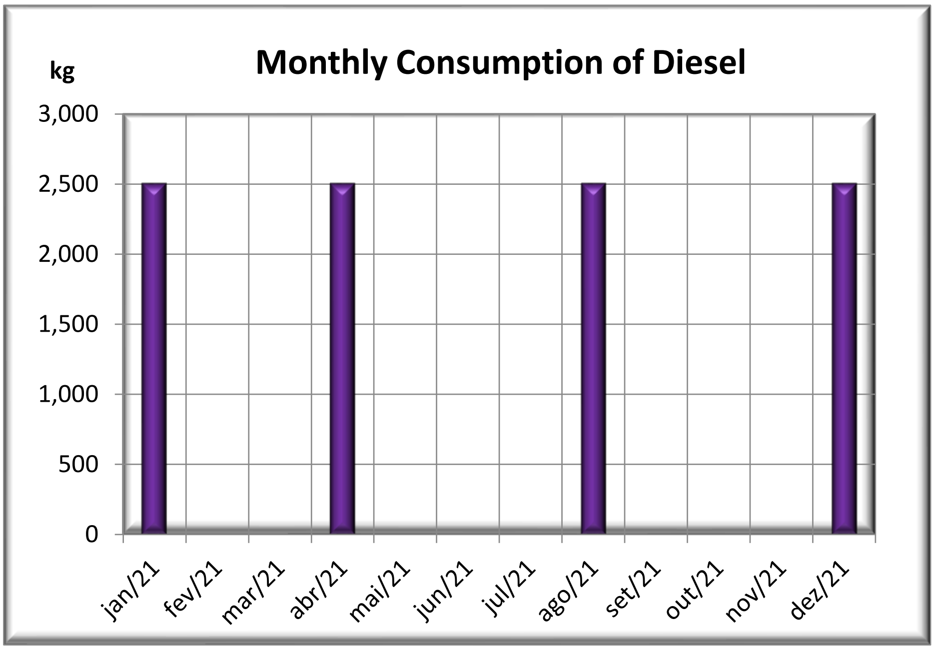


Figure 28: Monthly Consumption of Diesel

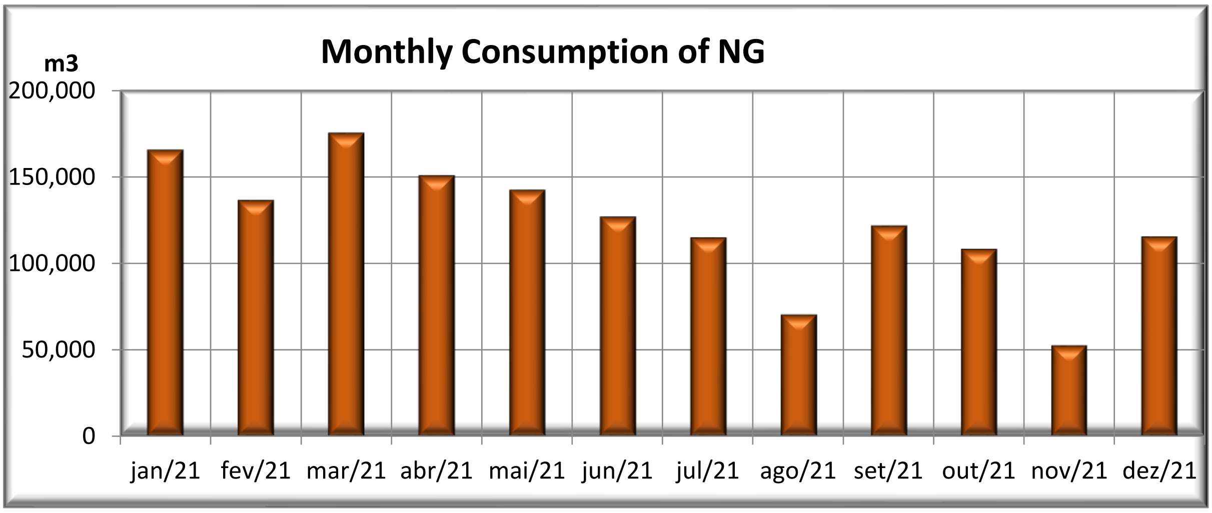


Figure 29: Monthly Consumption of NG

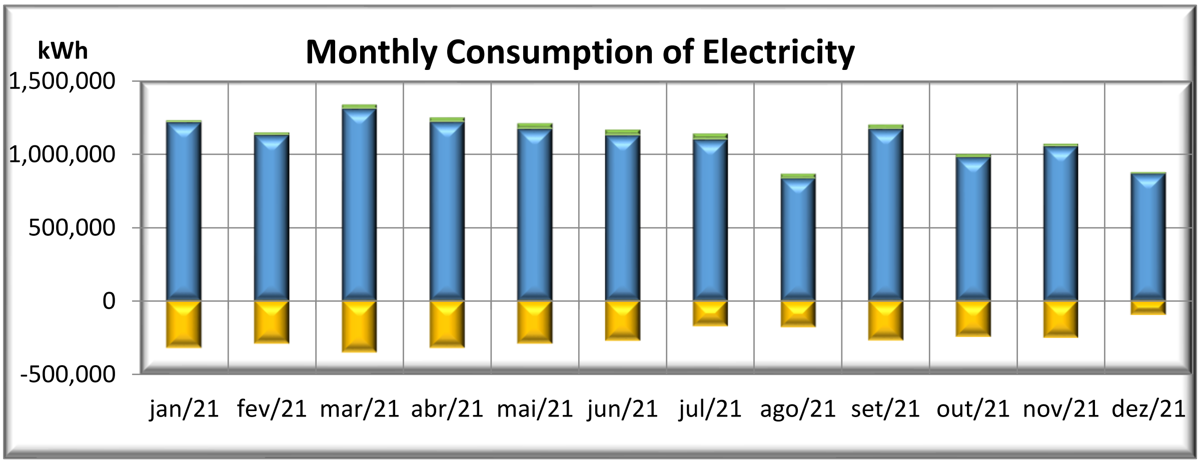


Figure 30: Monthly Consumption of Electricity

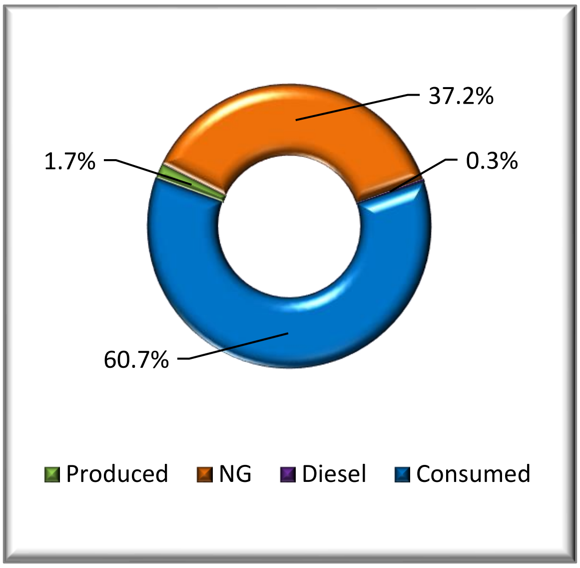


Figure 31: Distribution of energy consumption by energy type

Analysing the information presented, it can be concluded that electricity is the highest source of energy that is used in the facility, representing around 60.7% of the installation's global consumption. Natural gas accounts for 37.2% of consumption, while diesel is only associated with less than 1%.

Through the study carried out on the graphs presented above, it appears that the energy consumption of the installation can be considered basically constant throughout 2021 when it comes to electricity consumption, despite the slight reduction during the second semester of the same year. Also for natural gas use we can deduct that the consumption of this type of energy is considered constant as well until we reach the second half of the same year where it has started to decrease month after month

Analysing the information presented, it can be concluded that:

- The use of natural gas at the facility was practically constant throughout for the first semester of 2021 then it started decrease month after month, the average monthly consumption value is approximately 112 toe per month. However, it is noted that March was the month with the highest consumption of this energy type by 175 toe and November was the month with the lowest consumption with 52 toe;

- Electricity consumption throughout the year did not show major discrepancies, its average monthly consumption value is 195 toe. Despite this, it is noted that march 282 toe was the month that registered the highest consumption of this energy type and that, on the other hand, August was the month with the lowest consumption 181 toe;

- As for diesel since its only used during 4 months of the whole year with constant values and amounts, consumption value during these months is equal which is 3 toe per month;

3.2 Energy Costs:

The financial costs related to energy associated to the facility depends on energy prices, referring to obtaining the different energy types used. In order to carry out the study of these costs, the analysis of the evolution of the costs associated with the energy consumption of the installation, with reference to 2021 and the result is represented in the next figure.

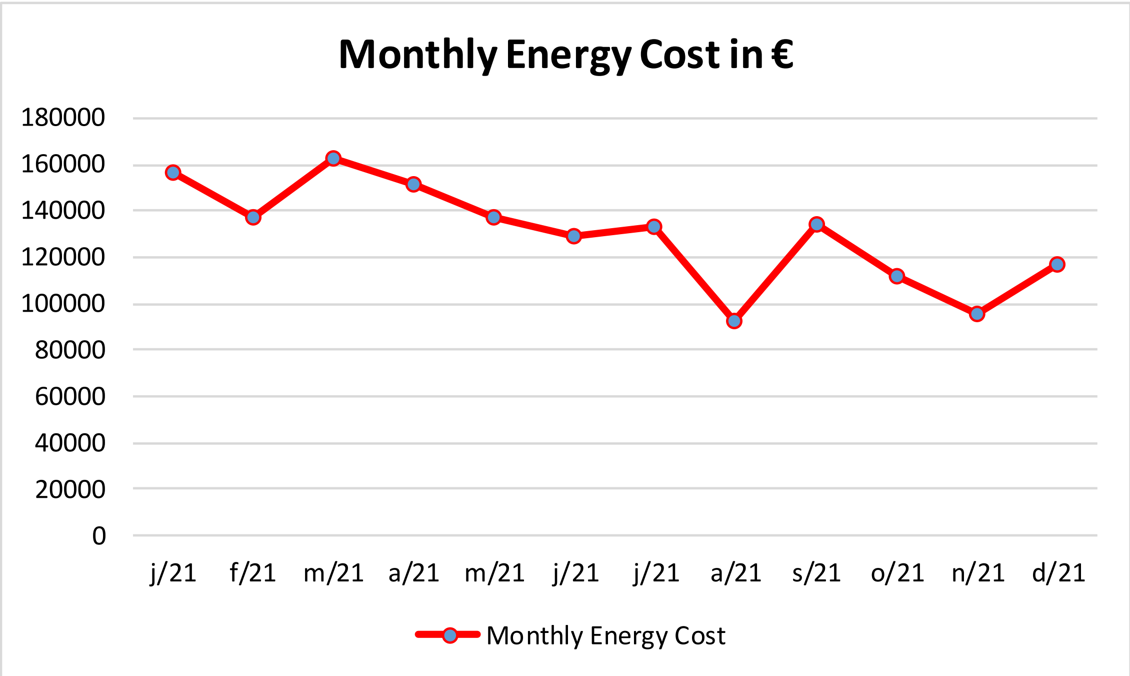


Figure 32: Monthly Energy Costs 2021

Through the study carried out on the previous table, it appears that the monthly costs of the facility's global consumption is basically constant throughout the whole year except for august and November where we had registered the lowest monthly costs. Nevertheless, the consumption peaks, and, consequently, the costs in analysis, were registered at the months of January and March.

Taking into account the analysis carried out, it became essential to relate the monthly costs of the facility, associated with energy consumption, with the different energy types used, the results of the performed analysis are represented in next table.

Month	Primary Energy					Monthly Energy Cost
	Electric Energy			Fossil		
	Consumed	Purchased	Shared	NG	Diesel	
	Eur	Eur	Eur	Eur	Eur	Eur
j/21	86,308	116,997	-30,690	66,798	3,178	156,284
f/21	80,305	108,055	-27,750	57,086	0	137,391
m/21	90,951	124,099	-33,148	71,867	0	162,818
a/21	85,029	115,049	-30,019	63,392	3,410	151,831
m/21	84,112	111,818	-27,706	53,230	0	137,342
j/21	81,570	107,402	-25,832	47,670	0	129,240
j/21	88,578	105,067	-16,489	44,738	0	133,316
a/21	62,882	80,252	-17,370	26,608	3,568	93,058
s/21	87,560	113,707	-26,147	47,126	0	134,686
o/21	71,301	95,206	-23,905	40,871	0	112,173
n/21	77,573	102,067	-24,494	18,008	0	95,581
d/21	73,220	82,469	-9,249	40,420	3,800	117,439
TOTAL	**969,389**	**1,262,189**	**-292,800**	**577,814**	**13,956**	**1,561,159**

Table 9: Monthly costs by energy type

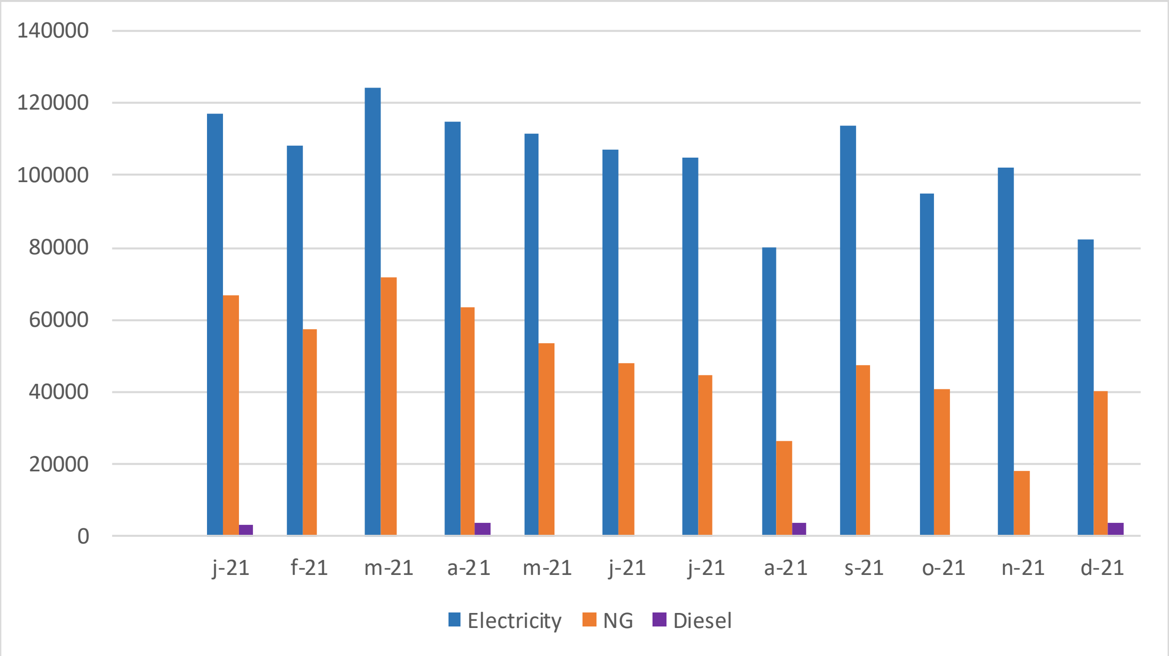


Figure 33: Representation of consumption costs by energy type during 2021

Analysing the information presented, it can be concluded that:

- Financial costs associated with the use of natural gas in the installation were practically constant during the first semester of the reference year, starting the second semester we registered a decrease of costs related to the decrease of consumption as well where the lowest values were registered during august and November, with that the average monthly value during 2021 is 47397 euros;

- Financial costs associated with the use electricity in the facility were practically constant during the whole reference year we registered a decrease of costs during the month of august which is similar to what we had for natural gas with value of 80251.9 euros, the highest costs value was registered during the month of march with a value of 124.099.11 euros the facility did not show in general major discrepancies throughout the reference year and the monthly average costs is around 107728.62 euros;

- The costs associated with the use of diesel by the facility were practically constant throughout the year, and the average monthly cost of this energy type was of approximately 1163 €. Nevertheless, it is important to mention that December was the month in which the highest financial costs were recorded for this energy type (3800€) and that the costs was only registered in 4 months as it shows on the graph.

3.3 Evolution of electricity consumption and costs:

In order to specify the use of electrical energy by the installation, it is essential to analyse the evolution of consumption of this energy type during our reference year 2021.The result of which is shown in the next figure.

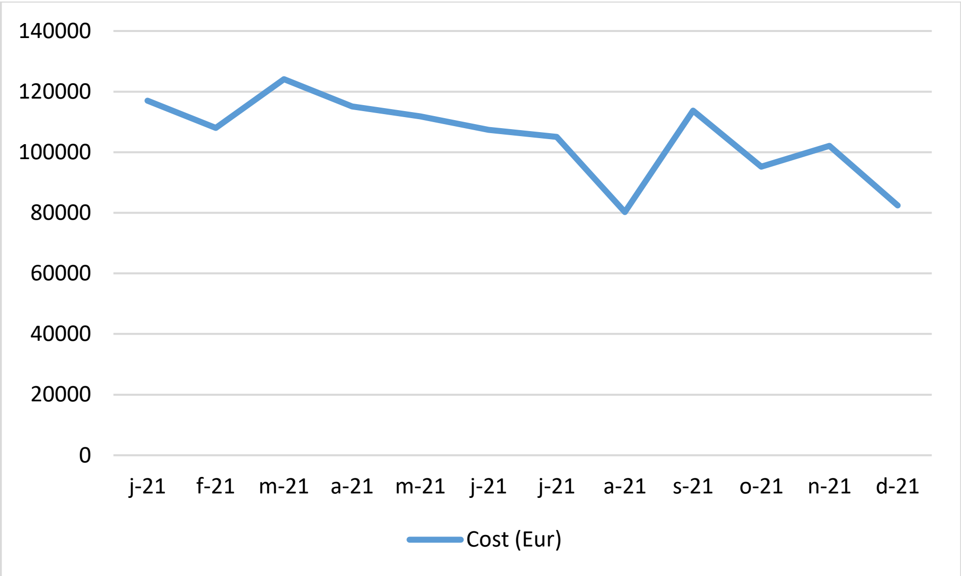


Figure 34: Evolution of electricity consumption in the facility in 2021

Through the study carried out on the graph, increases in electricity consumption can be seen during February and March where we reached the most expensive financial charges for the facility during that year and we registered a decrease of approximatively 13% during July and august where the facility was charged with 80251,9€. But in general we can say that the monthly consumption of electricity was constant during most of the year.

With regard to the financial charges associated with electricity consumption, it is presented in next figure the distribution of global and specific electricity costs over the reference year.

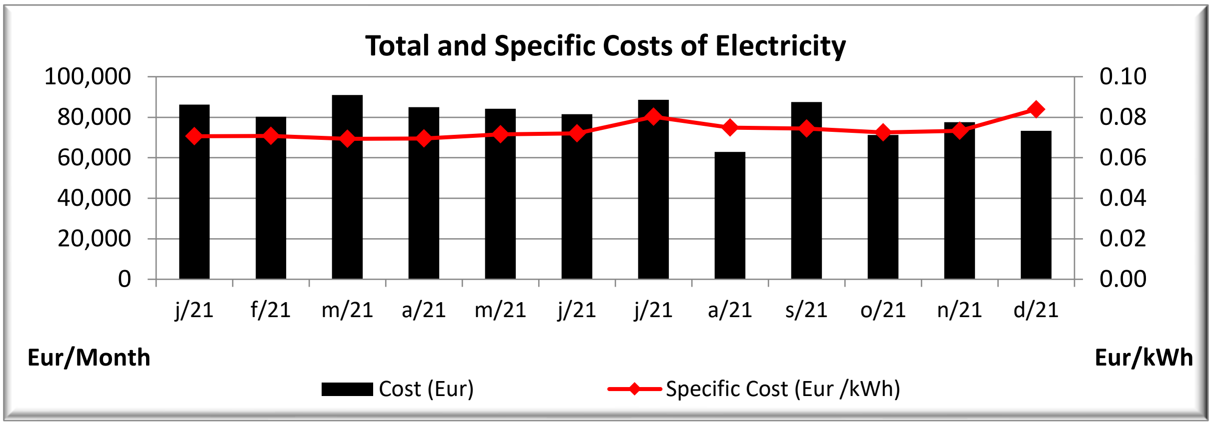


Figure 35: Total and specific costs of electricity

The analysis of the graph presented allows us to conclude that during the reference year, the specific cost of electricity was almost constant during every month as it is shown in the graph above us, just a slight increase during the second semester of the year from October until December.

The processing and treatment of electricity bills provided by the facility allowed to verify how the electrical energy consumption in the installation was distributed, according to the number of available hours in each charged schedule of the optional weekly cycle, adopted in 2021.

	Super Off-Peak (kWh)	Off-Peak (kWh)	Standard (kWh)	Peak hour (kWh)	Contracted Power (kW)	Power in peak hours [kW]	Cost (Eur)	Specific Cost. (Eur /kWh)
j/21	151,937	211,759	609,176	248,270	4,136	2,483	116,997	0.0958
f/21	138,658	190,758	568,720	236,540	4,136	2,365	108,055	0.0952
m/21	166,495	209,342	675,498	260,465	4,136	2,390	124,099	0.0946
a/21	161,581	207,373	692,953	162,240	4,136	2,575	115,049	0.0940
m/21	155,318	202,893	655,829	161,408	4,244	2,562	111,818	0.0951
j/21	150,249	210,910	620,709	150,379	4,244	2,506	107,402	0.0949
j/21	146,373	188,316	621,860	147,846	4,244	2,240	105,067	0.0951
a/21	111,624	154,038	462,998	110,894	4,244	1,680	80,252	0.0956
s/21	133,171	188,984	682,871	171,294	4,244	2,595	113,707	0.0967
o/21	125,525	179,078	541,345	137,646	4,244	2,294	95,206	0.0968
n/21	130,534	167,699	536,057	223,445	4,244	2,128	102,067	0.0965
d/21	110,702	189,687	403,533	168,541	4,244	1,605	82,469	0.0945
Sub-Total	**1,682,167**	**2,300,837**	**7,071,549**	**2,178,968**			**1,262,189**	**0.0954**
Total (kWh/year)	**13,233,521**							

Table 10: Energy and Power Consumption by tariff periods

Through the study carried out on the table above us, it is concluded that the highest values of consumption of electric energy by the facility were mainly charged during standard pricing as it is shown on the next graph.

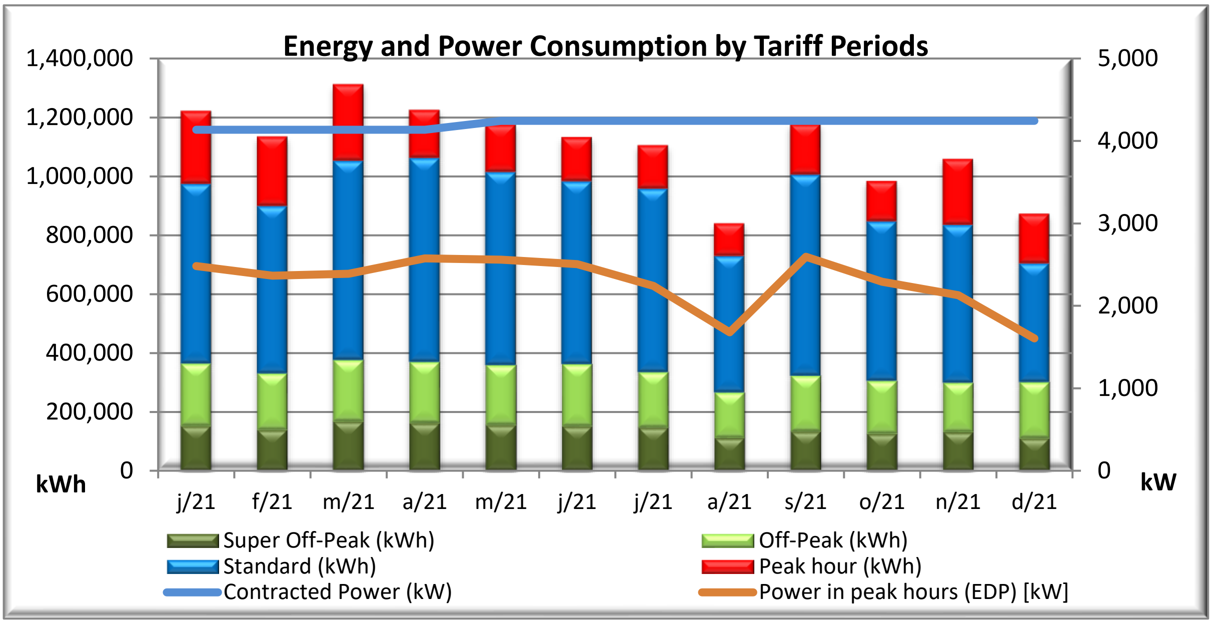


Figure 36: Energy and Power Consumption by tariff periods

3.4 Evolution of consumption and costs of natural gas:

In order to specify the facility's use of natural gas, it is essential to analyse the evolution of consumption of this energy type during the reference year 2021. The results are shown on the next figure.

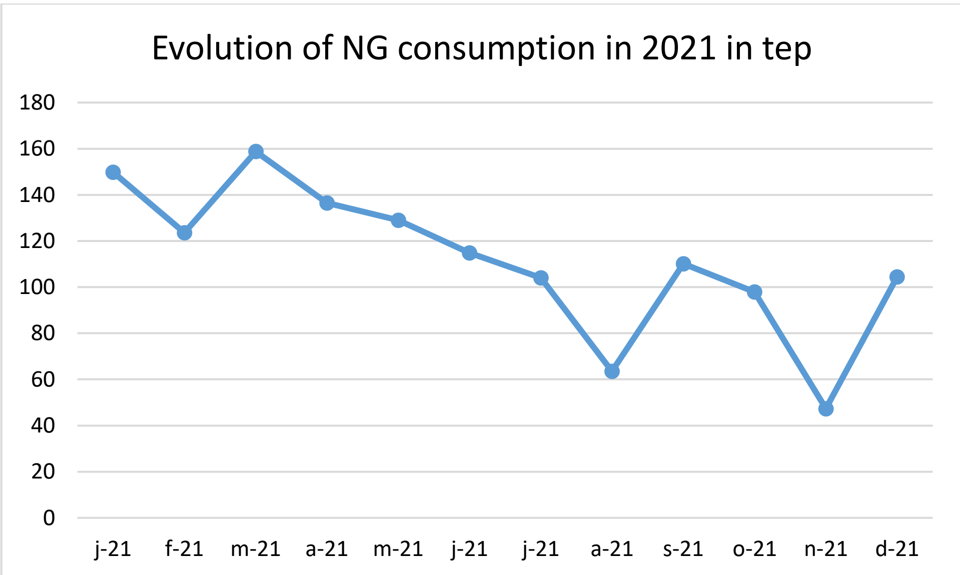


Figure 37: Evolution of NG consumption in 2021 in tep

Analysing the graph presented, it can be concluded that the consumption of natural gas in the installation can be considered inconstant, as it is shown in the graph above us during the first semester the consumption values of Natural Gas were decreasing starting March until August then for the rest of the year it was changing every month. The highest consumption value during the reference year was registered on March with 159 tep of consumption while the lowest was during November with 47 tep of consumption.

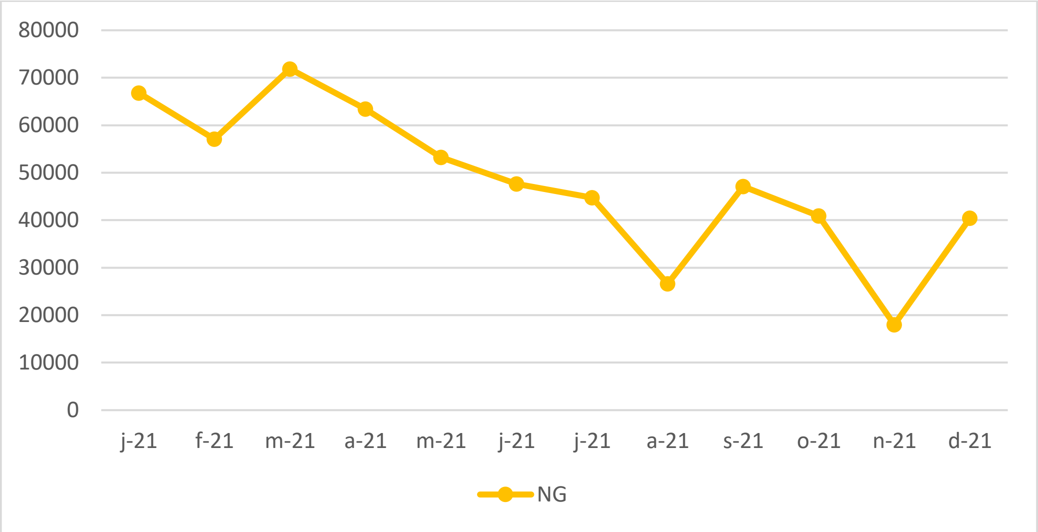


Figure 38: Costs associated with the use of natural gas in the reference year

The previous graph represents the monthly costs associated to the natural gas consumption, we can deduce that the financial costs due the consumption of this type of energy was inconstant throughout the whole year, during the month of March we had registered the highest financial cost with 71867 € and for the lowest value it was registered during November with 18008 €.

3.5 Evolution of diesel consumption and costs:

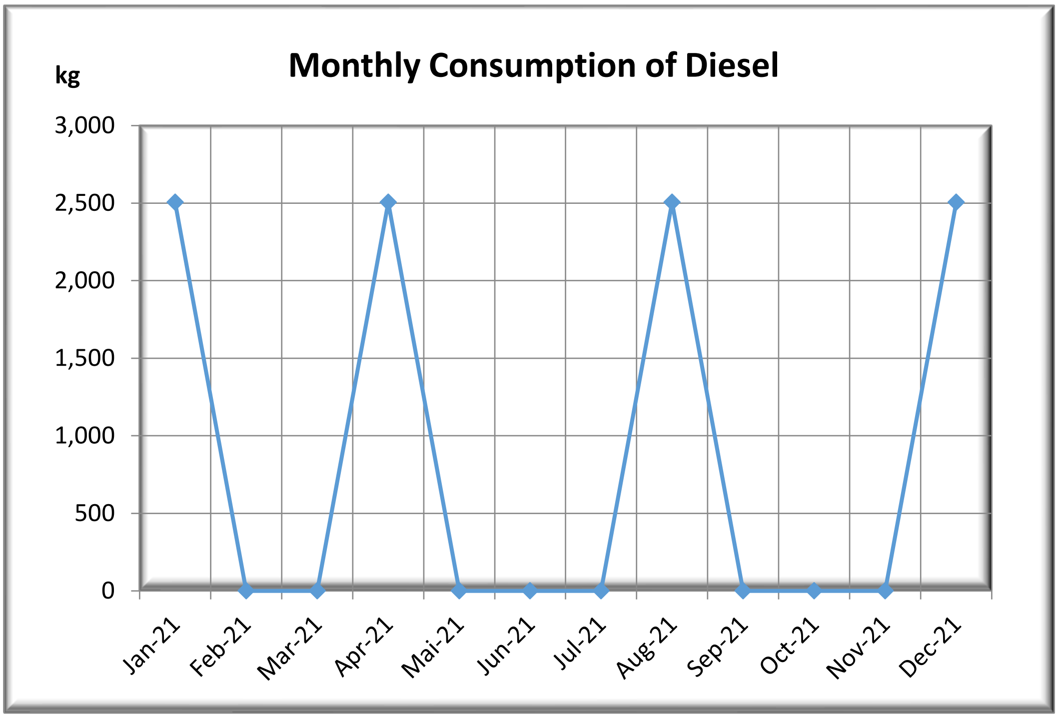


Figure 39: Monthly Consumption of Diesel in 2021

Analysing the graph presented, it can be concluded that the consumption of diesel in the facility is considered quarterly which means that diesel is consumed every 3 months with constant values with 2505 kg which is the maximum.

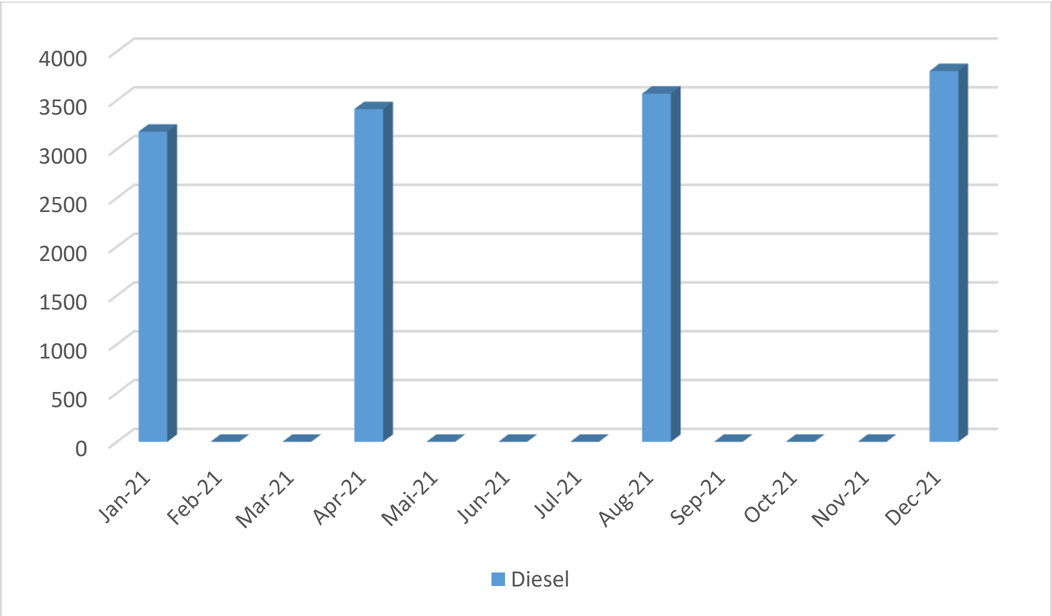


Figure 40: Diesel Monthly Cost in 2021 in €

As this type of energy is baught only once every 3 months, we get to have this type of graph, the small variation that we have depends on the change of diesel prices in Portugal.

3.6 Production:

In order to proceed with the calculation of the production of the audited facility, production results were given by the facility itself were it was measured by m2 painted on each piece.

The results for the reference year 2021 are presented in the next table.

	Production
	m^2
January	159.957
February	156.119
March	186.074
April	179.176
Mai	170.635
June	136.103
July	157.631
August	68.404
September	125.888
October	129.891
November	160.476
December	133.585
Total	1.763.938

Table 11: Production results during 2021 in m2

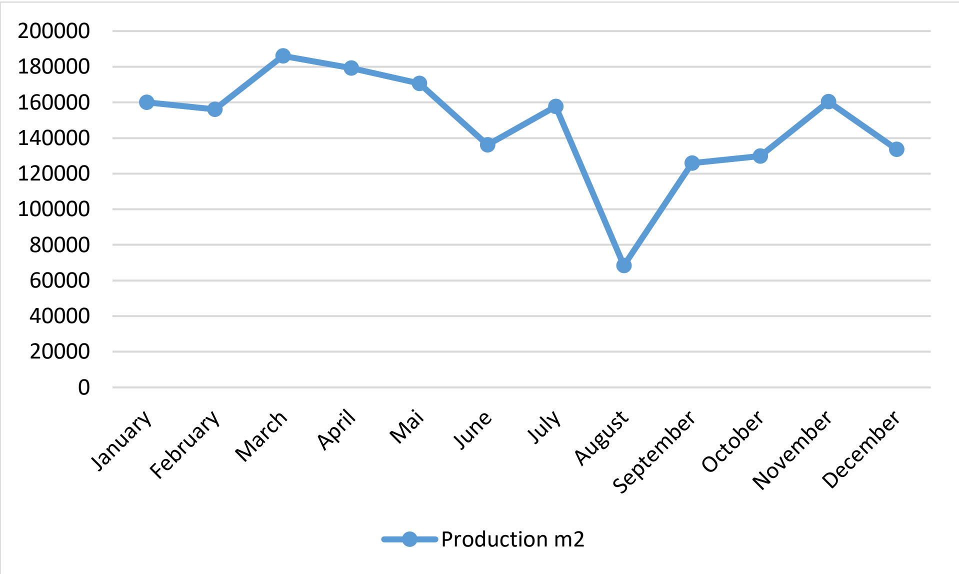


Figure 41: Production results during 2021 in m2

Analysing the previous graph, the production results were not constant throughout the year as we can see from the graph. The highest production result was registered during March with 186.074 m^2 but the lowest was registered during August which was 68.404 m^2.

Chapter 4

Analysis of Energy Audit Results:

- During the field work of this audit, measurements was carried out on the facility's energy-consuming equipments so that their respective energy consumption could be displeased.

This chapter presents the results obtained from the monitoring carried out using some measurement equipments.

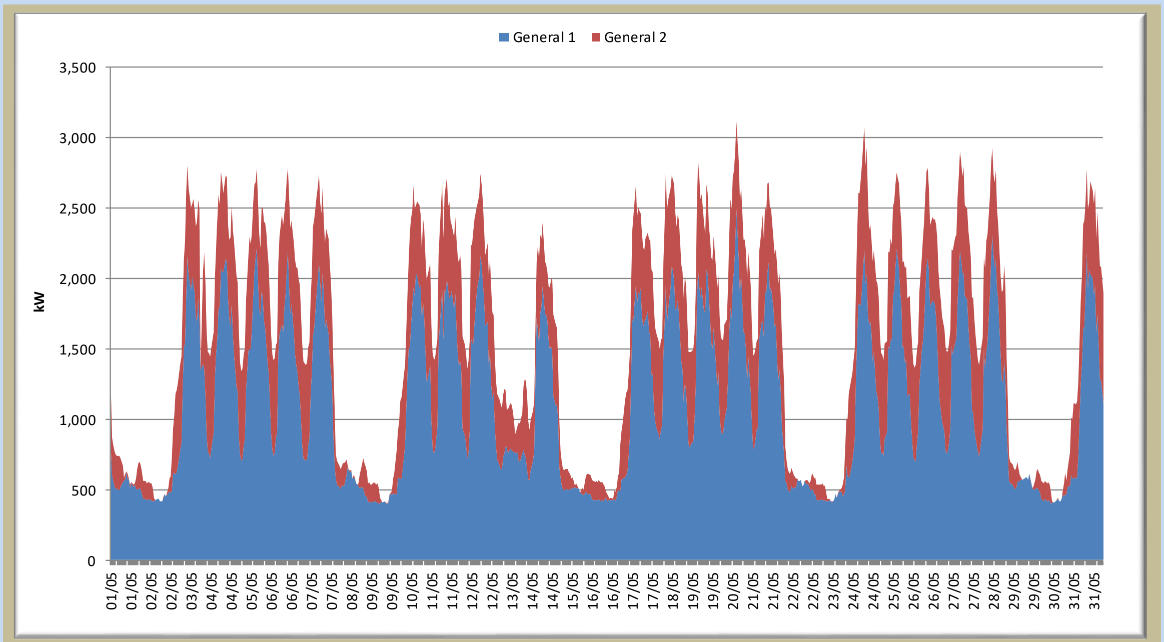
4.1 Measuring the Use of Electricity

Electricity is responsible for 26.2% of the installation's energy consumption, with its use is associated with almost all equipment and sectors of the facility the financial costs associated with this energy type represent around 1.262.189 €/year.

This subchapter presents the load diagrams obtained for each equipment or measured subsector, as well as the breakdown of electricity consumption by equipment/subsector used.

4.1.1 General Circuit:

The load diagram of the installation's input circuit, shown in the next figure shows a trend of higher electrical consumption on weekdays, requiring an average daily electrical power of 1000 kW. On Weekends the average power required is much lower (about 500 kW).



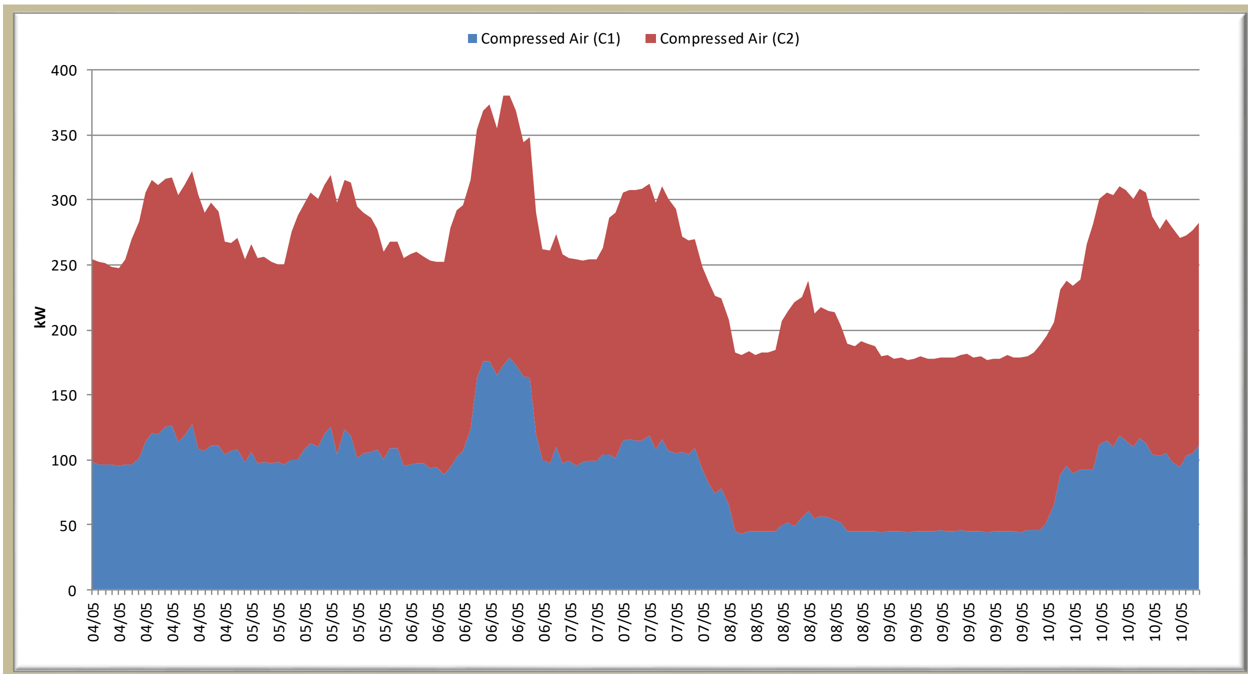
kW	Min.	Máx.	Avr
General 1	402	2,496	1,116
General 2	0	896	462

Figure 42: Load diagram of the facility's general circuit

The data collected and presented in the graph originate the electricity consumption profile of the facility. This data allow the calculation of the average daily electrical power required by the facility throughout the week.

4.1.2 Compressed Air Sub-Unit

Following the breakdown of the facility's electricity consumption, the circuit that feeds the compressed air unit was measured. The measures that were registered for this unit are represented at the next figure.



kW	Min.	Máx.	Avr.
Compressed Air (C1)	43	179	91
Compressed Air (C2)	132	207	166

Figure 43: Load diagram of the 2 compressed air

The measured circuit presents an inconstant load diagram, maintaining an absorbed power above 43 kW for (C1) and 132 kW for (C2) during the measured period from 04/05 to 10/05.

4.1.3 Cold Water Sub-Unit:

The facility's cold water sub-unit responsible for the cold water production, belonging to the auxiliary services which it is used in 3 lines of the production process (L6, L7, L8), was also measured, namely the circuit that supplies it, in its respective period of operation. The load diagram resulting from the measures carried out is represented in the next figures.

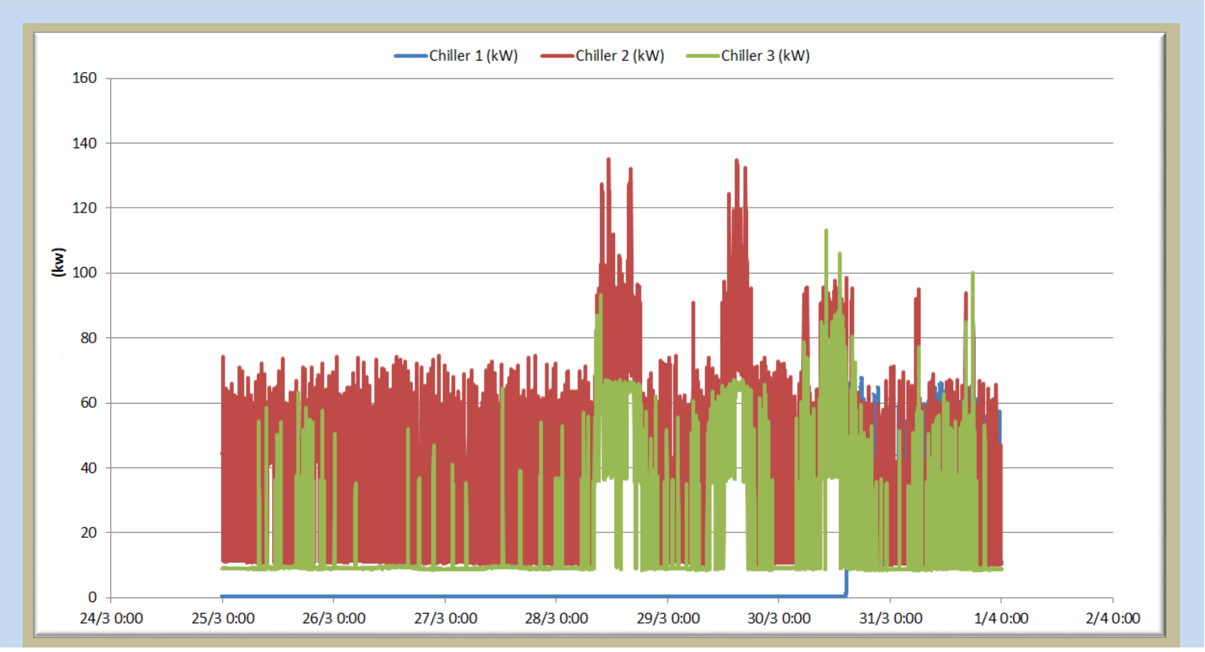


Figure 44: Load profile (kW) of Cold Water Central 1 (integration step 1min)

The first cold water central is composed of 3 chillers, the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
Chiller 1 (kW)	0,1	67,7	5,3
Chiller 2 (kW)	9,4	135,2	33,9
Chiller 3 (kW)	8,4	113,1	19,7

Table 12: Chillers taken measures

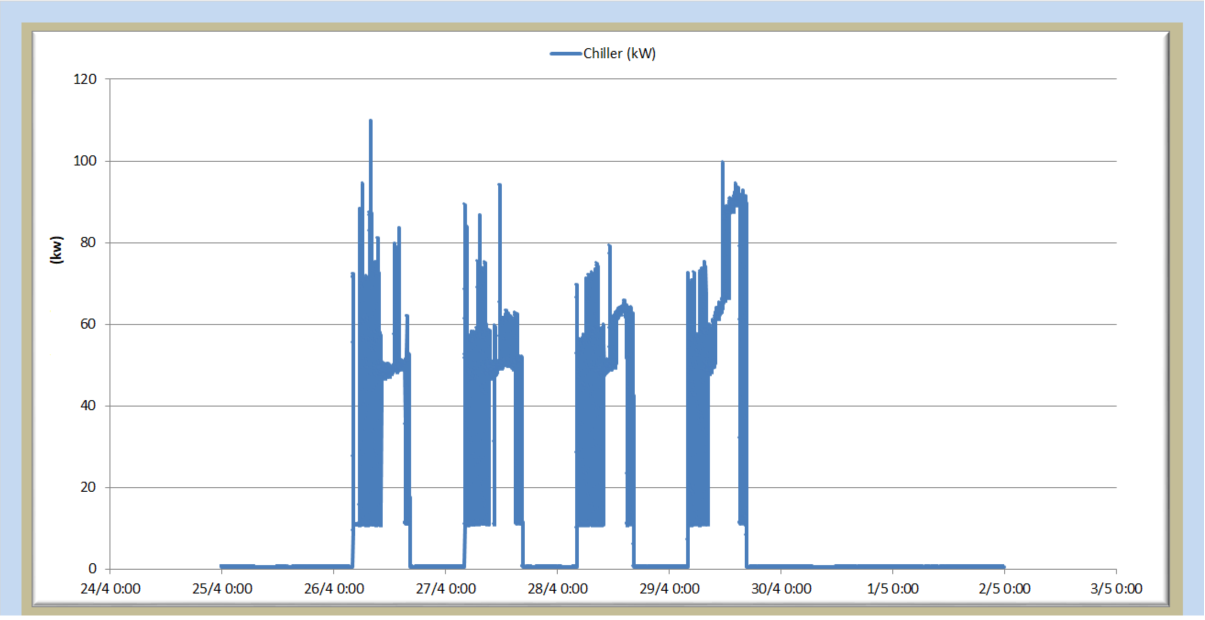


Figure 45: Load profile (kW) of Cold Water Central 3 (integration step 1min)

The second cold water central is composed of a chiller, the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
Chiller (kW)	0,5	109,8	13,5

Table 13: Chiller Taken Measures

Figure 46: Load profile (kW) of Cold Water Central 4 (integration step 1min)

The third cold water central is composed of 3 chillers, the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
Chiller 1 (kW)	-0,2	32,0	18,7
Chiller 2 (kW)	0,3	52,7	10,6
Chiller 3 (kW)	0,0	51,9	7,3

Table 14: Chillers taken measures

4.1.4 Ventilation Sub-Unit:

Following the breakdown of the facility's electrical energy consumption, the circuit that feeds the ventilation sub-units was also measured during its respective period of functioning, and the load diagram resulting from this measurement is represented in next figure

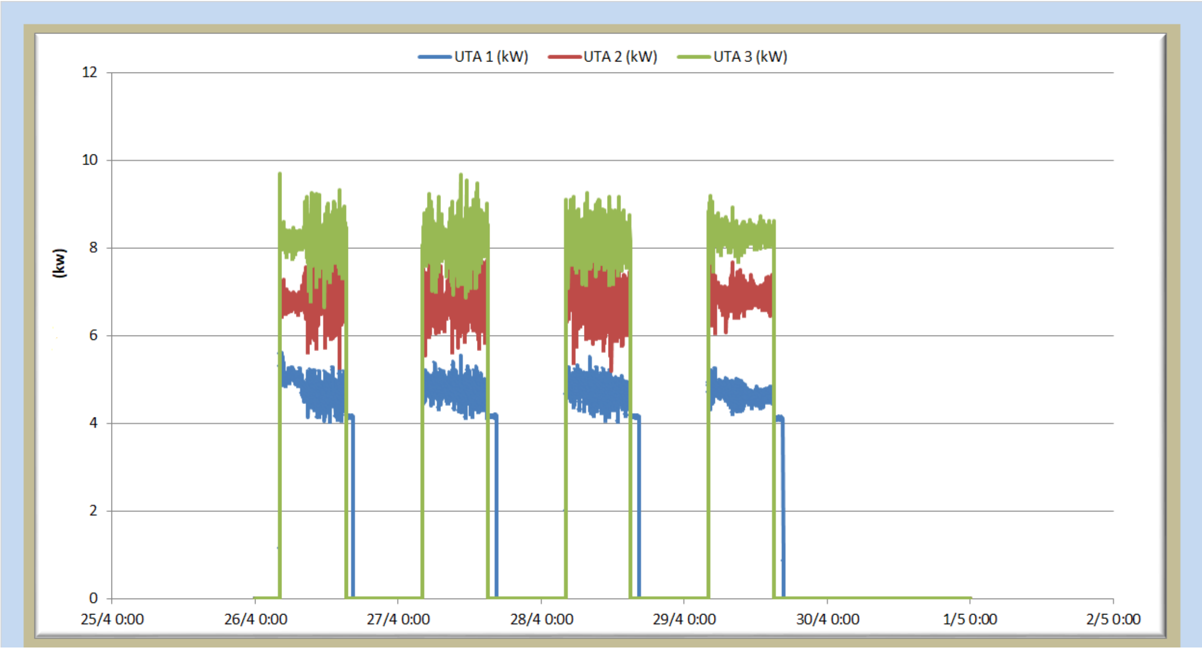


Figure 47: Load profile (kW) of UTAs Line 6 (integration step 1min)

Line 6 is has 3 Air Handling Unit (Unidade de Tratamento de Ar UTA), the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
UTA 1 (kW)	0,0	5,6	1,9
UTA 2 (kW)	0,0	8,6	2,5
UTA 3 (kW)	0,0	9,7	3,0

Table 15: UTAs taken measures

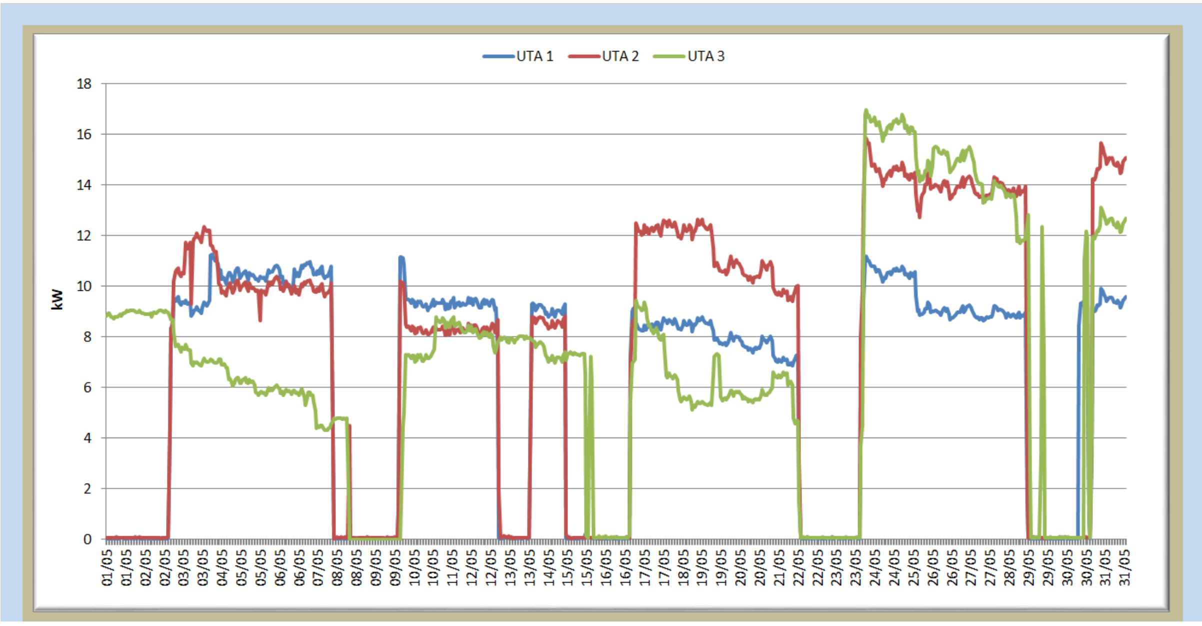


Figure 48: Load profile (kW) of Line 8 UTAs (integration step 1h)

Line 8 is has 3 Air Handling Units (UTA), the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
UTA 1 (kW)	0,0	11,3	6,1
UTA 2 (kW)	0,0	15,8	7,4
UTA 3 (kW)	0,0	17,0	7,0

Table 16: UTAs taken measures

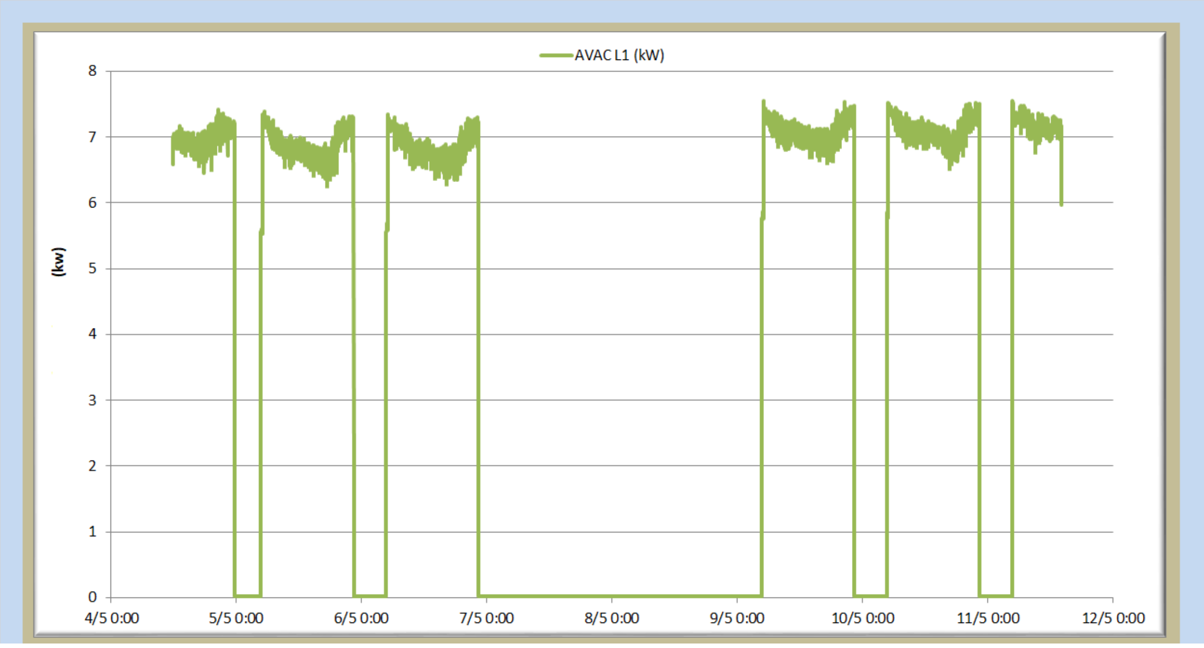


Figure 49: Load profile (kW) of UTAs Line 1 (integration step 1min)

Line 1 is has one Air Handling Unit (UTA), the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
AVAC 1 (kW)	0,0	7,5	3,8

Table 17: AVAC measures

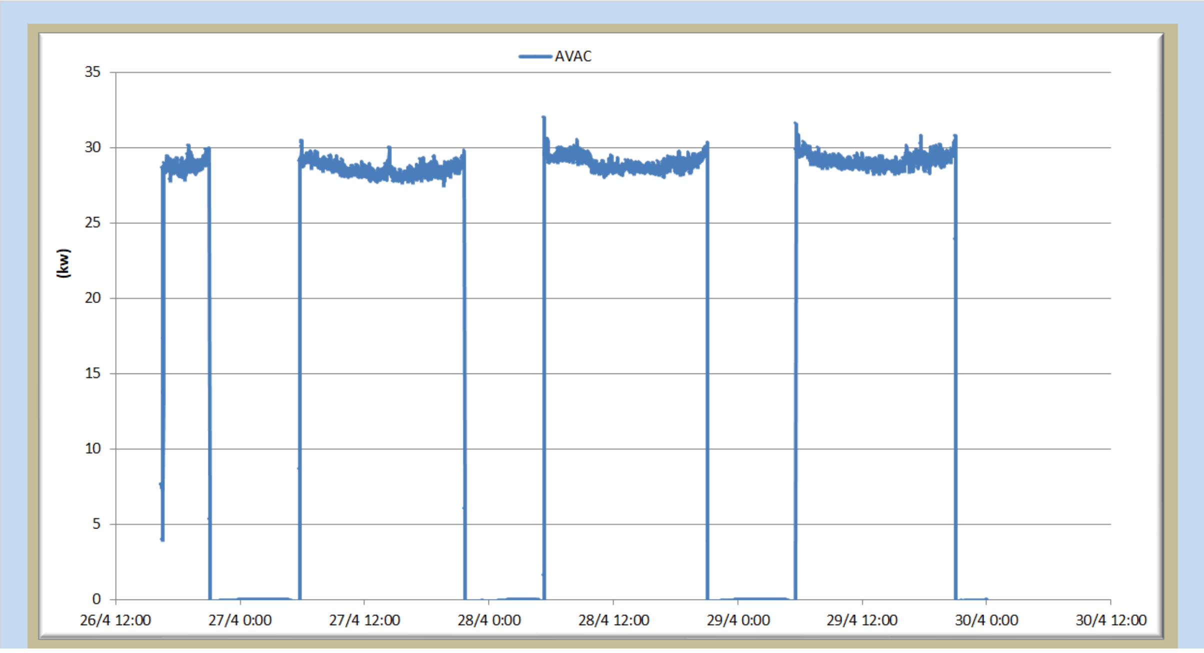


Figure 50: Load profile (kW) of cooling fans Line 1 (integration step 1min)

Line 1 has one cooling fans (AVAC cooling), the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
Cooling AVAC	-0,2	32	18,7

Table 18: AVAC taken measures

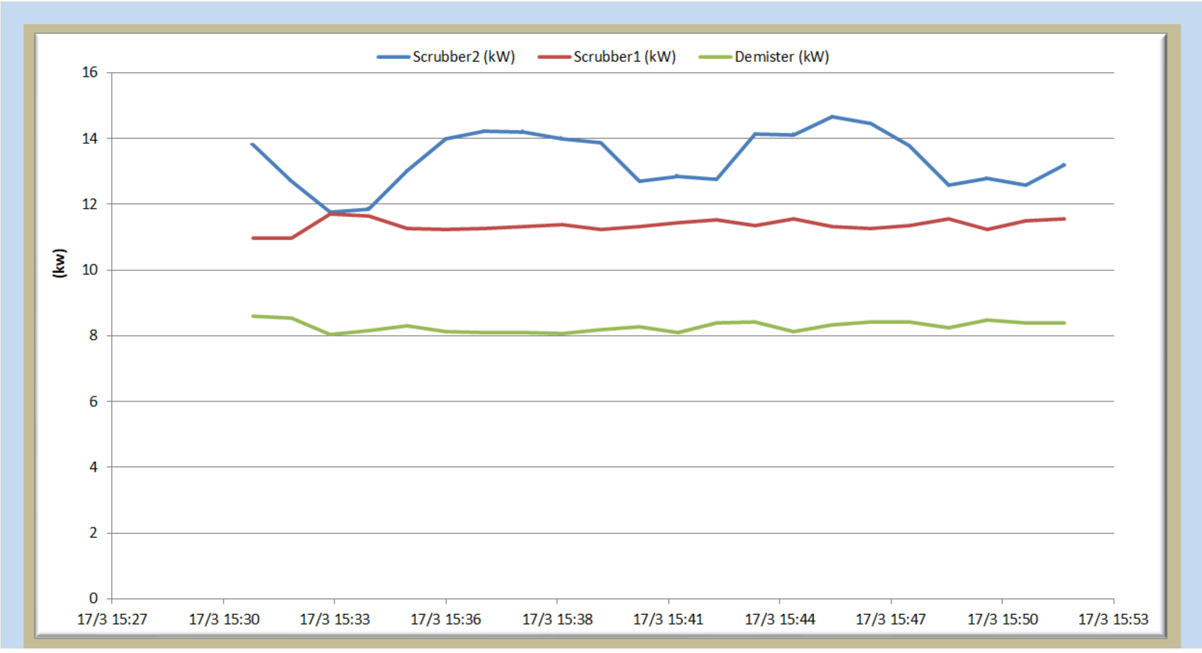


Figure 51: Load profile (kW) of L7 scrubbers (integration step 1min)

Line 7 is has 2 scrubbers and 1 demister to control gas emissions, the measures that were registered are the following:

Active Power (kW)	Min.	Max.	Avg.
Scrubber 2 (kW)	11,8	14,7	13,4
Scrubber 1 (kW)	11,0	11,7	11,4
Demister (kW)	8,0	8,6	8,3

Table 19: Scrubbers and Demister taken Measures

4.1.5 Lighting:

Lighting consumption was not measured during a short period of time because we simply cannot measure every single lamb in the facility to come up with a load diagram as other sub-units, in next graph we presented the lightning consumption throughout the whole year:

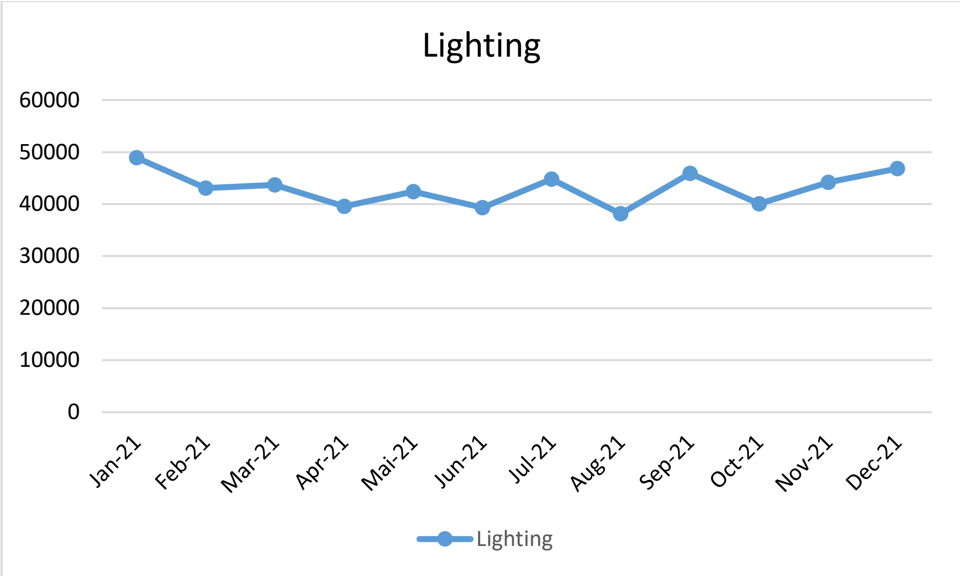


Figure 52: Lighting consumption in 2021

4.1.6 Water Collection and Treatment Sub-Unit:

The water collection and treatment sub-unit is composed of a reverse osmosis, water bore and effluents (ETAR), the measures that were registered on these equipments during the month of Mai are represented in the following graph:

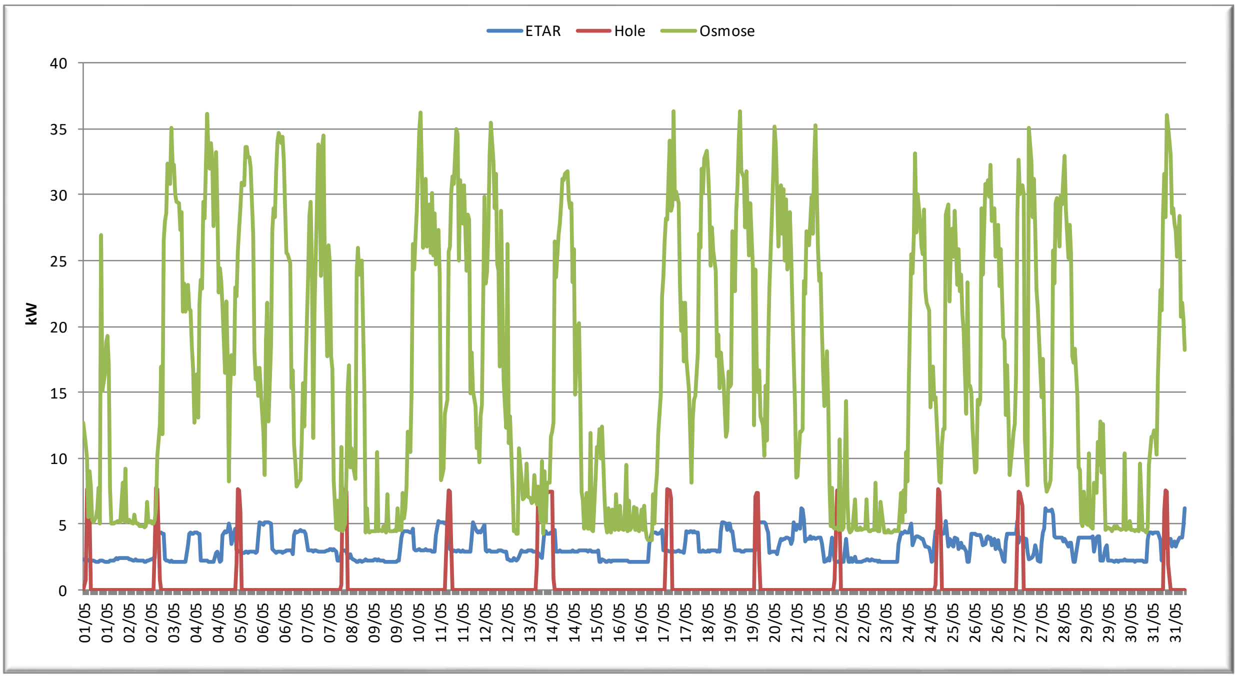


Figure 53: Load profile (kW) of the water collection unit

Active Power (KW)	Min.	Max.	Avg.
Osmose	3,8	36,4	16,7
Water Bore	0,0	7,8	0,5
ETAR	2,1	6,2	3,2

Table 20: water collection equipment measures

4.2 The Facility Energy Balance by Line of Production:

In this section we will analyse the Facility's energy balance for each lines of production and how much it represents to the global energy consumption of the whole facility.

4.2.1 Lacquering:

This section represents the energy consumption associated with the Lacquering production lines (L1/L2). Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this one essentially aggregates the consumption of electricity in the lines - tunnels, pumps and agitators (~70kW of installed power).

Line	Process Step	Nominal Power [kWt]
1 **2**	Pre- degreasing	396
	Degreasing	879
	Drying Oven	230
	Polymerization Oven	230

Table 21: Energy consumption associated with the Lacquering production line

Performed Measures:

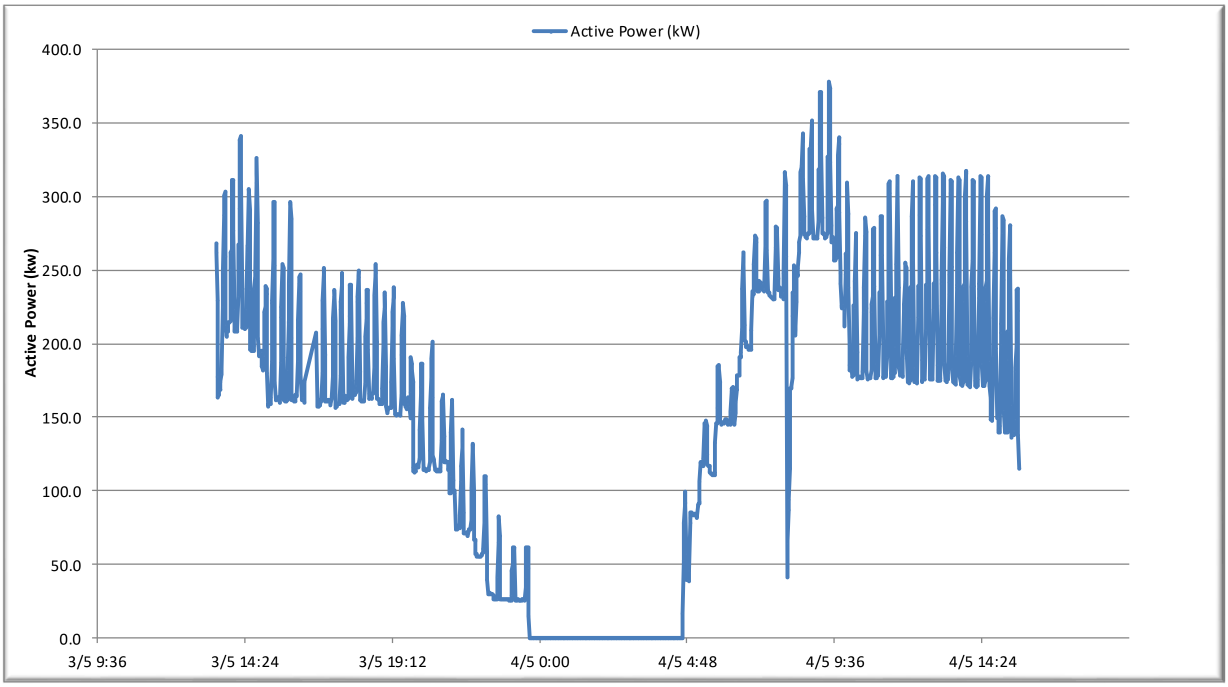


Figure 54: Lacquering load profile (kW) (integration step 1min)

Active Power (kW)	Min.	Max.	Avg.
Active Power (kW)	0,0	377,9	147,2

Table 22: Active power taken measures

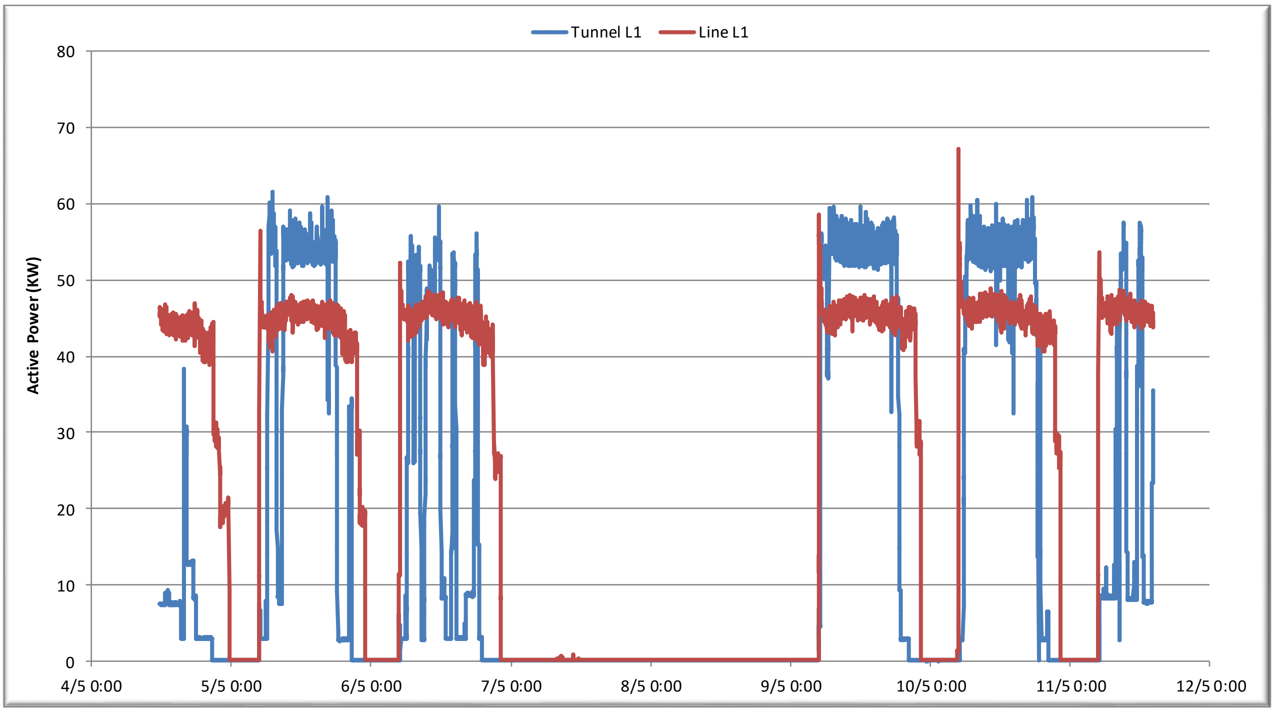


Figure 55: Load profile (kW) of Line 1 boards (integration step 1min)

Active Power (kW)	Min.	Max.	Avg.
Tunnel 1	0,1	61,5	15,6
Line 1	0,1	67,1	23,6

Table 23: Line 1 taken measures

4.2.2 Liquid paint (Line 6):

This section represents the energy consumption associated with the Liquid paint production line (Line 6). Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this one essentially aggregates the consumption of electricity in the line - tunnel and pumps.

Performed Measures:

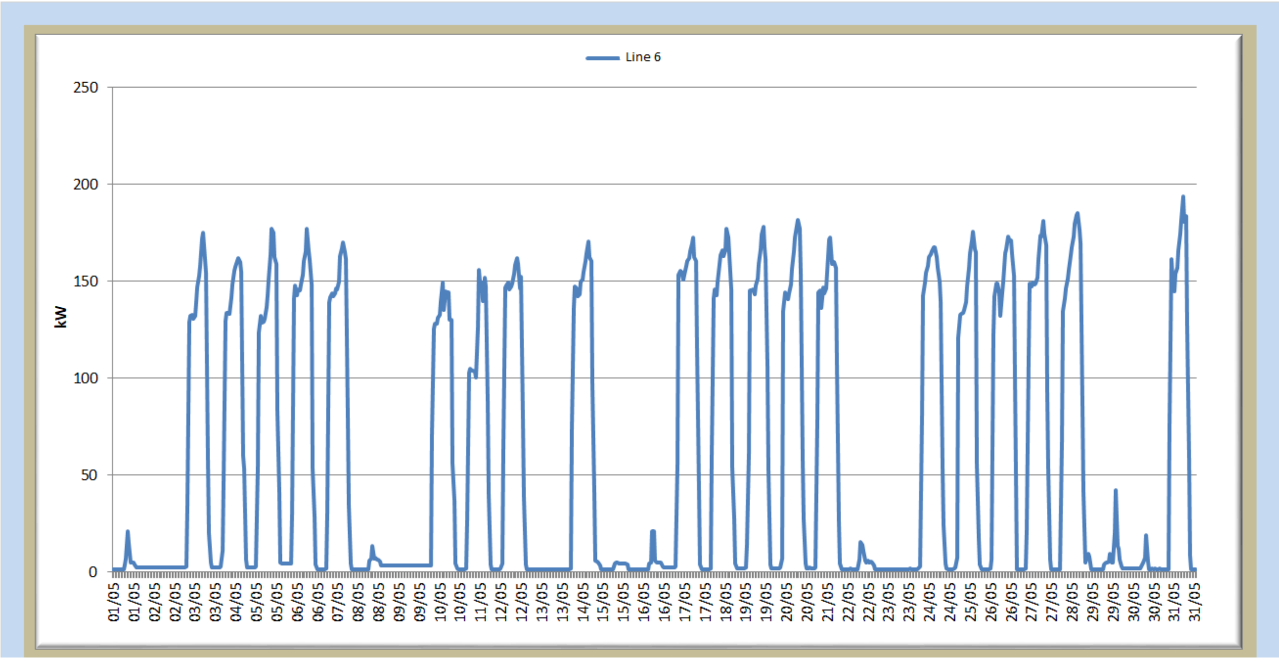


Figure 56: Load profile (kW) of Line 6 (integration step 1h)

Active Power (kW)	Min.	Max.	Avg.
Line 6	2	194	59

Table 24: Line 6 taken measures

4.2.3 Cataphoresis (Line 5):

This section represents the energy consumption associated with the Cataphoresis production line (L5). Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this section essentially aggregates the consumption of electricity in the line - tunnel, agitators and pumps (~70kW of installed power.).

Figure 57: Cataphoresis (Line 5)

Performed Measures:

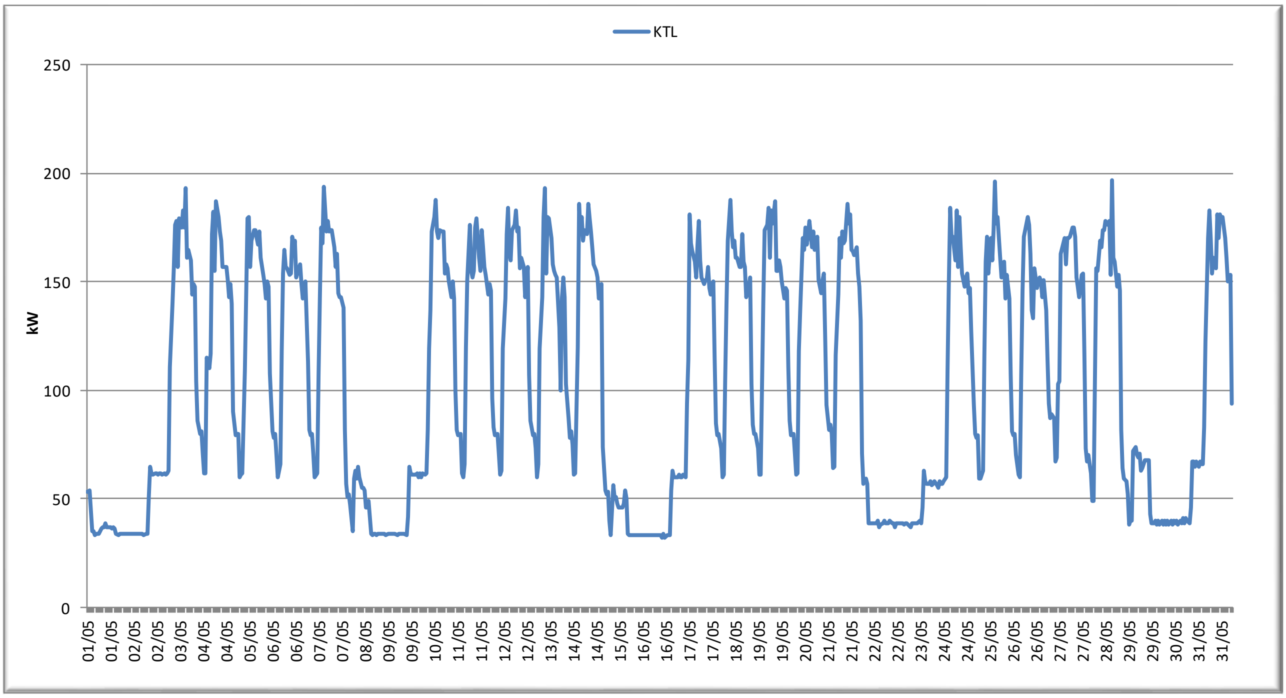


Figure 58: Cataphoresis load profile (kW) (integration step 1h)

Active Power (kW)	Min.	Max.	Avg.
KTL	32	197	105

Table 25: KTL taken measures

4.2.4 Anodizing (L7):

This section represents the energy consumption associated with the Anodizing production line (L7). Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this section essentially aggregates the consumption of electric energy in the line - two rectifiers for electropolishing (individual pot. estimated at 250kW), circulation pumps, stove fans sealing, overhead cranes and others.

Figure 59: Line 7 (Anodization)

Performed Measures:

Below is the monthly load profile of Anodizing and electropolishing rectifiers:

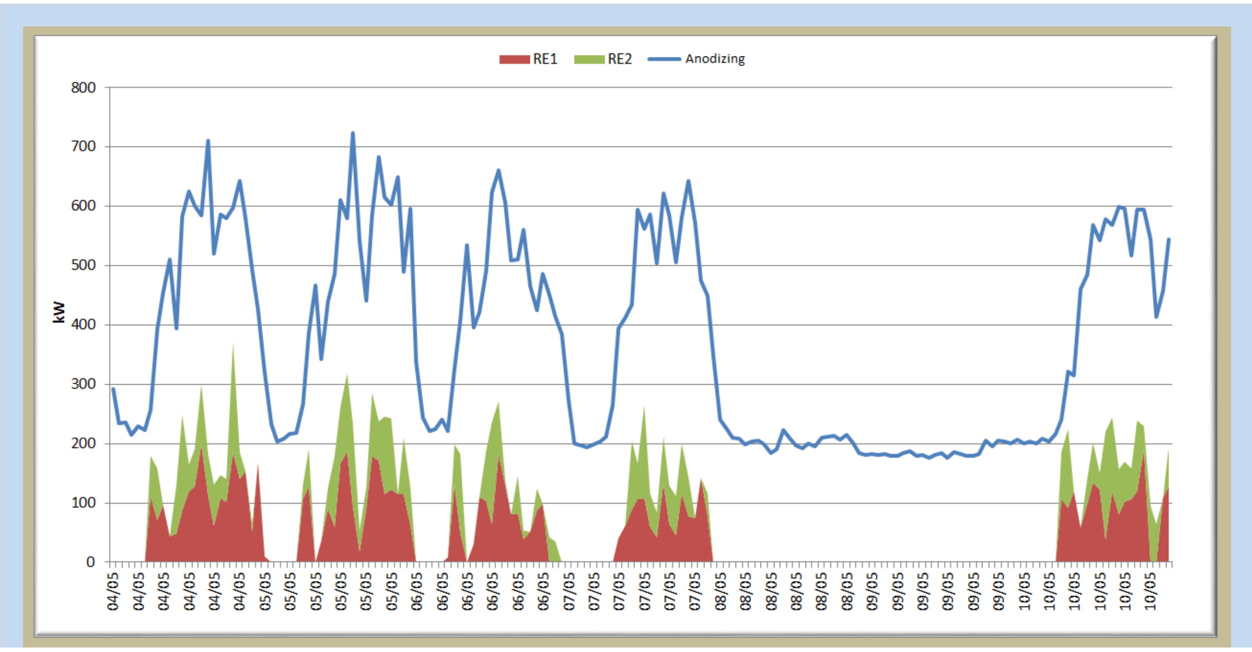


Figure 60: Load Profile (kW) of anodizing (integration step 1h)

Active Power (kW)	Min.	Max.	Avg.
RE 1	0	199	48
RE 2	0	185	31
Anodizing	177	724	367

Table 26: Anodizing line taken measures

4.2.5 Liquid Paint (L8):

This section represents the energy consumption associated with the Liquid Paint production line (L8). Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this section essentially aggregates the consumption of electricity in the line - tunnel and pumps in the line's stove burners.

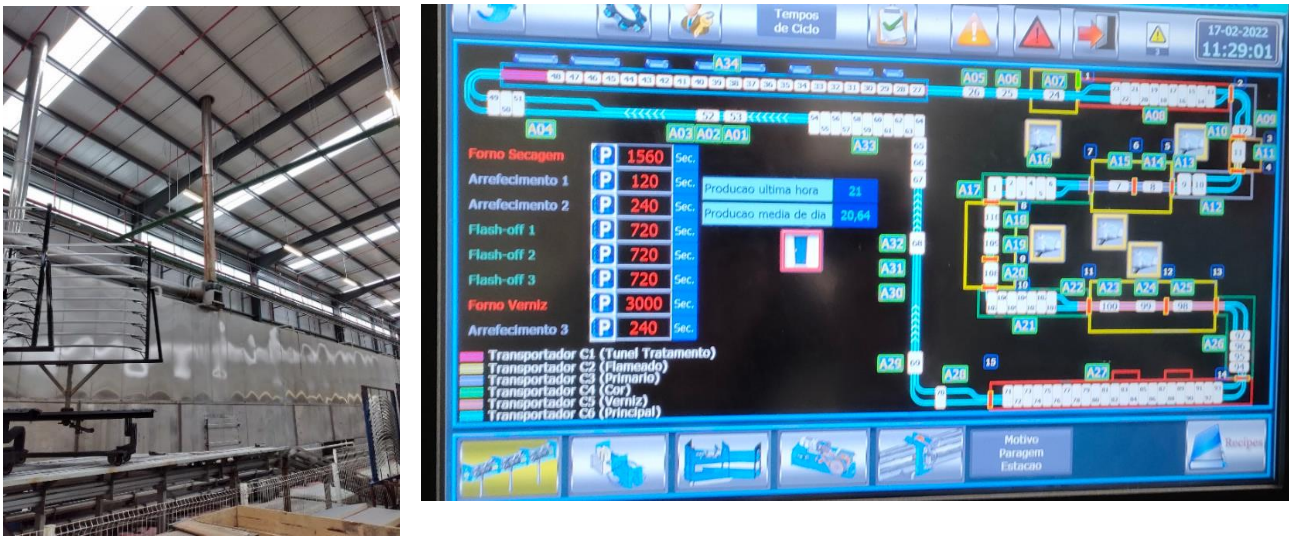


Figure 61: Line 8 (Liquid Paint)

Performed Measures:

Below are some point measurements of the tunnel shower pumps:

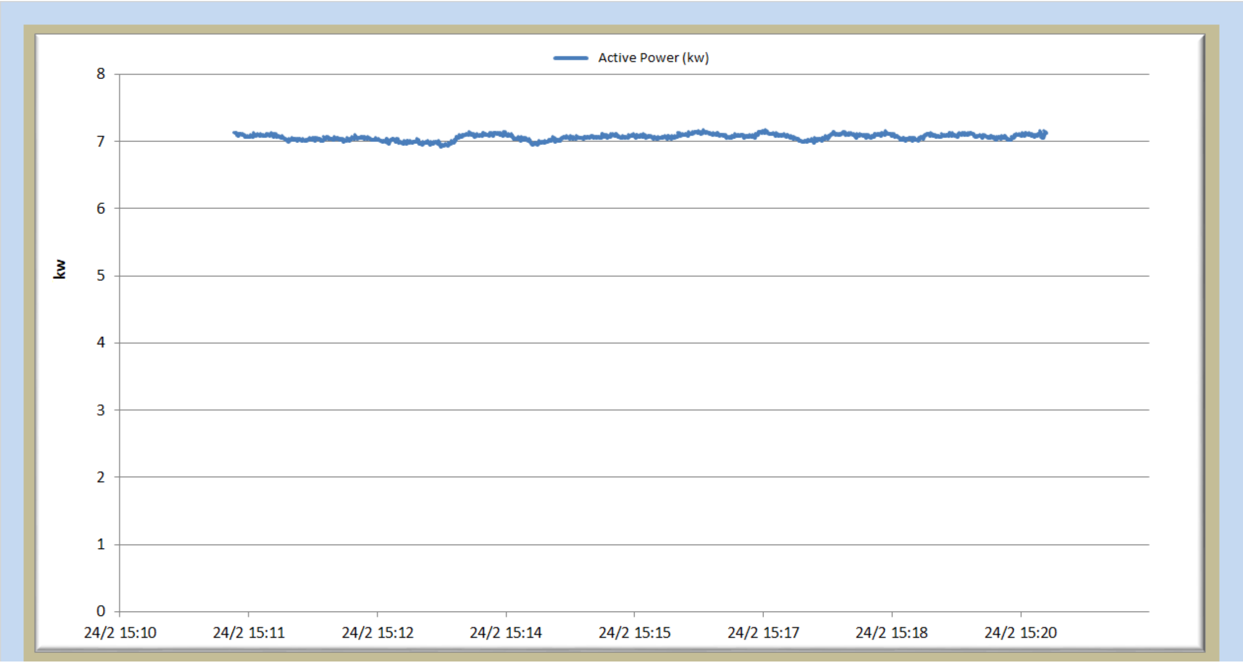


Figure 62: Load profile (kW) of the L8 pre-degreasing shower pump (integration step 1min)

Active Power (kW)	Min.	Max.	Avg.
Active Power	6,9	7,2	7,1

Table 27: L8 pre-degreasing shower pump taken measures

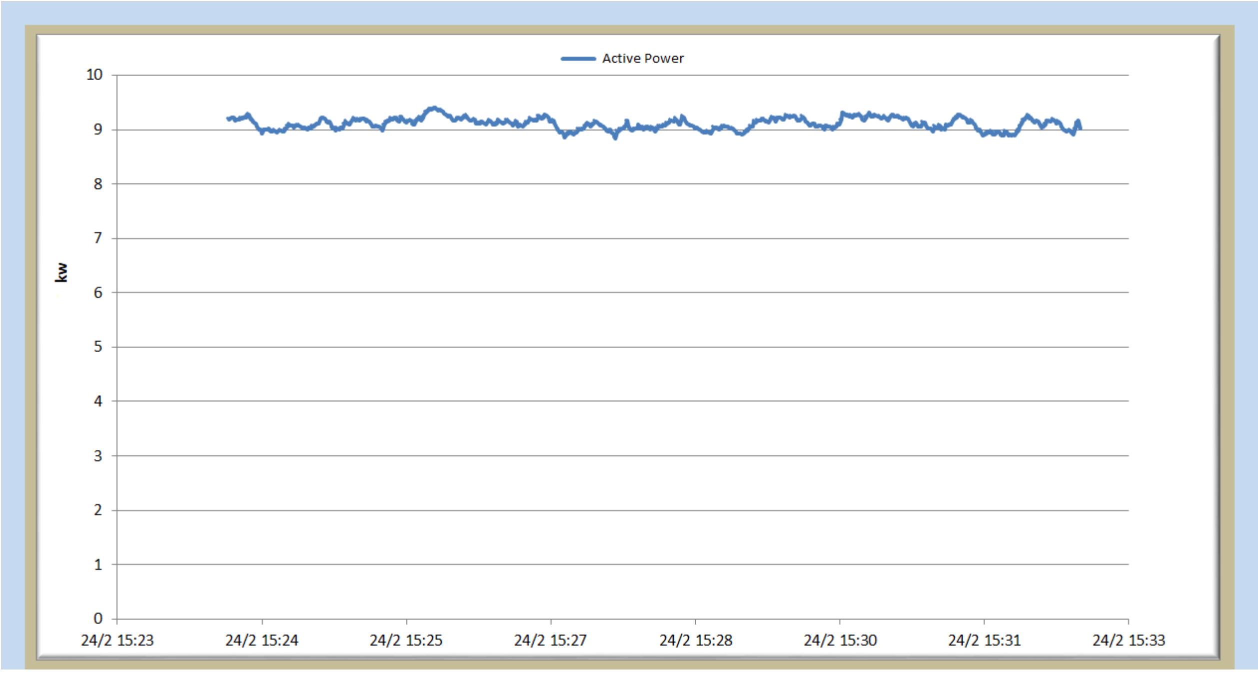


Figure 63: oad profile (kW) of the L8 degreasing shower pump (integration step 1min)

Active Power (kW)	Min.	Max.	Avg.
Active Power	8,8	9,4	9,1

Table 28: L8 degreasing shower pump taken measures

There is potential to improve the consumption in the pumping systems associated with the L8 tunnel, as will be seen afterwards.

Figure 64: Line 8 shower pumps

4.2.6 Pickling:

This section represents the energy consumption associated with the Pickling line. Part of the consumption of the equipments in this line has already been identified and characterized in previous sections, and this section essentially aggregates the consumption of electricity in the pyrolysis ovens (504kW) and other equipment with residual consumption.

Figure 65: Pickling line

Indirectly, pickling still consumes a considerable amount of compressed air. Measures will also be suggested to reduce consumption in this sector, namely with the installation of a dedicated blower (instead of the use of AC).

Performed Measures:

Below is the load profile of the pickling line (May/2021):

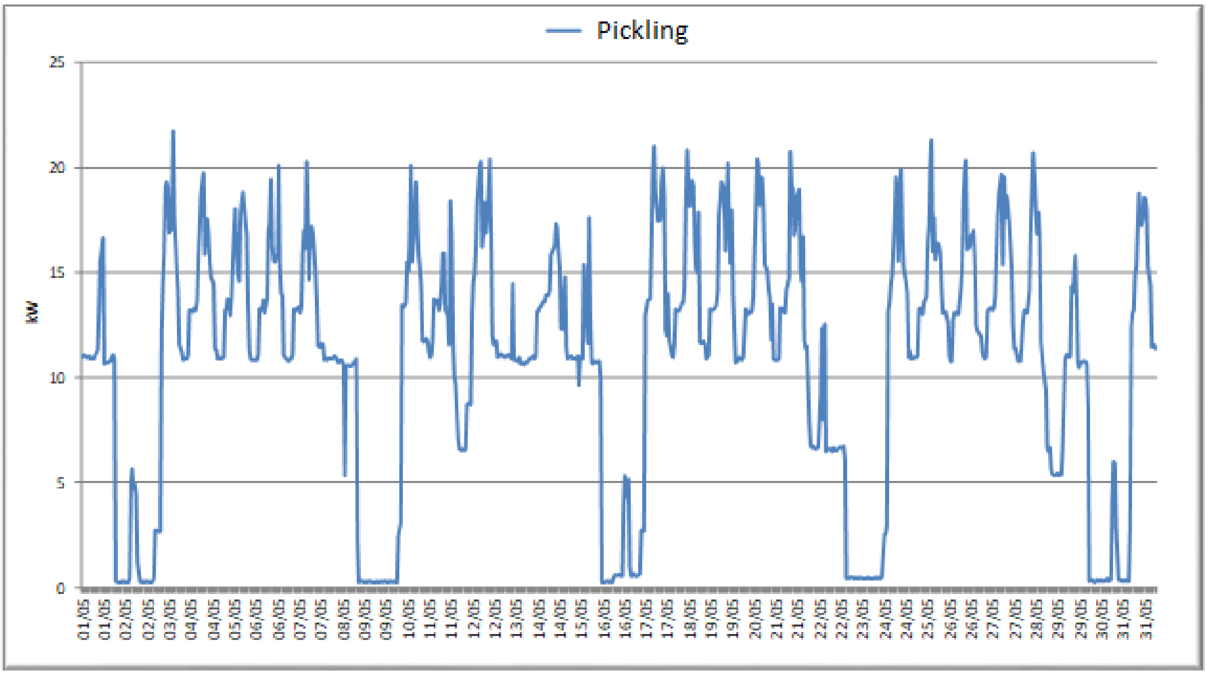


Figure 66: Load profile (kW) of Pickling (integration step 1h)

Active Power (kW)	Min.	Max.	Avg.
Pickling	0,2	21,7	10,8

Table 29: Pickling line taken measures

Chapter 5

Energy Rationalization Plans Proposed:

After the analysis that has been presented previously and the measures that has been made to the machinery a rationalization plan must be proposed in order to reduce energy consumption of the facility, improve its energy efficiency and to save its financial costs.

First, the MRCE's (Measures for Rationalization of Consumption of Energy) are presented, which were analysed and classified as applicable from a technical-economic point of view. Note that they do not necessarily have to be part of the ERP (Energy Rationalization Plan).

Each MRCE, will have the following information:

- A description of the measure;
- An estimated values for the reduction of energy consumption and costs (by type of energy);
- An estimated investment needed;
- The expected payback period.

5.1 Detailed presentation of the Identified Measures:

5.1.1 MRCE#1 – Adjusting the pre-degreasing and the degreasing pumps speed L8

The vertical centrifugal pumps responsible for feeding the showers and recirculating water for heating in the pre-degreasing and degreasing of Line 8 are highly oversized in relation to the flow actually required.

Thus, these equipments see their performance, already intrinsically low, compromised by the excessive pressure drop imposed by the system (valves partially closed) to regulate the flow.

As vertical pumps in PVDF (polyvinylidene fluoride) with higher performance or more suitable sizes were not found on the market, a solution was chosen that maintains the existing pumps. Taking into account the great degradation of the performance with the reduction of the diameter of the impellers, it was decided not to reduce them (the loss of performance does not significantly compensate for the lesser pumping work).

The flow delivered by each pump was measured and its operating point was checked (both are at 40 Hz).

The most economical option is to further reduce the frequency of the inverters, something that has already generated problems in the past, but which should be easily overcome by the reconfiguration of them to work with a variable torque ramp and not with the factory configuration, of constant torque. , which induces an excessively high current and combined with the reduced cooling capacity, causes the motor to overheat (>100ºC in the case of degreasing), something that should only happen at much lower speeds (close to 30 Hz).

Model		
Tecnium BV 6.16 D165		
50 Hz		
Q (m3/h)	H (m)	r ((%)
120	18	44%
100	24.5	55%
80	27	51%
40	29	27%
Current Frequency	Hz	40
Required flow	m3/h	45
Current height	m	**18.0**
Current efficiency	%	**35.2%**
Current power of the shaft	kW	**6.27**
Intended frequency	Hz	37
Required flow	m3/h	45
Future height	m	**15.3**
Future income	%	**37.6%**
Futue power of the shaft	kW	**4.98**
Savings	kW	**1.29**

Figure 67: Current and future pre-degreasing pump point

Modelo		
Tecnium BV 6.16 D177		
50 Hz		
Q (m3/h)	H (m)	r ((%)
120	25.5	59%
100	30	62%
80	32	53%
40	34.8	27%
Current Frequency	Hz	40
Required flow	m3/h	56
Current height	m	**20.9**
Current efficiency	%	**45.2%**
Current power of the shaft	kW	**7.05**
Intended frequency	Hz	34
Required flow	m3/h	56
Future height	m	**14.7**
Future income	%	**53.7%**
Futue power of the shaft	kW	**4.18**
Savings	kW	**2.86**

Figure 68: Current and future point of the degreasing pump

5.1.1.1 Methodology of Calculation:

MRCE Nº	MRCE TITLE
1	Adjusting the speed of the pre-degreasing and degreasing pumps L8

Assumptions:

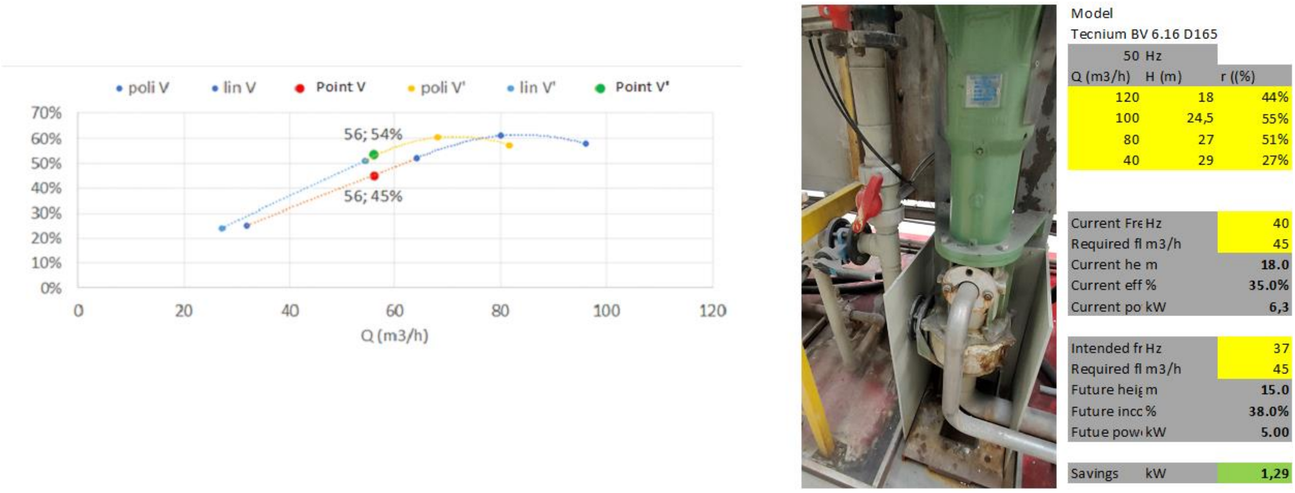


Figure 69: MRCE 1 assumptions

Presumptions:

Required head height	**1.5**	**bar**
Operating hours (with aluminium)	3,500	hours/year

Table 30: 1 Presumptions

Pre-Degreasing L8:

engine power	18.5	kW
Pump electrical consumption (measured)	7.5	kW
Pump flow (measured)	45	m3/h
Calculated pump height	1.8	bar
engine frequency	40	Hz
Pump's efficiency	35%	
power of the shaft	6.3	kW

Table 31: Pre-Degreasing L8 presumptions

Degreasing L8:

engine power	30.0	kW
Pump electrical consumption (measured)	9.1	kW
Pump flow (measured)	56	m3/h
Pressure in the showers (manometer)	2.1	bar
Motor's frequency	40	Hz
Pump's efficiency	45%	
power of the shaft	7.1	kW

Table 32: Table 32: Degreasing L8 presumptions

Calculations:

Pre-Degreasing L8:

Pre-degreasing engine losses	1.23	kW
Pre-degreasing engine losses	6.60%	
Proposed frequency	34.0	Hz
future frequency	38%	
future power of the shaft	4.98	kW

Table 33: Pre-Degreasing L8 calculations

Degreasing L8:

Degreasing engine losses	2.05	kW
Degreasing engine losses	6.80%	
Proposed frequency	34	Hz
Future efficiency	54%	
future power of the shaft	4.18	kW
Savings	4.16	kW
Savings	25%	

Table 34: Degreasing L8 calculations

5.1.1.2 Savings:

Electrical Energy Savings	14.560	kWh/year
Electrical Energy Savings	1514.2	Eur/year
Electrical Energy Savings	3.1	tep/year
Total savings (All types of Energy)	1514.2	Eur/year
Total savings (All types of Energy)	3.1	tep/year

Table 35: MRCE 1 Savings

5.1.1.3 Investment:

Inverter configuration	200	Eur
Design	0	Eur
Installation	0	Eur
T&C + Start-Up	0	Eur
Other Costs	0	Eur
Total Investment	200	Eur
Annual O&M Costs	0	Eur
Total Savings	1514	Eur/year
Pay-back	0,13	years

Table 36: MRCE 1 Investments

5.1.2 MRCE#2 – Pressure control of all Line 8 tunnel pumps:

We proposed to install pressure sensors downstream of all pumps and speed variators in those that do not currently have them, with the flow adjustment being made based on a pressure set-point to be defined by operators in control interfaces. (SP/PV or rheostat and display) instead of using valves.

A savings equivalent to that calculated in MRCE#1 is estimated for the particular case of pre-degreasing and degreasing pumps.

It is considered the need to install variators in 3 motors, 5.5, 7.5 and 11 kW, and the industrial water pump, of 15 kW, already has a variator, as well as pre-degreasing and degreasing.

5.1.2.1 Methodology of Calculation:

MRCE Nº	MRCE TITLE
2	Pressure control of all Line 8 tunnel pumps

Assumptions:

Figure 70: Line 8 tunnel pumps

Velocity adjustment savings (instead of throttling)	25%	
Power of uncontrolled throttled pumps	39	kW
Estimated load factor	70%	
Annual operating hours	5000	hours

Table 37: MRCE 2 assumptions

Calculations:

Estimated Savings	6.8	kW

Table 38: MRCE 2 Calculations

5.1.2.2 Savings:

Saving Electric Energy	34.125	kWh/year
Saving in Electric Energy	3.549	Eur/year
Saving in Electric Energy	7.3	tep/year
Total Saving (All types of Energy)	3.549	Eur/year
Total Saving (All types of Energy)	7.3	tep/year

Table 39: MRCE 2 Savings

5.1.2.3 Investment:

Variators 5.5 + 7.5 + 11 (with installation)	5.400	Eur
x6 pressure transducers	3.600	Eur
Panel for defining set-points	2.400	Eur
Design	0	Eur
Installation	0	Eur
T&C + Start-Up	0	Eur
Other Costs	1.200	Eur
Total Investment	12.600	Eur
Annual O&M Costs	630	Eur/year
Pay-back	4.32	years

Table 40: MRCE 2 Investments

5.1.3 MRCE#3 – Turning off L8 chillers between December and February:

Verifying the typical meteorological year in loading and comparing it with the requirements of the air fed to the spray booths of Line 8 (HR 60±5 %, T 23±2 ºC) has concluded that between December and February there is a probability of ~0 % of need to cool or dehumidify the air. It is therefore suggested to stop the chillers in this period.

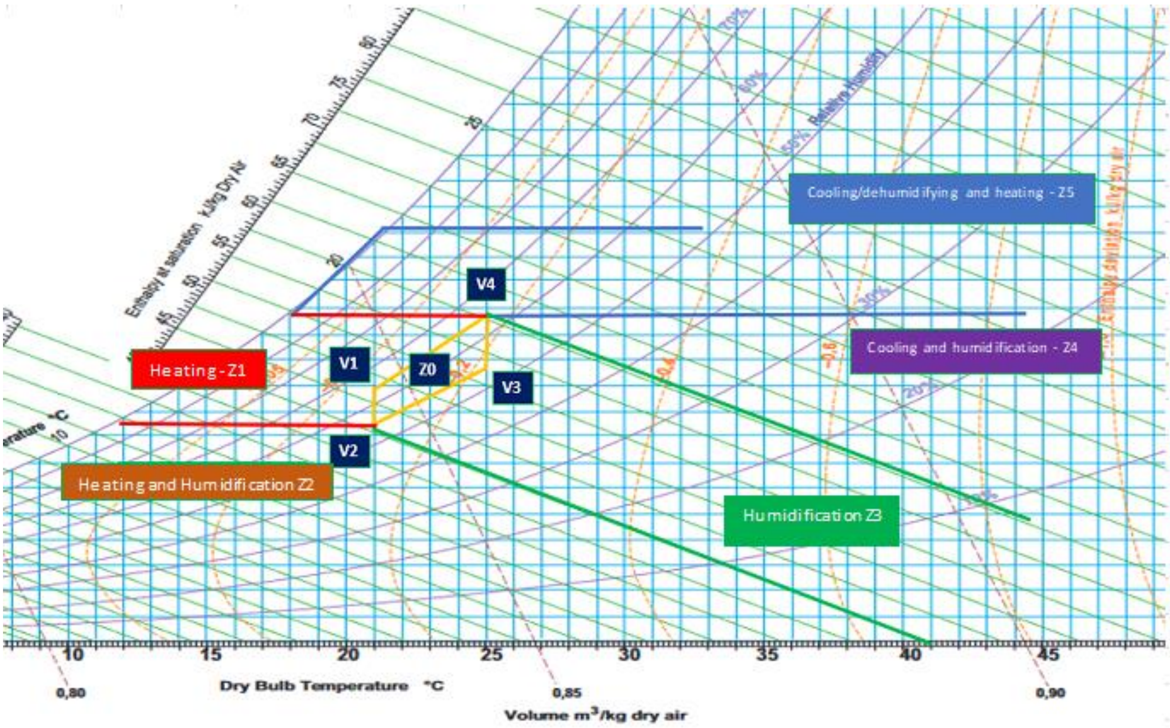


Figure 71: Operating modes of spray booths' AHUs depending on ambient conditions

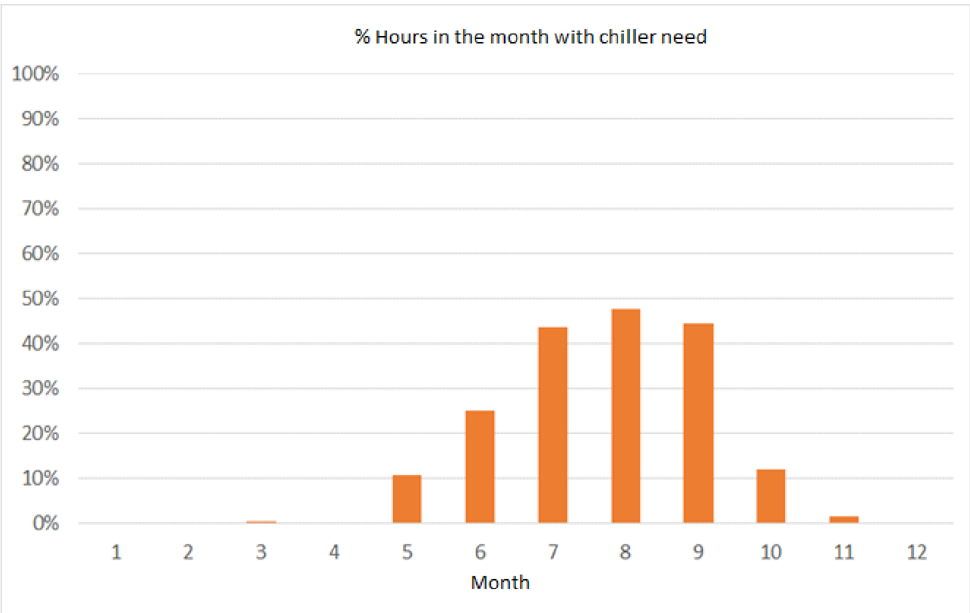


Figure 72: Analysis results based on typical year (ambient air at Z4 and Z5 conditions)

5.1.3.1 Methodology of Calculation:

MRCE Nº	ECRM TITLE
3	Turning off L8 chillers between December and February

Assumptions:

Consumption chillers between December and February	42846	kWh/year
Consumption of pumps between December and February	14410	kWh/year
Estimated COP between December and February	4.0	
% of sensible cooling (to be compensated with heating)	50%	

Table 41: MRCE 3 assumptions

Calculations:

Variable consumption (thermal load)	28436	kWh/year
cooling load	113744	kWh/year
Heating load created by chillers	56872	kWh/year

Table 42: MRCE 3 Calculations

5.1.3.2 Savings:

Saving Electric Energy	42846	kWh/year
Saving Electric Energy	4456	Eur/year
Saving Electric Energy	9.2	tep/year
Saving NG (Natural Gas)	56872	kWh/year
Saving NG (Natural Gas)	2149.8	Eur/year
Saving NG (Natural Gas)	4.9	tep/year
Total Saving (All types of Energy)	6606	Eur/year
Total Saving (All types of Energy)	14.1	tep/year

Table 43: MRCE 3 Savings

5.1.3.3 Investments:

Design	0	Eur
Installation	0	Eur
T&C + Start-Up	500	Eur
Other Costs	0	Eur
Total Investment	500	Eur
Annual O&M Costs	25	Eur/year
Pay-back:	0.08	year

Table 44: MRCE 3 investments

5.1.4 MRCE#4 - Reducing the velocity of the Line 7 gas/steam extraction fans:

The vapours from the L8 vats are extracted using 3 fans that worked 24/7 under nominal conditions.

In March 2022, work was carried out to progressively reduce the speed of the fans and the Scrubber 1 was even stopped at the weekend.

Consumption before and after were obtained using spot measurements.

This measure only reflects actions already taken.

An additional effort can also be made using the calibration of records at extraction points, with the following procedure for each extraction network:

1. Total opening of all valves/valves;
2. Progressive reduction of speed until at some point it is considered that the extraction has lost efficiency (monitor closely and for some time);
3. Establishing a slight safety margin (in terms of speed) above that point;
4. In order of decreasing fan distance, adjust the damper until it is considered that the extraction has lost efficiency, leaving it slightly more open than that point (monitor closely and for some time). Do this procedure at least twice, as when closing one damper the flow in the others will be slightly increased;
5. If there is no damper that needs to be left almost completely open, reduce the speed a little more and repeat step 4.

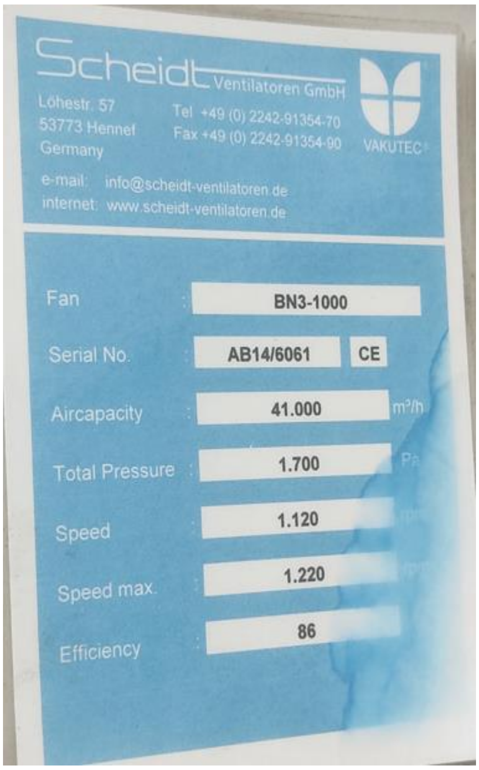


Figure 73: Technical sheet of line 7 fans

5.1.4.1 Methodology of Calculation:

MRCE Nº	MRCE TITLE
4	Reducing the velocity of the Line 7 gas/steam extraction fans

Assumptions:

Total consumption of fans (Scruber1 + Scruber 2 + Demister) before	42	kW
Total consumption of fans (Scruber 1 + Scruber 2 + Demister) after	31	kW
Scruber consumption 1 later	11.4	kW
The line's operating time	5000	
Stoppage time	2000	

Table 45: MRCE 4 Assumptions

Calculations:

savings per week	12	kW
Savings at the weekend	31	kW

Table 46: MRCE 4 Calculations

5.1.4.2 Savings:

Savings in Electrical energy	119,446	kWh/year
Savings in Electrical energy	12,422	Eur/year
Savings in Electrical energy	5.2	tep/year
Total savings (All Types)	4551	Euro/year
Total savings (All Types)	9.8	tep/year

Table 47: MRCE 4 Savings

5.1.4.3 Investments:

Follow-up (internal resources)	1500	Eur
Design	0	Eur
Installation	0	Eur
T&C + Start-Up	0	Eur
Other Costs	0	Eur
Total Investment	1500	Eur
Annual O&M Costs	960	Eur/year
Pay-back:	0.13	years

Table 48: MRCE 4 Investments

5.2 Summary of the Identified Measures:

In accordance with what was mentioned in on the previous section of this dissertation, the Rationalization of Energy Consumption (PREn in portuguese) is based on a set of measures aimed at improvement of the energy efficiency of the audited installation, through the reduction of its consumption of energy and, consequently, the related energy costs. These measures are defined in the following an energy audit and are responsible for setting targets to be achieved, at the end of the term of the respective plan (eight years), concerning the energy intensity indicators, specific energy consumption and carbon intensity.

The next table summarizes the main characteristics of the MRCE proposed for the audited facility, as well as the results obtained within the scope of reducing analyzed energy indicators.

MRCE Nº	Description	Energy Reduction [teo/year]	CO2 Reduction [tonCO2/year]	Value per MRCE		
				MRCE Saving [Eur/year]	Invest. [Eur]	Pay-Back [years]
3	Turning off L8 chillers between December and February	14.1	33.3	7.902	500	0.06
1	Adjusting the speed of the pre-degreasing and degreasing pumps L8	3.1	6.8	1.817	200	0.11
2	Pressure control of all Line 8 tunnel pumps	7.3	16.0	4.034	12.600	3.12
4	Reducing the velocity of the Line 7 gas/steam extraction fans	2.6	5.7	546	4500	8.24

Notice that the mentionned MRCEs are not the only measures that has been proposed to the facility but they were the only ones that ‘’ the Masters candidate’’ has contributed on developing.
As for the schedule of the implementation of the MRCEs, MRCE 1 would be implemented starting 2023, MRCE 2 would be implemented starting 2024, MRCE 3 is at 2023, MRCE 4 is at 2024.

Chapter 6

CONCLUSION:

- The elaboration of the present work had as main focus the analysis and characterization of the conditions of energy use of a specific industrial installation in Portugal.

The study described the performance on energy aspect to the mentioned establishment, the final objective being the definition of a Plan of Rationalization of Energy Consumption (PREn) of the installation. In order to carry out the different stages that make up an energy audit industrial sector, it has proved to be essential to carry out a careful inspection and analysis of the way in which the main energy consuming equipment/sub-units of the facility.

In line with the emphasis given to energy efficiency throughout the present dissertation, Measures of Rational Use of Energy were identified and designed (MRCE)) for the audited facility, with a view to reducing its energy consumption, as well as of the respective GHG emissions and energy costs. The energy efficiency measures presented mainly focus on the chillers on Line 8 and Line 7 of production

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