Master's Thesis

OPTIMIZATION OF BIOBASED PRODUCTS MANUFACTURING

2023-2024

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1. Introduction and context

The paper-making process is essentially a very large dewatering operation. The major sections of the paper machine consist of: the forming section, press section and dryer section. The dryer section removes between 1.1–1.3 kg of water per kg of paper production, as compared with the 200 and 2.6 kg removed in the forming and press section [1]. Although the dryer section is responsible for a small fraction of total dewatering, it is the major energy consumer in the paper mill because porous and hygroscopic pulp fibers have hard-to-remove water that is considered to be located in the fiber cell wall and trapped in the fiber network geometry. According to the report prepared by the Institute of Paper Science and Technology (IPST), 61.9% of the total energy required for paper making is consumed in the paper drying process [2], and about 65% of the thermal energy is used for water evaporation based on Chen's investigation [3,4]. In spite of its key role in papermaking and its high energy consumption—taking approximately 60% of the total physical length and accounting for almost 40% of the total capital cost of a common paper machine—paper drying is arguably the least understood papermaking operation. Perhaps the reason is the complexity of the paper drying process that involves heat transfer, evaporation, and the water removal process where steam pressure, air conditions, and condensate removal play key roles in determining the drying capacity and final product quality. The papermakers often treat the dryer section as a "black box". Nevertheless, rising energy costs are forcing papermakers to pay more attention to the dryer section, and especially steam usage.

The thermal energy consumption during paper drying is mainly used to evaporate the water in the moist paper. According to the diverse binding force, the water in the moist paper can be divided into different types, such as free water and bound water, of which thermodynamic and physical properties are different. For the bound water, evaporation heat is used not only to vaporize water, but also to overcome the interaction between cellulose fibers and water. The quantitative measurement of evaporation heat is important to understand the interaction between fibers and water (drying mechanism) and the resulting impact on the paper drying behavior for optimizing the capital and operating costs of the dryer section. [5]

1.1. Hinojosa Paper Group

Hinojosa Group was founded by Rafael Hinojosa in 1947 in Spain. This group is a packaging company that owns its own paper mills and is composed of Hinojosa Food, Hinojosa Packaging, and Hinojosa Paper.

Hinojosa Group manufactures its packaging from recycled fibers of old packaging certified by FSC. The company produces several types of cardboard including corrugated cardboard, flat cardboard, compact cardboard, and plasticized cardboard.
Hinojosa Paper Sarrià is one of the paper mill plants belonging to Hinojosa Group since 2016. It is situated in Sarrià de Ter (Girona, Spain). This plant primarily produces three types of paper (Testliner 1 (TL-), Testliner 2 (TL2), and Semi-chemical) with different basis weights. Additionally, their papers are coated with a starch solution.

The main activity sectors of the group are packaging for the industrial, food, and agricultural sectors.

1.2. State of the art:

To analyze the factory's energy consumption, a comprehensive series of reference indicators have been established. These indicators serve as a guide to identify the most effective starting points for reducing energy usage. The primary focus encompasses three key areas: electricity, steam, and water consumption. By understanding the consumption patterns in these areas, it becomes possible to implement targeted strategies for energy reduction. However, for the purposes of this project, the scope will be limited to an in-depth examination of electricity and steam usage.

Indicator	Unit
Electric consumption	KWh
Electric ratio	KWh/kg
Total steam consumption	Tn
Steam ratio	kg/kg
Machine steam ratio	kg/kg
Kitchen steam ratio	kg/kg
WWTP steam ratio	kg/kg
Total steam generation	kg
Biomass generated steam	Tn
Biomass generated steam	%
Biogas generated steam	Tn
Biogas generated steam	%
Natural gas generated steam	Tn
Natural gas generated steam	%

Figure 1. Energy consumption metrics

1.2.1. Electric consumption

To study the factory's electric consumption, some electrical analyzers have already been installed. Some of these analyzers are linked to specific processes, such as *Pastas (pulps)*, which is the plant where recycled paper is mixed with water before being sent to the paper machine. However, most of the analyzers monitor a mix of different processes.

DCS NAME	Function
Vacuum and Auxiliary Systems	Generates vacuum before the press section in paper manufacturing
Machine Head Cleaning	Mixed motor list
Drive 1 and 2	Motors responsible for rotating the rollers through which the paper moves
Water and treatment plant	Treats incoming and outgoing river water, adjusting treatment based on the water line
Transf. 1 and 2 Pulp	The pulp is generated by mixing recycled paper with water in the pulper
Compressors	they supply pressure to machines that require compressed air
Boiler and Osmosis	Boilers and osmosis system

Figure 2. DCS analyzer and function on the factory

Figure 3 shows its main function, while Figures 4 and 5 display its consumption as a percentage of the total factory consumption.

TRANSFORMER	DCS NAME ANALYZER (Spanish)	DCS NAME (English)	UNIT	% OVER THE TOTAL
62	Vacío y Auxiliares Sarria	Vacuum and Auxiliary Systems	U – 28 + U- 36	20.00%
62	TURBOSOPLANTE-2	Turbo blower 2	U - 36	7.50%
62	TURBOSOPLANTE-1	Turbo blower 1	U - 36	5.50%
67	Depuración cabeza máquina Sarria	Machine Head Cleaning	U 1 - 2- 3	17.30%
60	Accionamiento 1 Sarria	Drive 1 Sarria	U - 3	13.40%
63	Aguas y depuradora Sarria	Water and treatment plant	U - 18 + U - 16	11.90%
63	General Depuradora	General water treatment plant	U - 16	3.40%
71	Trafo 2 Pastas Sarria	Transf. 2 Pulp	U - 35	11.40%
70	Trafo 1 Pastas Sarria	Transf. 1 Pulp	U - 35	10.10%
61	Accionamiento 2 Sarria	Drive 2 Sarria	U - 3	8.20%
26	COMPRESORES SARRIA	Compressors	U - 13	5.70%
26	COMPRESOR-1 SARRIA	Compressor-1	U - 13	0.80%
26	COMPRESOR-2 SARRIA	Compressor-2	U - 13	0.20%
26	COMPRESOR-3 SARRIA	Compressor-3	U - 13	0.20%
26	COMPRESOR-4 SARRIA	Compressor-4	U - 13	0.50%
9	Caldera y Ósmosis Sarria	Boiler and Osmosis	U - 14	3.30%
11	Bobinadora Sarria	Rewinder	U - 15	1.00%
14	Acabados Sarria	Finishing	U 4- 27	0.90%
15	Auxiliares 2 Sarria	Auxiliary systems 2	U - 10	0.80%
21	ALUMBRADO SARRIA	Ligthing	ED -B	0.50%
5	Auxiliares sarrià	Auxiliary systems 1	U - 11	0.30%

Figure 3. List of electrical analyzers installed in Hinojosa- Sarrià

These analyzers send the data to Power Studio- Circutor web:

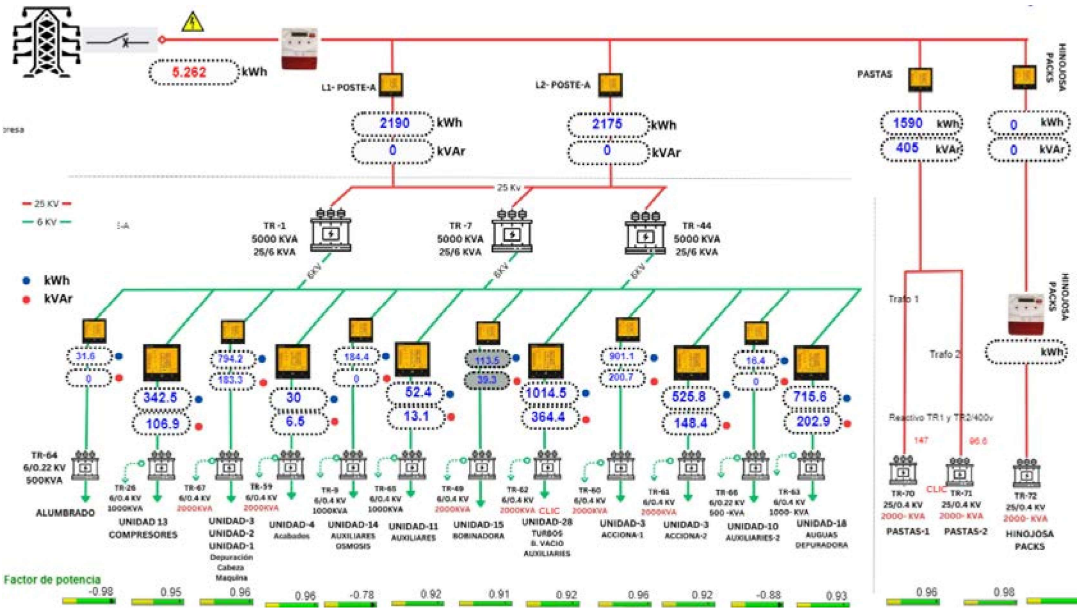


Figure 4. Single-line diagram from the Circutor web.

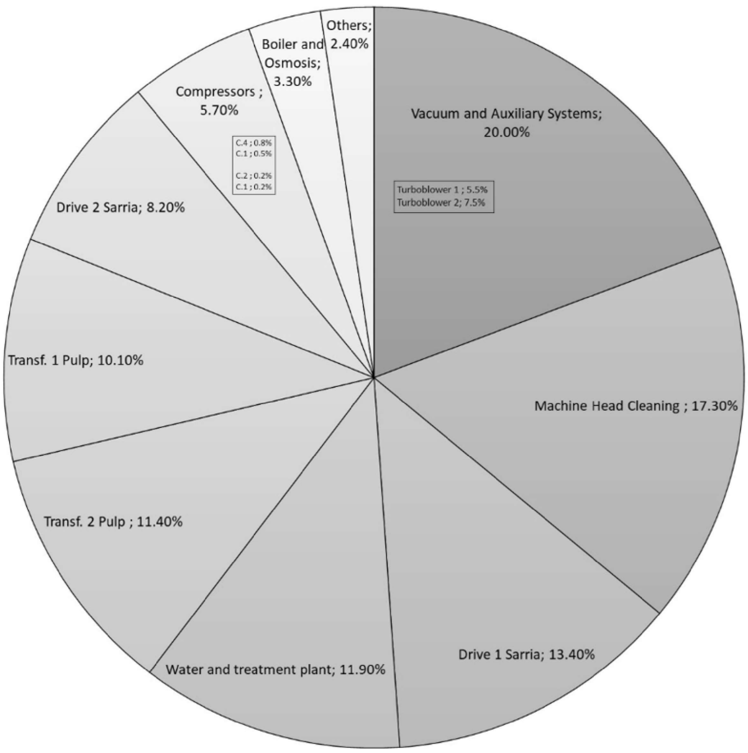


Figure 5. Percentage consumption chart of plant analyzers.

1.2.2. Steam consumption

1.2.2.1. Steam diagram

The general steam lines of the paper mill are represented by the following two diagrams.

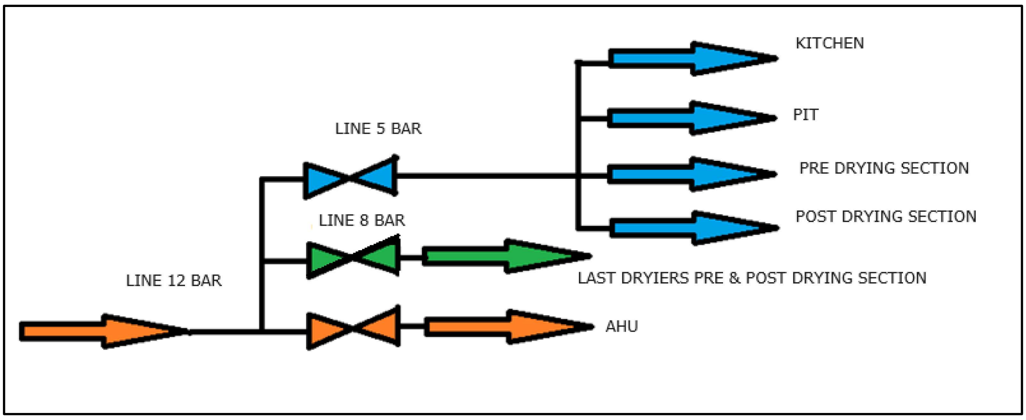


Figure 6. Pressure steam lines diagram.

In the following one the flow meters are shown according to the line.

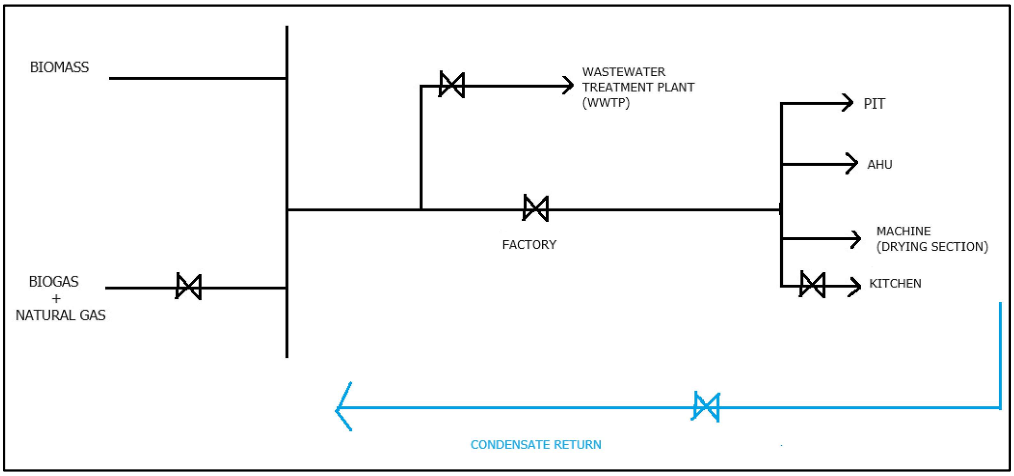


Figure 7. Installed steam flowmeters in Hinojosa-Sarrià.

Here is the scheme of the flowmeters installed in the plant. There are 4 steam flowmeters and one condensate return flowmeter at the steam level. To measure the steam consumed in the pre and post drying sections, they perform the operation known as "factory-kitchen."

1.2.2.2. Pre-drying and post drying process

Figures 11 and 12 show a simplified layout of the existing system with the results of the simulations. The cylinders from 2 to 44 are rated 5 bars while the last six cylinders are rated 8 bar. So, there are two steam lines supplying live steam to the drying section: one which pressure is set 5 bar and the other one with pressure 8 bar. All the steam is coming from a unique steam line from the boiler with pressure 11 bar.

The paper machine has a cascade steam and condensate system. It means that there is necessarily a pressure drop between the drying groups for enabling the blow through steam to flow from one's group separator to the previous drying group.

In the pre-drying section, the main group is composed from the cylinders 17 to 34 and provides the major drying capacity in the pre-drying section. Its condensate is collected by the separator S2A and its blow through steam goes to the cylinders 8 to 16. During sheet breaks, the excess of steam from this separator is vented to atmosphere.

The dryers 8 to 16 also receive some live steam for controlling the pressure of the cylinders 10 to 16. The steam header of this group also supplies steam to the dryers 8 and 13 that are individually pressure and differential pressure controlled. The condensate from the dryers 10+12+14+16 is collected by the separator S2 that also receives the condensate from separator S2A. The blow through steam from these dryers is used for the steam supply of the early dryers 2, 4 and 6. During sheet breaks, the excess of steam from the separator S2 is vented to atmosphere. The condensate from the separator S2 is sent directly back to the boiler.

Finally, the dryers 2, 4 and 6 are individually pressure and differential pressure controlled. In addition to the flash and blow through steam that they receive from the separator S2, make up steam is added for differential pressure control of the dryers 10-16.

The condensate from the drying cylinders 2, 4, 6, 8 and 13 is collected in the separator S1. The blow through steam goes to the ventilation system for pre-heating of the blowing air to the hood. The condensate and excess of steam flows to the condenser and then to the vacuum separator. The condenser has no water flow control. The vacuum is created by a double ejector Vortech unit. The condensate from this separator is sent to the separator S5 while the condensate from S1 goes back to the boiler.

The after-drying section has a full top/bottom division for curl control. On the grades observed, this functionality was not in use and the top and bottom groups were set at the same pressure.

The final groups (top and bottom from 44 to 49) are steam supplied by the 8 bar steam line. Their condensate is collected in the separators S6 and S7 and their blow through and flash steam supplies the drying cylinders 39 to 43 (still with top/bottom division). During sheet breaks, when there is an excess of steam at the separators S6 and S7, control valves are venting it to the atmosphere. The condensate from the separators S6 and S7 goes respectively to the separators S3 and S4.

The make up steam to the cylinders 39 to 43 comes from the 5 bar steam line. These cylinders are draining to the separators S3 and S4. Currently, the condensate from the separator S3 flows back to the boiler while the one from S4 goes to the separator S5.

The blow through steam from these separators supplies the cylinders 35 to 38. Those have individual pressure and differential pressure controls. Their condensate is sent to separator S1. [16]

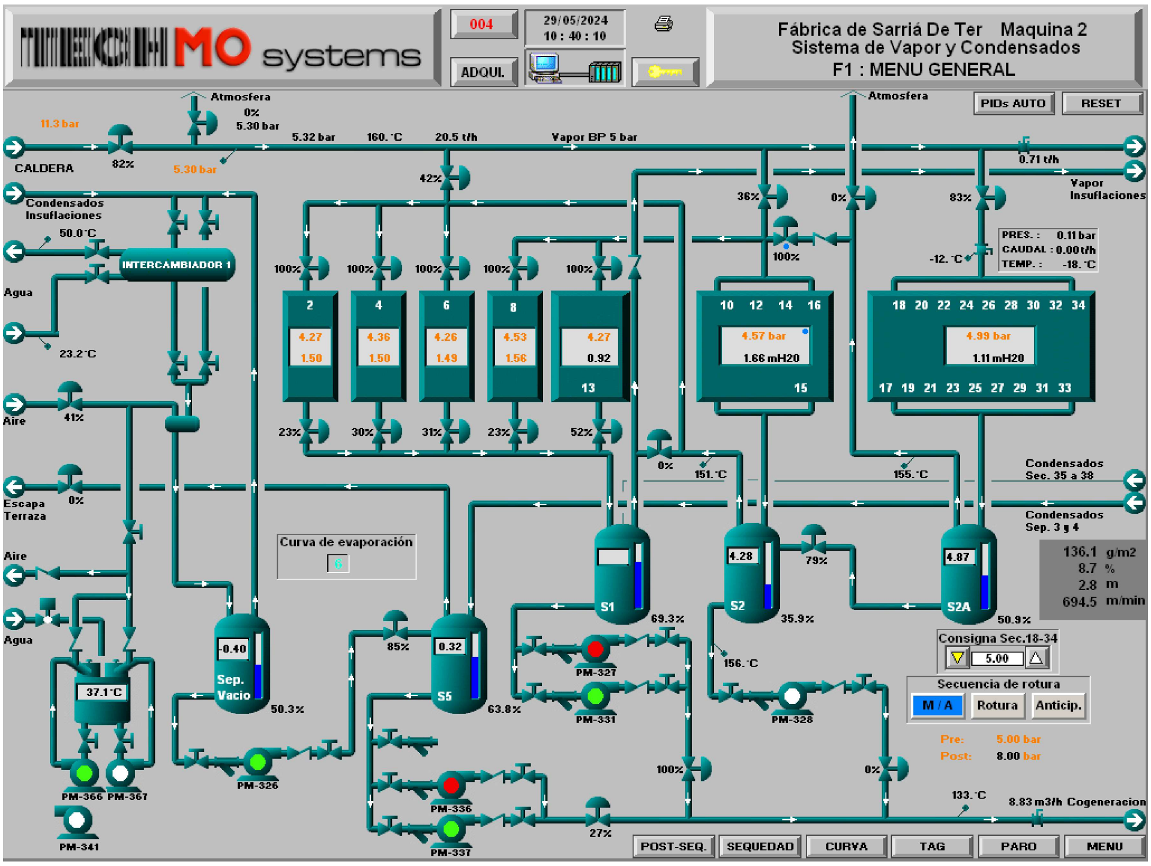


Figure 8. General pre-drying section steam diagram.

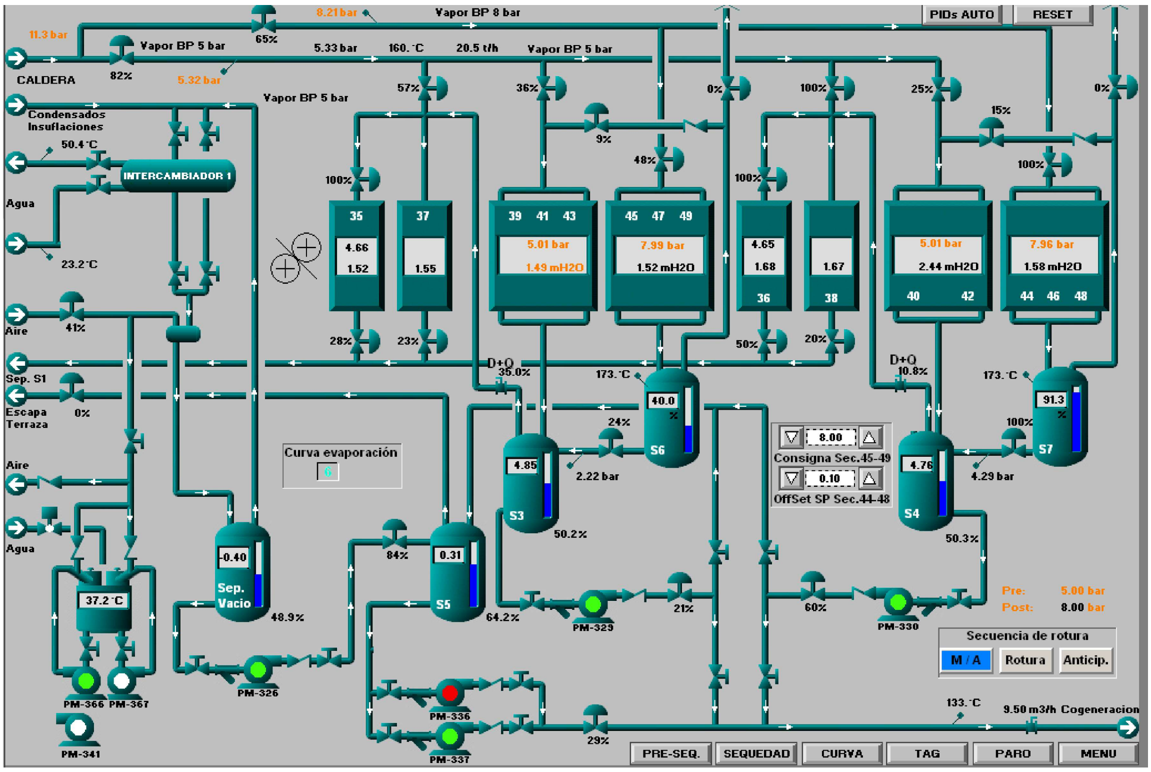


Figure 9. General post-drying section steam diagram.

1.2.2.3. Gas mix boilers for steam production

To generate the steam at Papelera de Sarrià, a company (Neoelectra) has been subcontracted, which has ensured a mix made with 3 boilers:

- Natural Gas
- Biogas (September 2021)
- Biomass (January 2022)

The priority is to use all the generated biogas, supplemented by the biomass boiler. If necessary, as a last resort due to breakdowns or peak demand, steam generated with natural gas is used.

Using the biomass boiler leads to higher steam consumption for two reasons: the natural gas boiler needs to remain operational to stay hot and be ready to generate steam whenever the biomass boiler is insufficient. When there are machine breakdowns and/or malfunctions in the paper production, the biomass boiler, due to its nature, continues to produce steam during the cooling ramp. For the same reason, it cannot be shut down for short stops, so during malfunctions, it continues to produce steam, which is released into the atmosphere.

Neoelectra has agreed with Hinojosa on the following percentages. They will guarantee the customer, starting from the delivery certificate, that the steam supply will be carried out using the combustion of the following fuels and in the following percentages (minimums for biomass, biogas, and natural gas/propane), which will be measured annually.

Fuel	Annual percentage (%)
Biomass boiler	70,1%
Biogas boiler	6,4%
Natural gas UMISA boiler	23,5%

Figure 10. Ensured steam boiler mixture by Neoelectra.

The actual mix from 2023 until June 2024 is shown in the next figure:

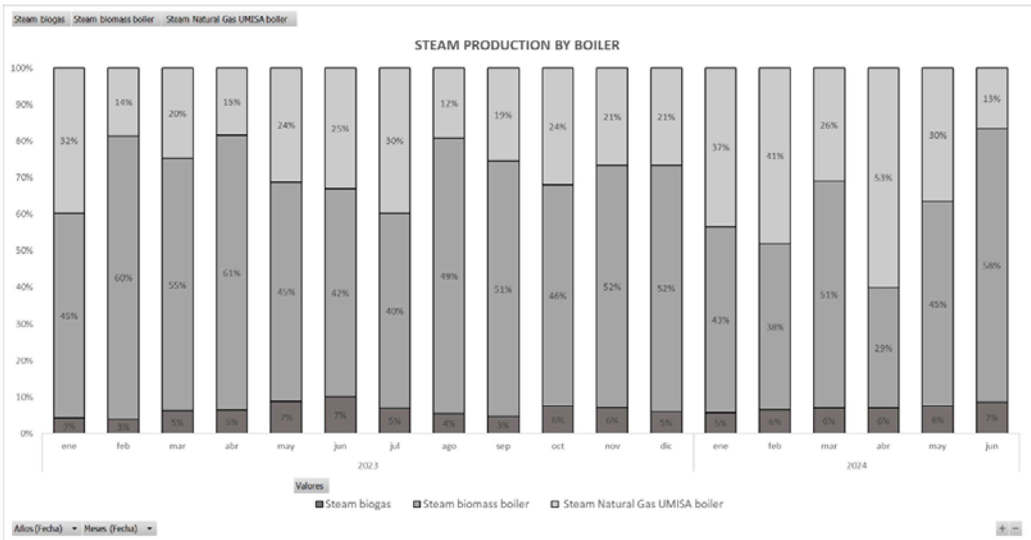


Figure 11. Steam production by each boiler.

1.3. <u>Objectives:</u>

- Monitor and analyze various supply consumptions.
- Propose improvements to reduce these consumptions.
- Reduce energy consumption through daily analysis.
- Optimize supply consumption to enhance plant energy efficiency, focusing on raw materials and alternative bioproducts.

The main objective of this project is to reduce energy consumption through daily analysis of the previous day's consumption. This involves comparing consumption data from different analyzers on days with similar production levels in terms of daily tonnage, average paper width, average grammage, and death time.

By identifying days with lower consumption under similar conditions, the aim is to investigate those process areas to reduce usage. As daily reports accumulate, common points of overconsumption will be identified, along with the reasons behind them, facilitating proactive measures to prevent future occurrences.

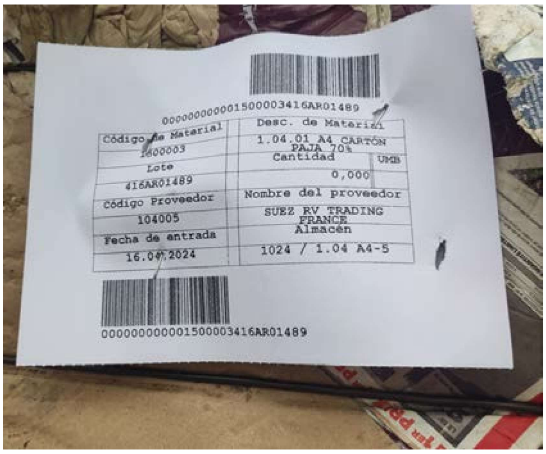
This approach seeks to optimize the process effectively over time, implementing energy-saving measures that contribute to long-term savings.

2. Materials and Methods

Software: Power Studio, Edison, DCS, EXCEL, Matlab, PRISMA, Outlook.

2.1. <u>Types of paper produced</u>

2.1.1. Raw materials

Name	Type	Label
A4 STRAWBOARD 70		

<table>
<tr><th>Name</th><th>Type</th><th>Label</th></tr>
<tr><td>A5 STRAWBOARD 100</td><td></td><td>
</td></tr>
<tr><td>A6 STRAWBOARD</td><td></td><td>
</td></tr>
<tr><td>D1 SEMIKRAFT</td><td></td><td>
</td></tr>
</table>

Name	Type	Label
KRAFT		

Figure 12. Type of raw materials

2.1.2. Paper recipes

	TL1	TL2	Semi-chemical
A4 STRAWBOARD 70%	10.94%	19.18%	0.0%
A5 STRAWBOARD 100%	18.80%	42.69%	43.3%
A6 NEW TRIMMINGS	34.19%	38.13%	34.0%
PULPER REEL	0.00%	1.77%	0.0%
D1 KRAFT	11.17%	0.00%	22.7%
CORES	0.58%	0.00%	0.0%
D1 SEMIKRAFT	24.32%	0.00%	0.0%

Figure 13. Types of paper made by raw materials in Hinojosa

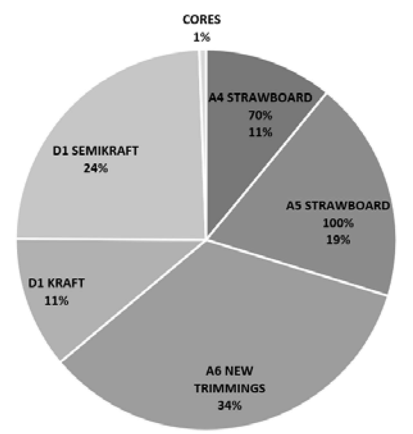
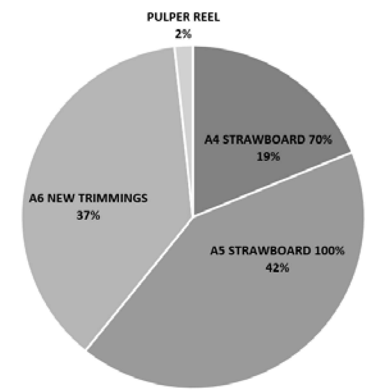
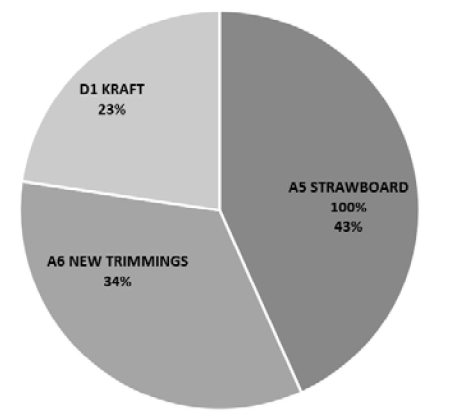
TL1	TL2	Semi Chemical
		

Figure 14. Types of paper composition

Physical properties

To enhance the comprehensiveness of the project, the laboratory kindly provided the properties of the paper produced. It is important to comment that consumption is influenced not by paper type or its physical properties, but primarily by its width and grammage.

TEST	ACCORDING TO	UNIT	GRAMMAGE									
Nominal basis weight	PA-IT02.13 PS-IT02.13	g/m^2	**165**	±4%	**170**	±4%	**195**	±4%	**215**	±4%	**245**	±4%
Nominal moisture content	PA-IT02.29 PS-IT02.107	%	9	±1	9	±1	9	±1	9	±1	9	±1
SCT, DT	PA-IT02.15 PS-IT02.77	KN/m	3.15		3.24		3.72		4.12		4.70	
		KN.m/kg	19.1		19.1		19.1		19.2		19.2	
Burst strenght	PA-IT02.19 PS-IT02.78	Kpa	421		433.2		490		548		625	
		Kpa.m^2/g	2.5		2.5		2.5		2.5		2.5	
Maximum Cobb 60	PA-IT02.12 PS-IT02.12	g/m^2	20-50		20-50		20-50		20-50		20-50	

Figure 15. Guaranteed characteristics TL1

TEST	ACCORDING TO	UD	GRAMMAGE									
Nominal basis weight	PA-IT02.13 PS-IT02.13	g/m^2	**120**	± 4%	**140**	± 4%	**150**	± 4%	**160**	± 4%	**170**	± 4%
Nominal moisture content	PA-IT02.29 PS-IT02.107	%	9	± 1	9	± 1	9	± 1	9	± 1	9	± 1
SCT, DT	PA-IT02.15 PS-IT02.77	KN/m	1.96		2.26		2.45		2.59		2.75	
		KN.m/kg	16		16		16		16		16	
Burst strenght	PA-IT02.19 PS-IT02.78	Kpa	235.2		274.4		294		313.6		333.2	
		Kpa.m^2/g	1.96		1.96		1.96		1.96		1.96	
Maximum Cobb 60	PA-IT02.12 PS-IT02.12	g/m^2	20-50		20-50		20-50		20-50		20-50	

Figure 16. Guaranteed characteristics TL2

	ACCORDING TO	UD	GRAMMAGE											
Nominal basis weight	PA-IT02.13 PS-IT02.13	g/m^2	**120**	± 4%	**140**	± 4%	**145**	± 4%	**150**	± 4%	**160**	± 4%	**170**	± 4%
Nominal moisture content	PA-IT02.29 PS-IT02.107	%	9	± 1	9	± 1	9	± 1	9	± 1	9	± 1	9	± 1
SCT, DT	PA-IT02.15 PS-IT02.77	KN/m	2.35		2.74		2.84		2.94		3.14		3.33	
		KN.m/kg	19.60		19.60		19.60		19.60		19.60		19.60	
CMT, DM	PA-IT02.18 PS-IT02.76	N	216		294		313		317		336		359	
		N.m2/g	1.8		2.1		2.1		2.1		2.1		2.1	

Figure 17. Guaranteed characteristics SQ

2.2. Steam production

Steam at Papelera de Sarrià is produced with the three existing boilers.

2.2.1. Natural gas Umisa boiler (See Figure 18)

2.2.2. Biogas Boiler (See Figure 19)

In Hinojosa-Sarrià, there is a biological WWTP for treating the plant's wastewater.

In this plant, biogas is generated in tanks IC1 and IC2 because of the water treatment process. The biogas boiler, also referred as López Hermanos boiler, consumes the biogas generated during the wastewater treatment process.

Brand	UMISA
Model	UMS-100 (16)
Boiler Type	Fire-tube
Year of Manufacture	2016
Steam Production (kg/h)	42160
Max. Permissible Pressure	16

Figure 18. UMISA boiler picture (a) and data (b).

Figure 19. Biogas digestor in WWTP.

This biogas is used as fuel in the steam boilers. There is a blower and a biogas dryer/cooler that can handle up to 200 m³/h. When the produced volume exceeds the blower's capacity, the excess is sent to the flare.

	Biogas Production IC1 (NMC)	Biogas production IC2 (NMC)	Use of Biogas (NMC)	Burned biogas (NMC)
Year 2020	1224454	1337864	1573098	989220
Production (%)	48%	52%	-	-
Consumption (%)	-	-	61%	39%

Figure 20. Biogas boiler data

"NMC" stands for "Normal Cubic Meter." It is used to measure the standard volume of biogas produced in the plant. Therefore, the estimated calorific value of 6.5 kWh/NMC refers to the amount of energy generated per standard cubic meter of biogas, assuming a composition of 65% methane. [15] (see Figure 21)

2.2.1. Biomass boiler (See Figure 21)

The biomass boiler is fueled by wood chips sourced from silvicultural operations.

These chips are transported using mechanical conveyors and burned to generate energy. After energy production, two residues are produced: ash and smoke. To prevent direct release of smoke into the atmosphere, it passes through four compartments of bag filters as shown in figure 23.

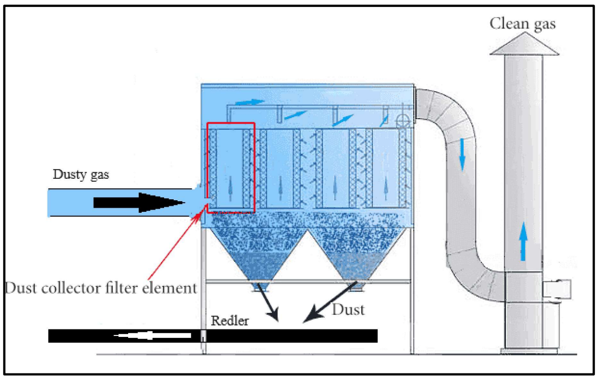


Figure 21. Biomass boiler real picture(a) and diagram (b).

For the bag filters to operate effectively, the gases need to enter at temperatures between 130 and 220 degrees Celsius. There's a safety valve in place to prevent the bag filters from burning.

- Entry conditions: 130ºC < T <220ºC
- If T<130ºC→ the filter becomes wet, causing steam to condense, crystallize and damage the filters, resulting in reduced filtration efficiency.
- If Ti > 220ºC → there is fire hazard → After firefighting, the filters end up with holes and they won't work properly anymore.

There are 4 compartments in the bag filters arranged in series, with the first compartment sacrificially designed to prevent temperatures from dropping below 130°C at the inlet, requiring regular replacement, as shown in Figure 22.

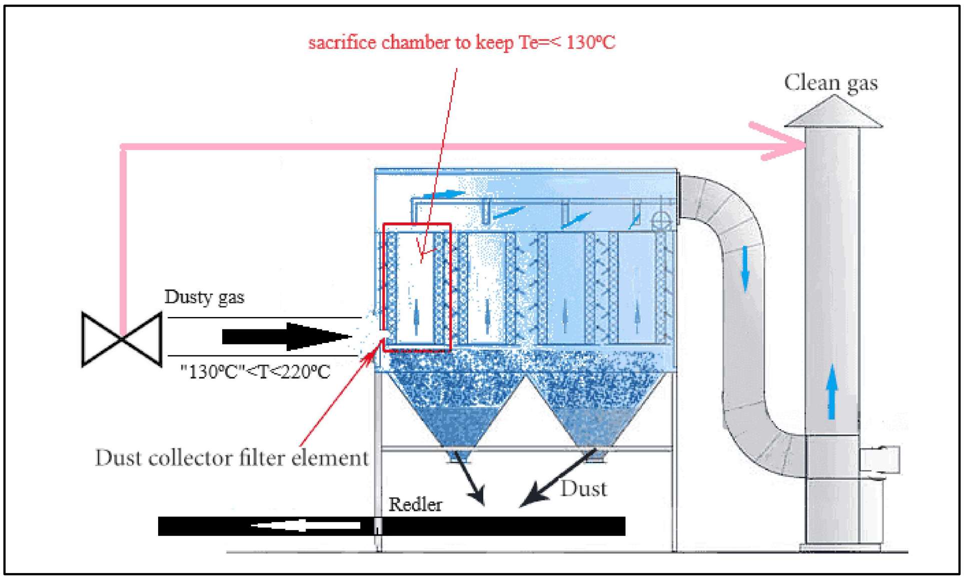


Figure 22. Biomass boiler diagram showing sacrifice chamber

2.3. Methods

The method is divided into three main parts: developing a complete motor list, sending daily energy analysis reports, and proactive communication with department heads through emails and meetings.

2.3.1. List of motors

With the aim of better understanding the factory and its processes, a comprehensive list of all factory motors was created. Ultimately, only those connected to the highest consumption analyzers were compiled. This included motors inside the electrical units connected to the following analyzers: Depuration and Machine Head, Water and Treatment, Vacuum and Auxiliaries, Drive 1, and Drive 2.

a. Starting from incomplete Excel lists of motors from 2016 and 2022, the following steps were taken:

   - Categorize the motors according to electrical lines (analyzers, transformers).
   - Enumerate the motors associated with each electrical line, reviewing older lists.

b. Physical Listing: Simultaneously, a physical listing of each motor in the factory was conducted.

Figure 23. Physical motor example (a) and data (b).

Typically, the code was written on the motor with a permanent marker. If not, the DCS (Distributed Control System) was used to locate the motor's process section to identify the electrical unit supplying its power.

c. Electrical Unit Identification: The first number on the tag indicates the electrical unit it is connected to.

Figure 24. Electric motor tag, physical label (a) and cabinet (b).

Each electrical unit contains cabinets that distribute power to the motors. Generally, each transformer supplies power to one or more electrical units, converting high voltage to low voltage.

An exception is Unit 3, which has three transformers, leading to a more complex configuration. cabinets. A plan was developed to identify which motors were connected to each transformer in the unit.

d. Verify the listed motors against the physical motors in each room.
   - If the motors are on the list, validate them.
   - If they are not, add them.

e. Final verification by confirming data with the electrical team and maintenance supervisor.

Once the list is finalized, the daily analysis tool can be employed to identify specific instances of overconsumption. Since electrical analyzers monitor multiple motors, identifying which motors contribute the most to overconsumption will guide the strategic placement of new electrical analyzers based on the motor list.

2.3.2. Daily energy analysis

The installed analyzers collect data hourly and send it to the Power Studio platform. After it, Power Studio sends it daily to a shared Excel file on the company cloud.
The file also includes production data and specific consumption details as gross production (kg), average width (mm), average basis weight (gr/m2), downtime (min), and total consumption (kWh).
The method involves a daily energy analysis reported by mail to the production and maintenance teams. It is also it is reported to the factory director of the factory to keep them informed. This reporting keeps them informed, enabling them to make necessary adjustments to reduce observed overconsumption.

The analysis refers to the previous day and aims to compare the factory's total consumption (kWh) in the following order:

1. Production ±5000 kg compared to the previous day.
2. Basis weight ±5 gr/m2.
    - Basis weight affects speed, which in turn impacts Drive 1 and Drive 2 analyzers, responsible for the paper-rolling rollers within the machine.
    - These analyzers account for 18% of the factory's total consumption.
3. Average paper width ± 2000mm
    - There is more flexibility because otherwise there wouldn't be enough days to compare, as it doesn't affect consumption as much as basis weight.
    - Daily average width is influenced by customer demand.
    - Gross production (kg) increases with greater width, which is determined by customer demand. However, consumption tends to remain similar even with narrower widths. Therefore, lower width results in reduced production and similar consumption, leading to low gross production levels with high electrical consumption.
    - If production alone is used to calculate the electrical ratio without considering daily average width, it may skew the ratio even in the absence of overconsumption.

Before this project, to make its daily analysis, Hinojosa Sarrià was using a theoretical electrical ratio based only on electrical consumption and production (ratio = 0.390 kWh/kg). The idea is to conduct the analysis considering additional parameters such as basis weight and average width by comparing the days with similar production values.

2.3.2.1. Steam equations

To improve the analysis, it was also important to compare the steam production ratio on different days. Currently, in Sarrià, they use the theoretical ratio from another Hinojosa's paper mill (Alquería), which is 1.80 tons of total steam per ton of paper produced.

The equations needed to solve the energy balance at the steam level concerning the pressure change valves are as follows:

Adiabatic equation

$$q_1 h_1 + P_2\left(-\frac{dV_c}{dt}\right) + P_{shaft} + Q = q_2 h_2 + \frac{dU}{dt} \qquad (1)$$

V_c (m^3) = valve inner volume accessible to fluid = constant.
P_{shaft} (kW) = refers to loss of energy on the wall heat flux, is negligible compared to the heat that goes through to the valve.
Q (kW) = 0 at it is an adiabatic valve.
U (kJ) = rate of variation internal energy, it is also considered negligible compared to the heat that goes through the valve.

$$q_1 h_1 + \cancel{P_2\left(\frac{dV_c}{dt}\right)} + \cancel{P_{shaft}} + \cancel{Q} = q_2 h_2 + \cancel{\frac{dU}{dt}} \qquad (2)$$

Then;

$$q_1 h_1 = q_2 h_2 \qquad (3)$$

As q_1=q_2 ;

$$h_1 = h_2 \qquad (4)$$

Knowing h_s and the Excel XSTEAM tool you can have access to T_s, S_s, and X_{vs}.

Non-adiabatic equation:

In non-adaibatic case, equation (1) would go as:

$$q_1 h_1 + \cancel{P_2\left(-\frac{dV_c}{dt}\right)} + P_{shaft} + Q = q_2 h_2 + \cancel{\frac{dU}{dt}} \qquad (5)$$

Signs of P_{shaft} and Q :

- Positive sign: some energy is gained by the fluid when its passes through the valve.
- Negative sign: some energy is lost by the fluid when it passes through the valve.

The normal case for a real valve (non-adiabatic) is that some energy is lost by the fluid when it passes through; then a lower T is observed after the valve.
But if the fluid is heated (by a heating source) when it passes through the valve, then it might gain some energy and a higher T might be observed.
Heat loss (thus energy loss) occur when thermal insulation of the valve is not good enough

To use the XSTEAM tool with the non-adiabatic valve, first it is must to read the exit temperature of the valve with some tool (ex. Laser) and then the excel will provide the values of h_2, s_2 and x_{v2} (vapor fraction on steam exiting the valve). After finding this values, the mass balance must be complete to find the value of Q. P_{shaft} is usually negligible.

Although the methodology described provides a detailed approach for performing the energy balance at the steam level concerning the pressure change valves, it is important to note that due to time constraints, the practical application of this energy balance was not completed.

2.3.3. Collaboration and communication

The project relied on teamwork, communication, and proactivity. Due to limited familiarity with the factory's processes and procedures, the project goals were accomplished through communication, seeking assistance, and collaborating with various departments as

- Energy optimization (Manuel Moya)
- Process team head (Adrián Garrido)
- Electrical team (Waleed, Rafa Ruiz and Josep Ríos)
- Maintenance team (Anna Capdevila, Colin Capon)
- Neoelectra (Rolando Galeano)
- Veolia (Maria Martínez)

Figure 90 and 91 in the appendix show the organizational chart for both the Sarrià Paper division and the total Paper division.
Energy consumption reductions identified through daily analysis were put into practice with the help of emails and regular meetings, both formal and informal, which included several discussions.

2.3.4. Gant chart

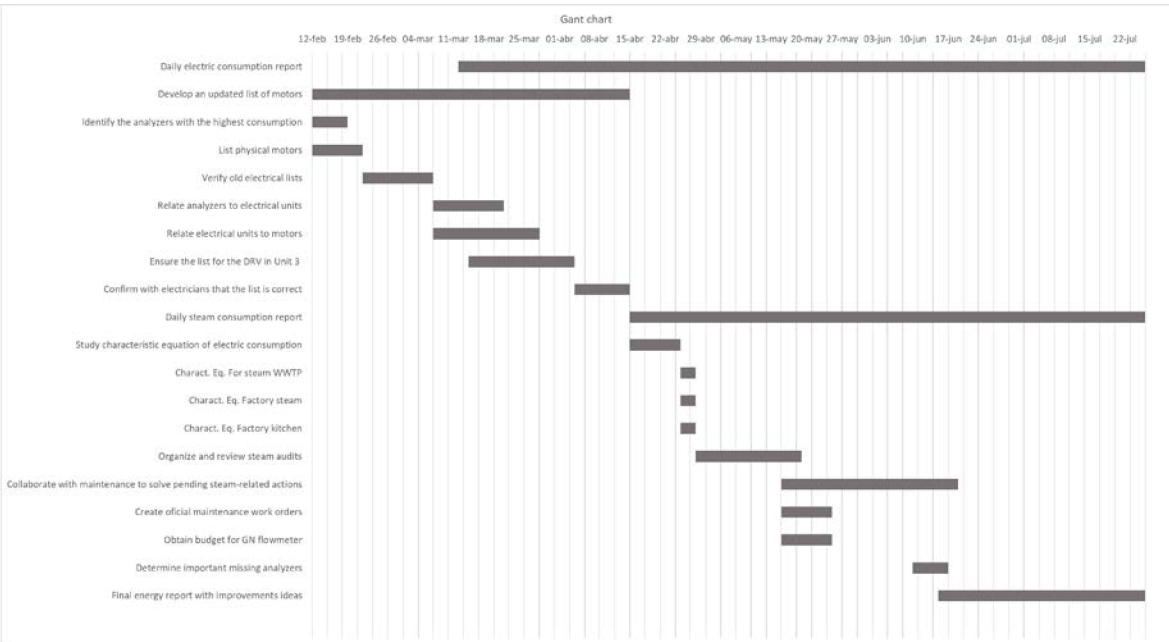


Figure 25. Gant chart

3. Results and discussions

3.1. Identifying the motors for the single line diagram.

The list of motors was developed mainly for the analyzer which represent bigger consumption over the total factory consumption:

- Machine Head Cleaning (DCM, U-1, U-2 and U-3 first 20 closets)
- Vacuum and Auxiliary Systems (*Vacío y auxiliares*, U-28 and U-36)
- Water and Treatment plant (*Aguas y depuradora*, U-18 and U-16)
- General Treatment plant (*Depuradora*, U-16)
- Boiler and Osmosis (*Caldera y Osmosis*, U-14)

Each analyzer depends on a transformer, usually each transformer feeds an electrical unit, except for Unit 3, which is fed by three transformers.
To create the list, there was no existing map to locate the physical electrical units. Therefore, after consulting with other workers at the factory, a map was developed so that everyone could know where to find them:

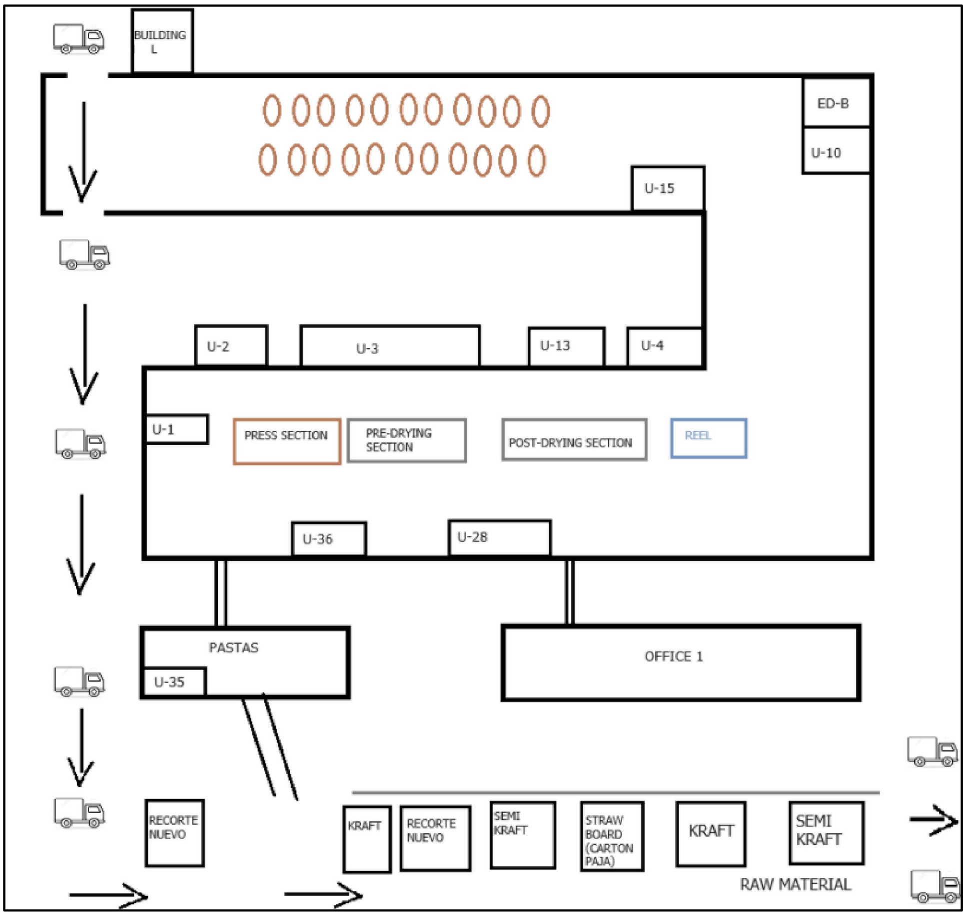


Figure 26. Electrical unit plant map

Another map for unit 3 was developed to know which transformer fed each analyzer and its motors.

Unit 3 is one of the most important units in the factory because U-3, U-2, and U-1 depend on the first 20 cabinets, known as Machine Head Cleaning, which accounts for around 20% of the factory's total consumption. Additionally, the motors from drives 1 and 2 are connected to this unit. Drive 1 consumes 13.4% of the total and Drive 2 consumes around 9%. Since all of them were mixed in the same electrical room, it was important to determine which motors depended on each analyzer to perform an electrical analysis.
To create the map for unit 3, electricians were consulted and the 2016 electrical diagrams were reviewed, some of which had been marked up by hand.
In this factory, the order of the electrical units does not follow the process sequence but rather the order in which motors have been replaced. For example, the rollers at the end of the machine are not in drive 2; instead, the motors of the rollers that have been replaced over time are there. Since drive 1 and drive 2 have different analyzers and transformers, and each accounts for a significant portion of the factory's total consumption, it was important to develop a map that could separate the two rows.

Figure 27. Drive DCS Press and pre drying section

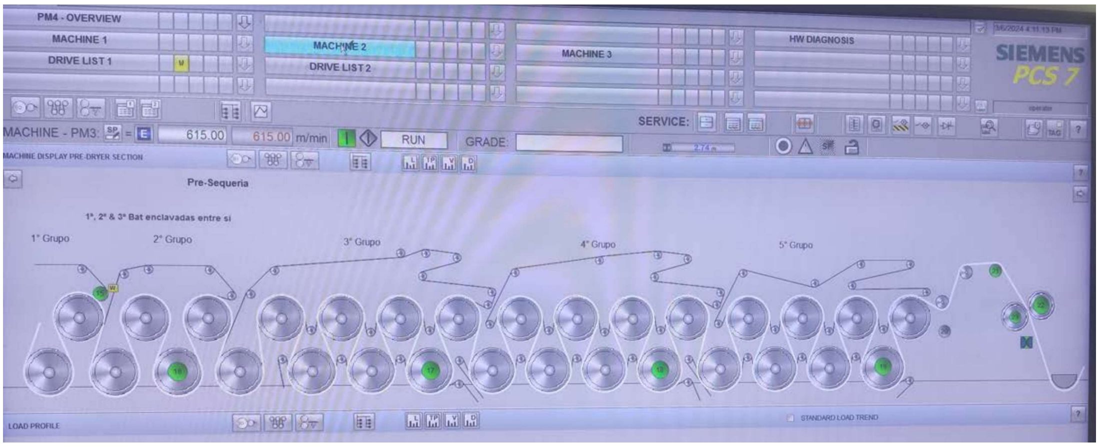


Figure 28. DCS Drive Post drying section

To ensure accuracy, the floor was lifted and the cables were traced with the help of a maintenance electrician to verify which electrical transformer fed each group of cabinets.

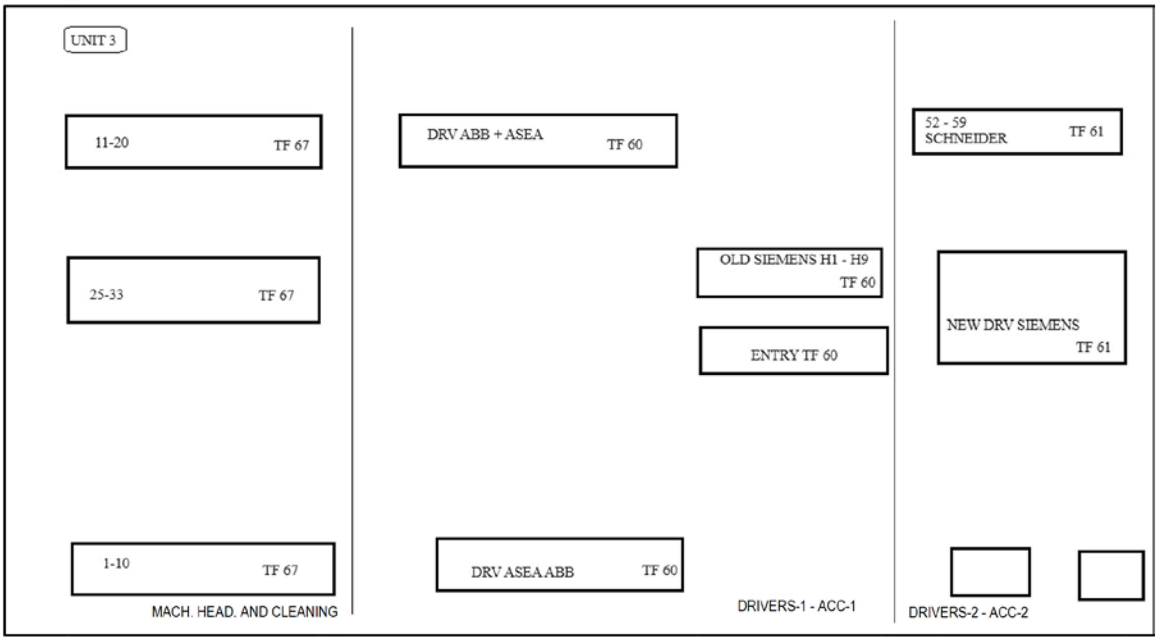


Figure 29. Unit 3 physical distribution

TRANSFORMER	ANALYZER	unit	CODI	CABINET	KW	RPM	COS FI	DESCRIPTION
60	**ACC-1**	U-3	DRV-01	YA02	248	1000	NO DATA	CILINDRE ASPIRANT
60	**ACC-1**	U-3	DRV-02	YA01	248	1000	NO DATA	ARRASTRE TELA
61	ACC-2	U-3	DRV-03	H16 (YA04)	75	1485	NO DATA	RODILLO AUXILIAR FOUDRINIER
60	**ACC-1**	U-3	DRV-04	YA12	343	1290	NO DATA	DUOFORMER
61	ACC-2	U-3	DRV-05	H10 (YA05)	200	1490	NO DATA	RODILLO DE RETORNO / TOP FORMER
61	ACC-2	U-3	DRV-06	H11 (YA06)	200	1490	NO DATA	CUSH ROLL / TOP FORMER
60	**ACC-1**	U-3	DRV-07	YA10	190	1253	NO DATA	PREMSA ASPIRANT 1 NIP (PICK-UP)
60	**ACC-1**	U-3	DRV-08	YA11	83	1500	NO DATA	PREMSA CENTRAL
60	**ACC-1**	U-3	DRV-09	YA08	178	1421	NO DATA	PREMSA SUPERIOR 2 NIP
60	**ACC-1**	U-3	DRV-11	YA19	7.5	1500	NO DATA	RODILLO GUIA ENTRADA PREMSA NIPCOFLEX
61	ACC-2	U-3	DRV-12	H15 (YA07)	500	1488	0.88	PREMSA NIPCOFLEX
60	**ACC-1**	U-3	DRV-13	YA19	5.5	750	NO DATA	RODILLO GUIA SALIDA PREMSA NIPCOFLEX
60	**ACC-1**	U-3	DRV-14	H2 (YA21)	55	1480	0.85	1ª BATERIA SECADORS
60	**ACC-1**	U-3	DRV-15	H2 (YA20)	37	1000	NO DATA	RODILLO GUIA 1ª BATERIA
60	**ACC-1**	U-3	DRV-16	H3 (YA22)	132	1500	NO DATA	2 BATERIA SECADORS M4-R-433 U3-YA22
60	**ACC-1**	U-3	DRV-17	H4 (YA23)	132	1488	0.85	3 BATERIA SECADORS M4 R-436 U3-YA23
60	**ACC-1**	U-3	DRV-18	H7 (YA24)	132	1488	0.85	4 BATERIA SECADORS M4-R-444 U3-YA24
60	**ACC-1**	U-3	DRV-19	H8 (YA25)	132	1488	0.85	5ª BATERIA SECADORS
60	**ACC-1**	U-3	DRV-20	H9 (YA20)	3.6	1488	NO DATA	FIBRON PASO DE TIRA SPEED SIZER
60	**ACC-1**	U-3	DRV-21	YA19	5.5	750	NO DATA	RODILLO GUIA SPEED-SIZER
60	**ACC-1**	U-3	DRV-22	H9 (YA27)	75	1500	NO DATA	PREMSA SPEED SIZER SUPERIOR (FIXA)
60	**ACC-1**	U-3	DRV-23	H9 (YA26)	75	1500	NO DATA	SPEED-SIZER INFERIOR (MOBIL)
60	**ACC-1**	U-3	DRV-24	YA15	46.9	1435	NO DATA	6ª BATERIA SECADORS
60	**ACC-1**	U-3	DRV-25	YA16	104	1710	NO DATA	7ª BATERIA SECADORS
61	ACC-2	U-3	DRV-26 derecha	H16 (YA28)	45	738	0.79	RODILLO DE PAÑO 1 SUPERIOR 8ª BATERIA?
61	ACC-2	U-3	DRV-26 izq	H16 (YA28)	45	738	0.79	RODILLO DE PAÑO 1 SUPERIOR 8ª BATERIA
61	ACC-2	U-3	DRV-27 abajo	H16 (YA29)	22	730	0.8	RODILLO DE PAÑO 2 SUPERIOR 8ª BATERIA
61	ACC-2	U-3	DRV-27 arriba	H16 (YA29)	22	730	0.8	RODILLO DE PAÑO 2 SUPERIOR 8ª BATERIA
61	ACC-2	U-3	DRV-28	H16 (YA30)	45	738	NO DATA	RODILLO DE PAÑO 1 INFERIOR 8ª BATERIA
61	ACC-2	U-3	DRV-29	H17 (YA31)	22	730	NO DATA	RODILLO DE PAÑO 2 INFERIOR 8ª BATERIA
61	ACC-2	U-3	DRV-30	H17 (YA32)	4	1435	NO DATA	FIBRON PASO DE TIRA POPE
60	**ACC-1**	U-3	DRV-31	YA18	104	1710	NO DATA	POPE
60	**ACC-1**	U-3	DRV-32 (ZM-345)	YA19	7.5	1500	NO DATA	EMBALADOR DE MANDRIL POPE
60	**ACC-1**	U-3	DRV-P304	PM-304	539	1293	NO DATA	BBA. FAN-PUMP
61	ACC-2	U-3	DRV-32-POPE	H17 (YA32)	124.1	1710	NO DATA	MOTOR
61	ACC-2	U-3	DRV-33	H17 (YA32)	45	738	0.8	MOTOR
61	ACC-2	U-3	DRV-34	H17 (YA32)	45	738	0.8	MOTOR
61	ACC-2	U-3	DRV-35	H17 (YA32)	55	740	0.81	MOTOR

Figure 30. U-3 Drive list final

A part of the motor list is presented on the appendix.

3.2. Daily report analysis example

For the daily energy analysis, this diagram is filled out based on the production characteristics of the previous day, including production in kg, width in mm, basis weight in g/m², and downtime in minutes.

SARRIÀ HINOJOSA PAPER

DÍA:	10
MES:	5

Producción bruta	Kg	368,900
Gramaje	Gr/m2	145
Tiempo muerto	min	85
ancho	mm	2,968

		Objetivo	Real	Obj. Acum. Mes	Acum. Mes	Desviación
Consumo eléctrico	kWh	143,871	144,531	1,650,609	1,616,471	34,138
Ratio eléctrico	KWh/Kg	0.390	0.392	0.390	0.382	-
Coste	€	25,262 €	25,378 €	289,828 €	283,834 €	5,994 €
Consumo Vapor Total	Tn	664	697	7,618	8,181	-563
Ratio Vapor Total	Tn/Tn	1.80	1.89	1.80	1.93	-
Consumo Gas	Nm3	14,983	39,737	171,898	259,832	-87,934
Ratio gas	Nm3/Kg	0.041	0.108	0.041	0.061	-
Coste	€	15,054 €	39,925 €	172,712 €	261,063 €	-88,351 €
Consumo Agua fresca	m3	3,265	3,157	37,456	30,305	7,151
Ratio agua	m3/Tn	8.85	8.56	8.85	7.16	-
Coste	€	0 €	0 €	0 €	0 €	0 €

Mix vapor		Real
Biomasa	%	7%
Biogas	%	6%
Gas Natural	%	85%

Autoconsumo eléctrico		Real
Generación FV	Kwh	11,503
% Autoconsumo	%	7.96%

Figure 31. Daily scheme

Where producción bruta – is gross production, gramaje is basis weight, tiempo muerto is down time and ancho is width.

The aim is to identify specific instances of overconsumption in electricity and steam.
Gas consumption was out off ratio because the biomass boiler was operating at minimum capacity, as explained in a later section.
The day with overconsumption is compared to days with similar characteristics to pinpoint the overconsumption in the various analyzers as shown in next Figure.

	Gross Production (kg)	Average width (mm)	Average basis weight (gr/m2)	Downtime (min)	Actual total consumption (kwh)	Electrical ratio (kwh/kg)
10/05/2024	368900	2968	145.0	85	144531	0.392
10/04/2024	368680	2748	145.0	110	142405	0.386
23/11/2023	363320	2794	145.0	45	142875	0.393
16/09/2023	369141	2763	145.0	0	147005	0.398

Figure 32. Daily comparison

Three days are chosen for comparison to broaden the range of comparison and include more possible scenarios.
Overconsumptions were investigated in the different analyzers

	Turboblower-1 (kwh)	Compressors (kwh)
10/05/2024	8153	8209
10/04/2024	7399	7553
23/11/2023	7421	7281
16/09/2023	10401	7327

	Turboblower-1 (kwh)	Compressors (kwh)
reference day consumption (kwh)	**8153**	**8209**
average compared days (kwh)	7410	7387
overconsumption average (%)	10.03%	11.13%
difference in consumption (kwh)	743	822

Figure 33. Found over consumptions

To calculate the overconsumptions, the average is taken using only the values with consumption lower than the calculated day, as these days 'demonstrate' that less could be consumed.

Which can be translated as

sum (kwh)	2151
real consumption - overconsumption (kwh)	141574
new electrical ratio	0.384

Figure 34. New ratio

Next, a study of the analyzers' evolution over the last 15 or 30 days is included, depending on the duration of the overconsumption.

Turboblower-1:

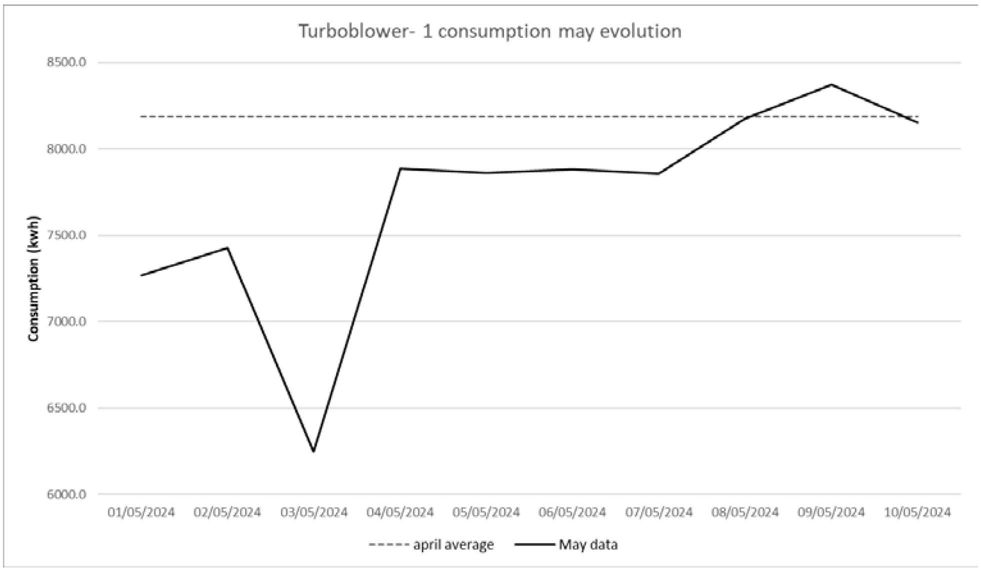


Figure 35. Turboblower 1 may evolution consumption

Regarding Turboblower-1, it is noted that further study is needed as it appears to show an upward trend. Monitoring will continue, and discussions will be held with the production supervisors.

Compressors:

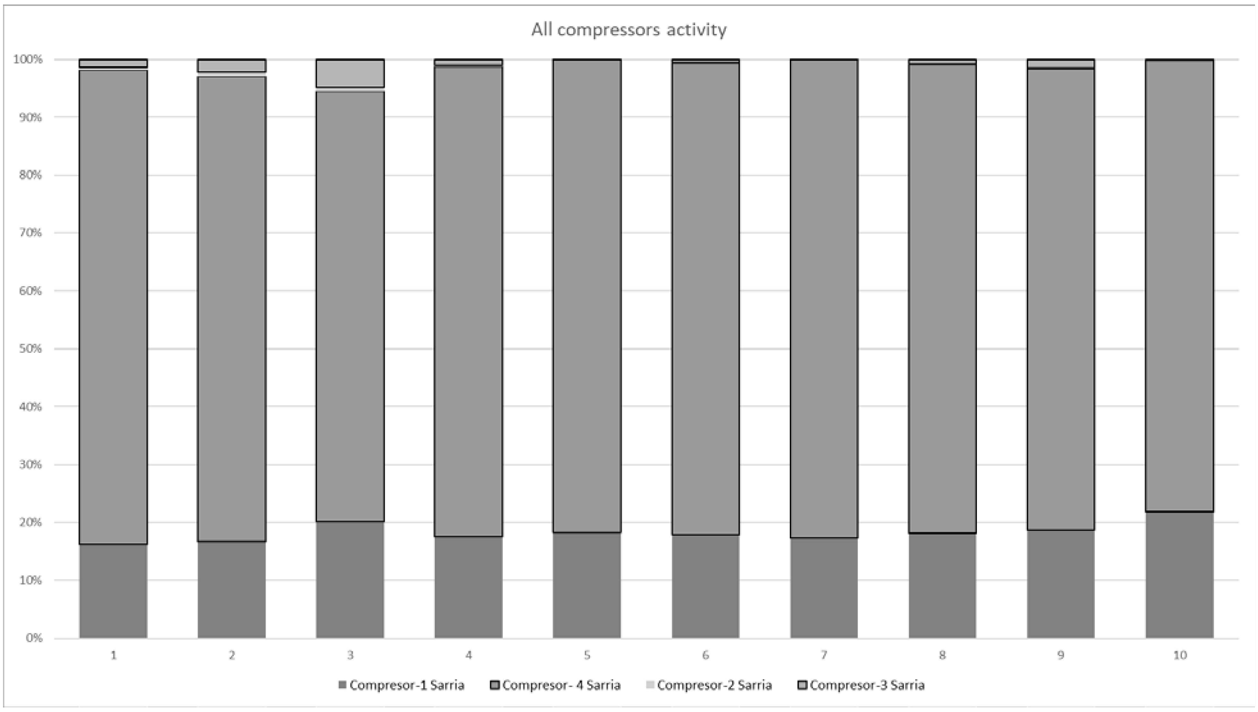


Figure 36. All compressors May activity

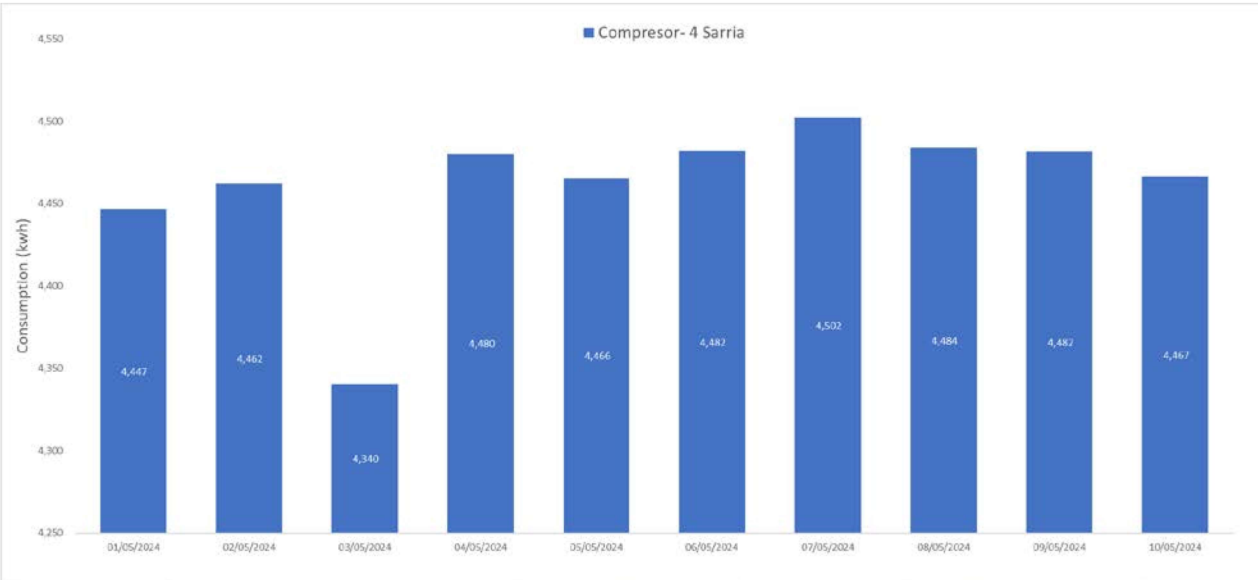


Figure 37. Compressor 4 may activity

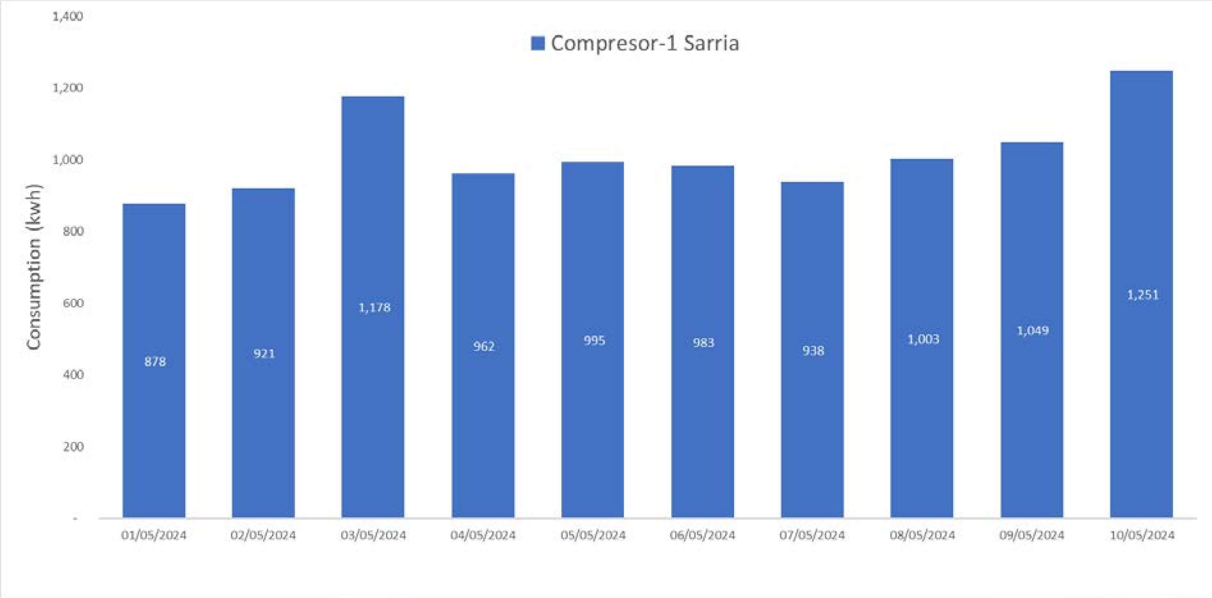


Figure 38. Compressor 1 may activity

The activity of the 4 compressors from May 1 to 10 is shown. According to the Sarrià plant schedule, only compressor 4 and 1 should be active, but it can be observed that compressors 2 and 3 were also activated during these days. However, the overconsumption on the 10th appears to be due to excessive activity in compressor 1, as compressor 4's activity is lower compared to other days.

While compressors 2 and 3 did not increase significantly in activity, compressor 1 consumed more than on other days, while compressor 4 consumed less. There was likely a malfunction in compressor 4, necessitating compressor 1 to compensate. Since compressor 1 is variable speed, it consumed more as its motor had to increase speed. It was asked to the maintenance supervisor to check this behavior with their electrical and mechanical operators.

3.3. Turboblower 2 reduction

In the daily reports from March 16, 17, and 28, an overconsumption of Turbo Blowers 1 and 2 was observed when comparing the average consumption in January and February 2023 to the average consumption the same months in 2024. The important part will be translated below:

Average consumption Jan-Feb kwh/day			
	2023	2024	% difference
Turboblower-1	8508	7770	-8,67%
Turboblower-2	7135	11116	55,80%
Total	15643	18886	20,73%

Figure 39. Turboblower comparison 2023 -2024.

It was observed that a year ago the turbo blowers consumed around 7,500 kWh each day and not around 11,000 kWh.

In the same email, information was requested from the production manager, about the vacuum level, and from the maintenance manager, about any leaks or breaks in the vacuum breakers of the turbo blowers.

There were some email exchanges between the head of the factory and the head of production, which led to a change in the set-point of the turbos. All of these exchanges are attached and translated in the appendix.

After some discussion, the production team managed to change the SP on turboblower 1 and 2 as:

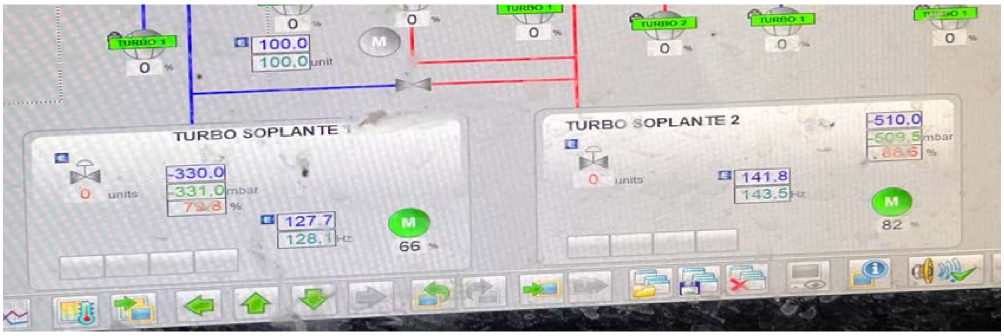


Figure 40. SP turboblowers March 12

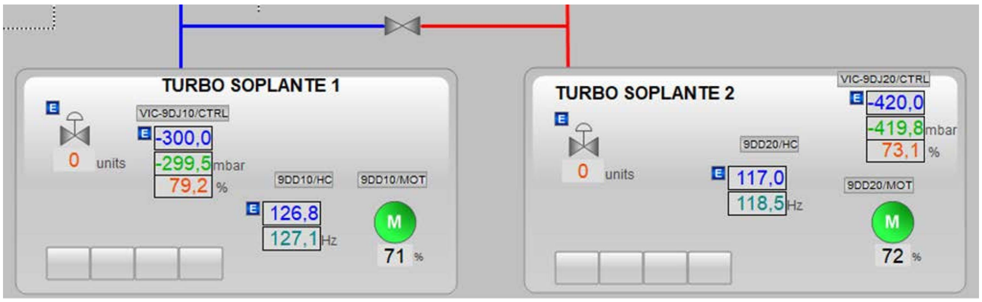


Figure 41. SP turboblower March 21

Date	Set Point
12/3/24	510 mbar
21/3/24	420 mbar

Figure 42.SP changed

Once the setpoint was changed, the motor was operating at 70% of its total consumption, resulting in a reduction in overall consumption.

In an energetic consumption way can be translated as:

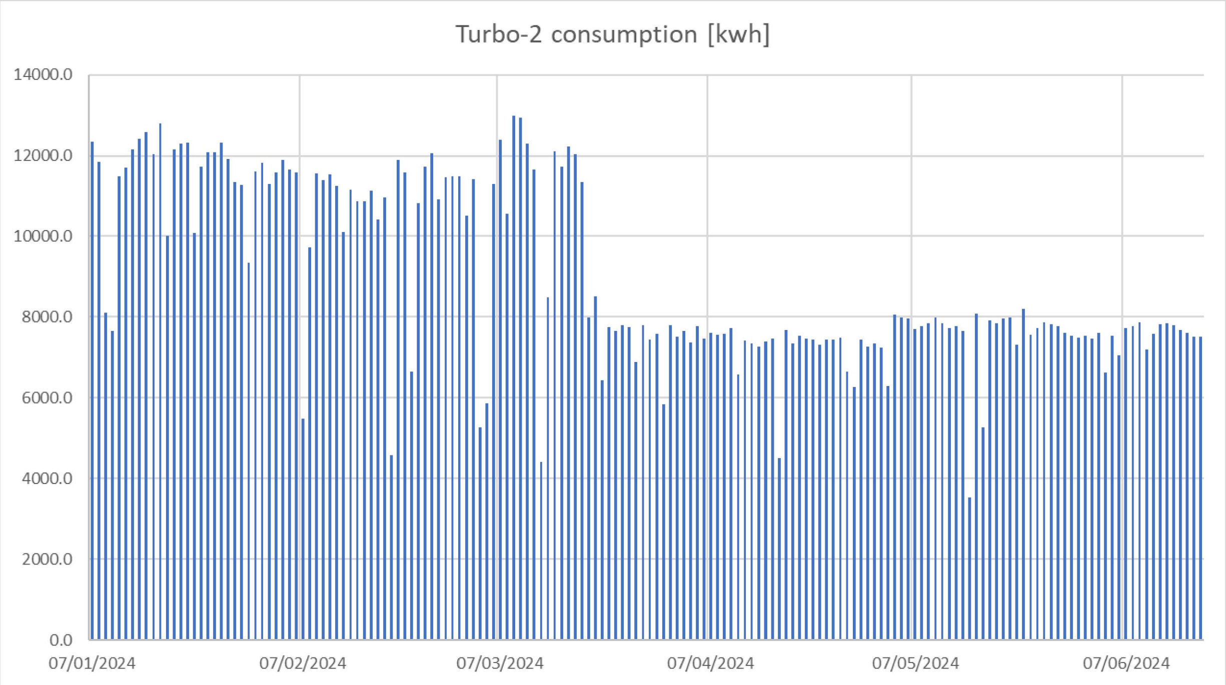


Figure 43. Turboblower- 2 daily consumption evolution from January until July

In figure 47 it is represented the daily consumption of turboblower-2 in kwh each day.

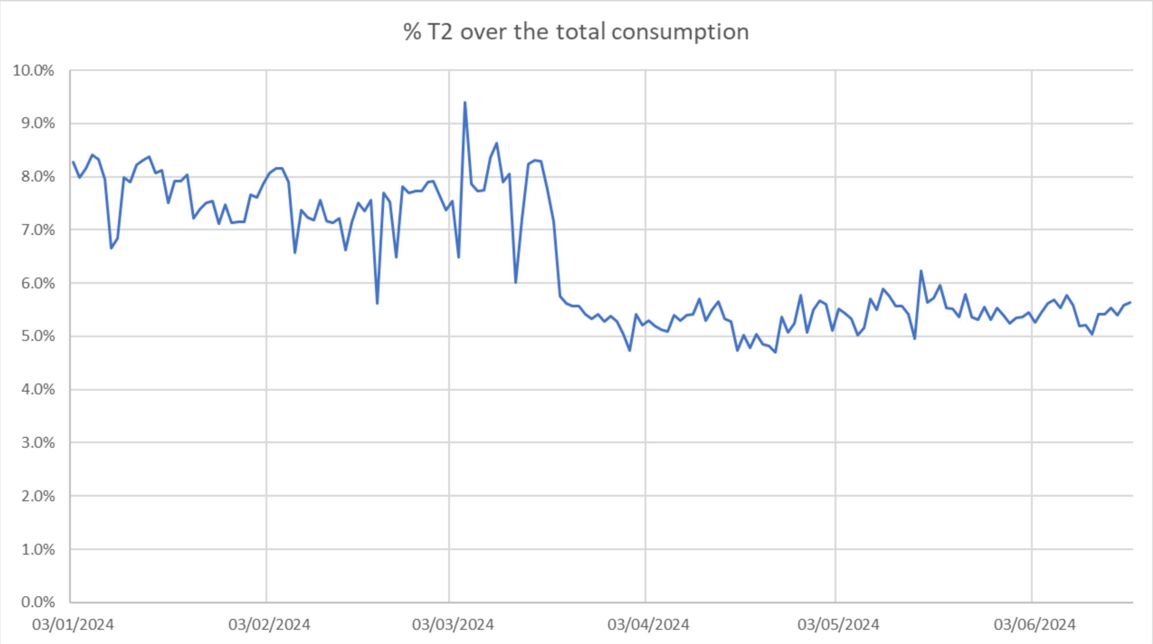


Figure 44. Graphic representation of T2 consumption evolution

In figure 48 it is represented the % of Turboblower 2 consumption against the total factory consumption each day.

This could be translated as an energy reduction of 5-7%, as indicated in Figure 45:

	Average consumption (kwh)		
	Total Factory	Turbo 2	% T2 over total factory
Before Set-point change	148350	11462	7.73%
After Set-point change	140465	7579	5.40%

Figure 45. Reduction in consumption after changing the SP

It is known that 0.056 €/kWh is charged, and economic savings have been calculated based on this rate:

Before SP change, turboblower cost an average of:

$$11462 * 0{,}056 = 642\ €/day$$

After SP change, the daily cost of turboblower 2 was:

$$7579 * 0{,}056 = 424\ €/day$$

$$642 - 424 = 218\ €\ saved\ each\ day$$

$$218 * 7 = 1526\ €\ saved\ each\ week$$

$$1526 * 4 = 6104\ €\ saved\ each\ month$$

From April until July it would be:

$$6104 * 4 = 24416\ €\ saved\ during\ the\ project$$

3.4. Wastewater Treatment Plant reduction

The 4th of April was detected overconsumption on the analyzer WWTP.

The overconsumption lasted around 15 days. In appendix there are shown the emails informing the factory team.
On April 4th, an overconsumption issue was detected on the WWTP analyzer. This overconsumption lasted for approximately 15 days.

Date report	WWTP behavior
3/4/24	Overconsumption detected
4/4/24	Overconsumption increased
10/4/24	Factory stop sending solids to WWTP
14/4/24	Overconsumption by Accumulative solids
18/4/24	Stop Overconsumption

Figure 46. WWTP reports

The emails detailing the communication with the factory team are included in the appendix.

However, below in the discussion of the results, the key points discussed with Veolia, the company responsible for the Sarrià WWTP, will be summarized.

In March, the average consumption of the WWTP analyzer was 1963 kWh, with a standard deviation of 868 kWh. In contrast, the General WWTP had an average consumption of 4722 kWh, with a standard deviation of 431 kWh.

The WWTP has two electrical analyzers installed: WWTP (U-18 and U-16), which account for 11.9% of the total consumption, and the General WWTP (U-16), which accounts for 3.4% of the total consumption.

The evolution of the WWTP analyzer these days is the following ones:

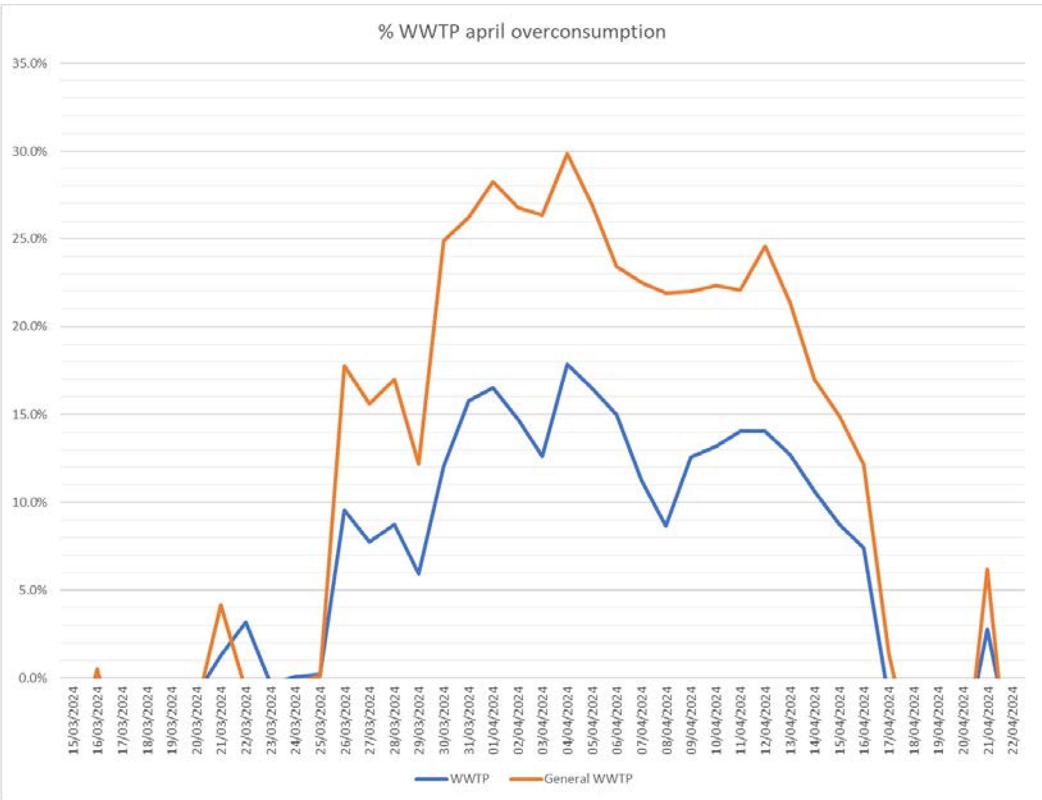


Figure 47.Overconsumption in April Compared to the March Average

Figure 52 shows the daily overconsumption compared to the March average for that analyzer; as

$$\frac{compared\ day - march\ average}{march\ average} * 100$$

On April 4th, it was detected that if the WWTP analyzer had been over its average, 4793 kWh could have been saved, allowing the factory to meet its electrical ratio. As a result, an investigation was initiated to understand why the consumption in the treatment section was higher, and the responsible from Veolia was contacted.

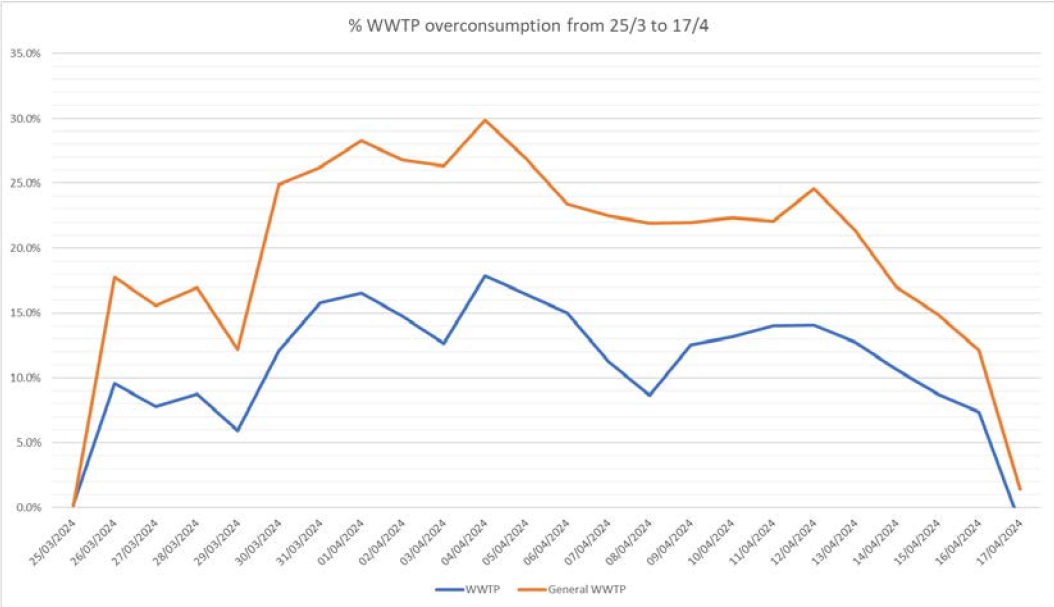


Figure 48. Zoom overconsumption

The responsible of Veolia explained that a massive influx of solids to the treatment plant due to failures in the DAF and pulp plants was limiting the treatment capacity of the WWTP and therefore the methane generation in the reactors. The pH was entering at 6 instead of 6.9 or 7, which was compensated by the amount of O2 that needed to be added, impacting the turbine speed, normally at 30 Hz, now around 43 Hz, generating higher consumption than usual.

Efforts were made to stop sending solids to the treatment plant by improving the operation of the DAF system, which is designed to clarify wastewater by removing solid particles, fats, and oils.

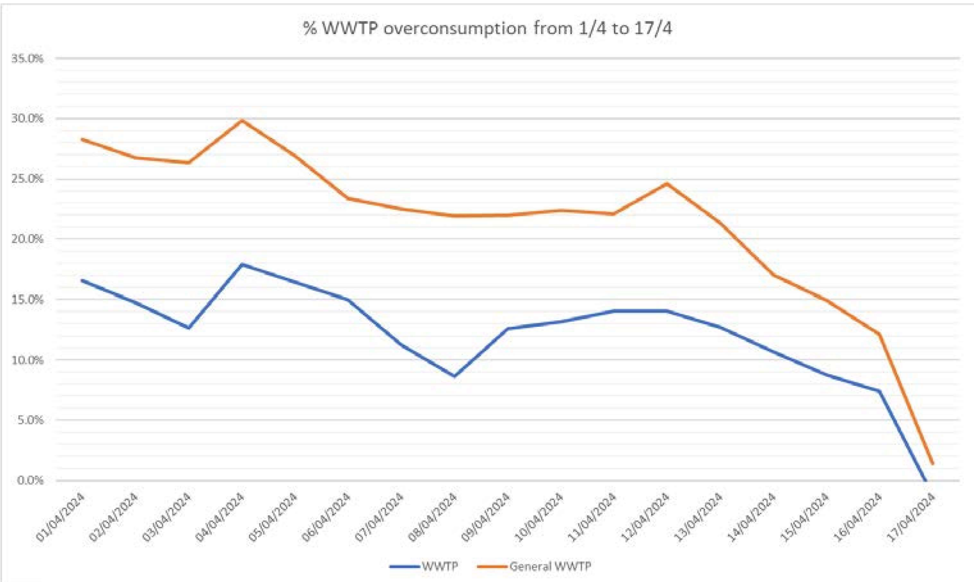


Figure 49. Reduction in final overconsumption

By around April 13th or 14th, these efforts succeeded in stopping the solids from being sent to the treatment plant.
However, overconsumption persisted due to the accumulated material. Although pulp was no longer being sent to the treatment plant, there was still some accumulated material, and until it was fully treated, the turbine continued to consume more than usual.

Accurate calculation of potential savings is challenging because constant supervision is necessary, particularly for the DAF system. Installing electrical analyzers on the reactor turbines and high-consumption motors in the water and treatment plant has been recommended to the factory managers. Since the WWTP accounts for about 12% of the factory's total energy consumption, improved monitoring could help detect and prevent future overconsumption issues.

Further investigation with the projects department revealed that solids were entering the system through an unknown pipe connected to the pipeline exiting the DAF, which then directed the water to the treatment plant. It is suggested that identifying and resolving the source of these solids is necessary, rather than simply blocking the pipe, as this could lead to new problems elsewhere.

Given that this issue varies and depends on multiple factors, an economic analysis has not been conducted.

3.5. Mix de vapor y Caldera de biomasa

On March 28, the bag filters in the biomass boiler started experiencing issues, which affected the gas mix used for steam production.

Date report	Biomass boiler behavior
28/3/24	Bag filter problems
26/3/24	Official slow down for bag filter problems
15/4/24	Stopped for changing bag filters
26/4/24	Working well
3/5/24	Feeding problems
6/5/24	Inspection of the filters

Figure 50. Biomass reports

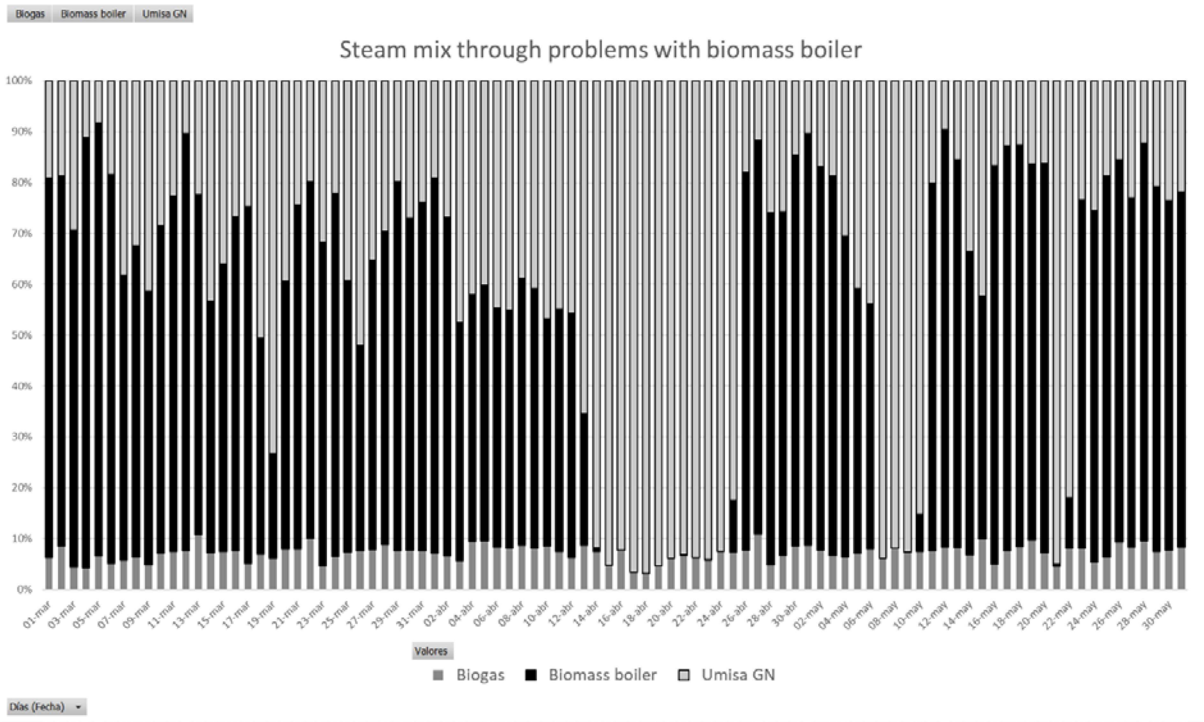


Figure 51. Steam mix through problems with boiler

The biomass boiler operates with four chambers of bag filters. Normally, two chambers are operational, a third is used to ensure the inlet air temperature exceeds 130°C, and a fourth is kept as a backup.

The issue began when the backup filter started to be blocked. It was planned to replace all the bags during the next scheduled shutdown. It was interesting to wait for the scheduled shutdown because the biomass boiler takes a few hours to fully start up, and when the paper mill shuts down, the biomass boiler it is not turned off. Instead, it is put to minimum load, and all the steam is vented to the atmosphere because the mill is not demanding steam. However, the problems started earlier than expected, forcing an advance on the replacement of the bag filters.

At this point, only the two functioning chambers and the third sacrificial chamber were being used. However, even though the chamber with the blocked filters was not in use, its filters started to break down due to air pressure, causing debris to fall into the valve that connects the redlers.
That valve isn't designed to handle large solids, which caused several issues. To mitigate these problems and until the bags could be replaced, the boiler was operated at minimum load to reduce the air pressure.

Afterwards, even while running at minimum capacity, another issue appeared: smoke containing ash from the biomass boiler chimney reached the town, leading residents to complain to the police. As a result, the factory director decided to move up the replacement of the bag filters by 15 days. Consequently, on Saturday, April 13, the biomass boiler was shut down.

The boiler stayed offline from April 13 to April 26. However, because some filters had started to come loose due to hastily done installation, requiring an additional 15 days beyond the originally planned replacement date, the boiler had to be shut down again from May 7 to May 10 for a thorough inspection. This shutdown was necessary to ensure they were properly installed.

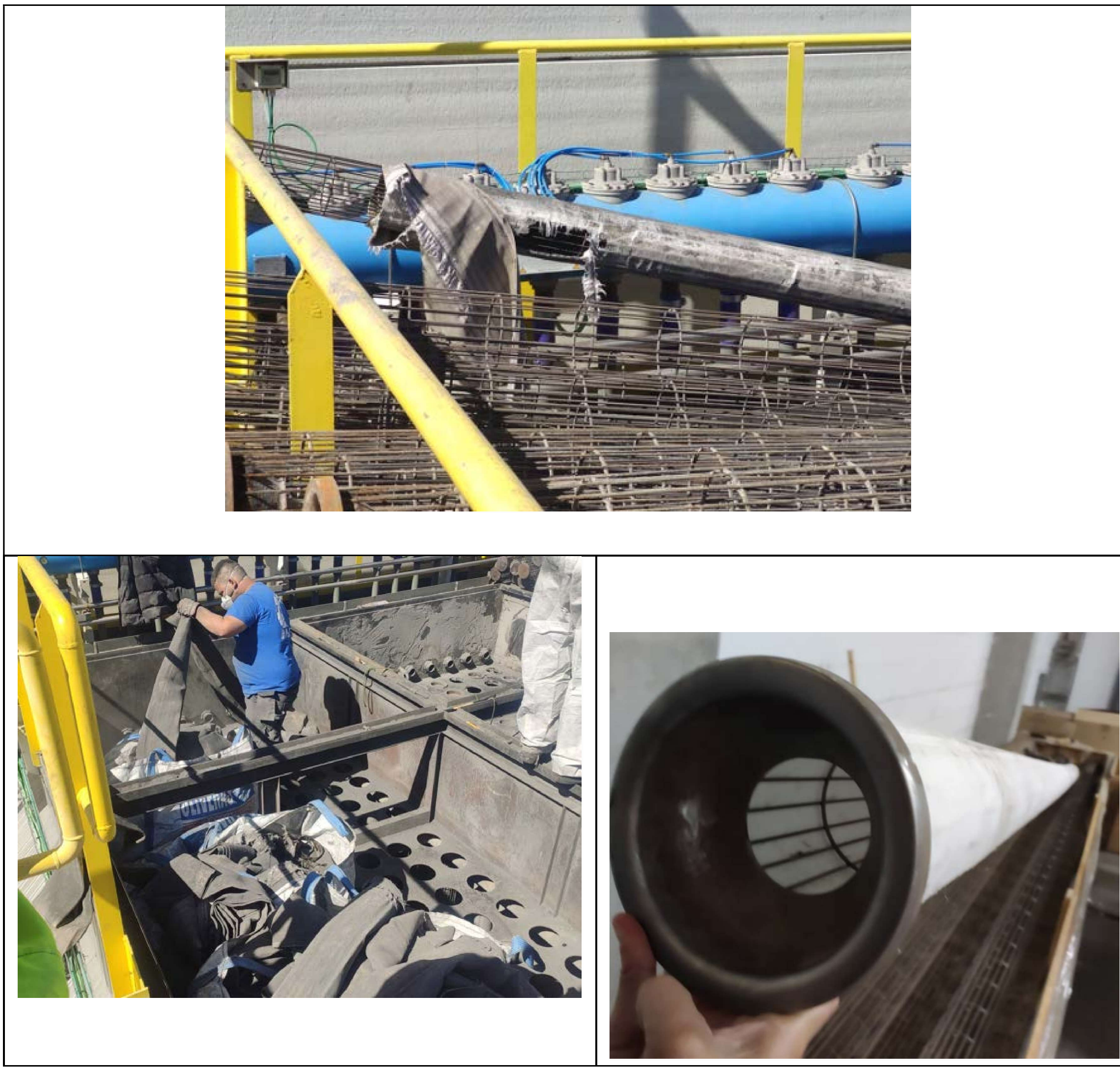


Figure 52 Old and new bag filters

Economically speaking, this would be interpreted as:

Total investment in bag filters:

Item	Unit Cost (€)	Quantity	Total Cost (€)
Bag Filters	80	576	46,080
Labor Costs and Crane Rental	-	-	10,000
Total Investment	-	-	**56,080**

Figure 53. Bag filters costs

There is a monthly consumption target that depends on monthly production and a ratio (0.0406 Nm^3 natural gas/kg paper production). The price of natural gas also varies based on the steam mix and whether a 24-hour advance notice is given, which may result in more natural gas being consumed than contracted for on a specific day. Therefore, an exact economic balance hasn't been achieved, but a small theoretical benefit has been estimated.

To simplify calculations, April is taken as the reference month because the biomass boiler operated at full capacity on some days, at minimum on others, and was idle for ten days. Therefore, it has been considered a suitable reference month for comparison. June was chosen for comparison, as the biomass boiler correctly operated every day of the month following the recent filter replacements.

	Natural Gas Consumption (Nm3)			
	Target	Real	Diference (Target-Real)	Different %
Poor month (april)	440459	825724	-385265	-47%
Good month (june)	397145	238916	158229	66%
	Cost (€)			
	Target Cost	Real Cost	Diference (Target-Real)	Different %
Poor month (april)	501502	940161	-438659	-47%
Good month (june)	266127	160098	106029	66%

Figure 54. Natural gas month comparison

If the investment in bag filter changes amounts to 56,080 euros, and the following month after the investment, was planned to spend 266,127 euros on natural gas (GN) was expected. However, due to increased biomass consumption resulting from the bag filter changes, only 160,098 euros were spent, saving 106,029 euros originally budgeted for natural gas consumption.

Assuming uninterrupted filter operation and no issues with biomass boiler, it has been determined that the filters must last a minimum of 5 months with performance similar to June while maintaining the steam mix for the investment to be economically viable.

$$(target\ € - real\ €) * good\ months - (target\ € - real\ €) * bad\ month - bag\ filter\ investment > 0$$

$$(266127 - 160098) * x + (501502 - 940161) * 1 - 56080 > 0$$

$$(106029) * x - 438659 - 56080 = 0$$

$$(106029) * x = 494739$$

$$x = 4{,}67$$

$$(106029) * 5 - 438659 - 56080 = 35406\ €$$

In the worst scenario, they would have to be replaced before 5 months due to malfunction, and then it wouldn't be amortized.

In the best scenario, it is estimated that they should be replaced every 4 years at most.

3.5.1. Natural Gas Boiler's Impact on Steam Measurement

The issue with the biomass boiler led to the observation that when it was inactive, there was an increase in error readings from the flow meters measuring steam consumption by the factory and production from Neoelectra' s boilers.
This occurred because the disparity between the steam used by the factory and that produced by the boilers widened. It was found that this was due to the natural gas boiler, which operates when the biomass boiler is not working. This month, it ran extensively because the biomass boiler was offline, and the natural gas boiler's flow meter does not correct for temperature, leading to inaccurate steam measurements for the factory.
Consequently, Neoelectra was billing for more steam than was actually produced (and used by the paper mill).
In a meeting with the relevant parties, it was decided to install a new flow meter with temperature correction, from the same brand as the existing ones. This will streamline the annual flow meter inspection process with a single vendor.
Budget estimates are provided in Figure 88 and 89 on the Appendix.

3.6. Steam audit actuations

In the daily reports, steam usage was reviewed starting from around April 20. The steam rarely fell within the stipulated ratio, only doing so with production levels above 400 tons per day or when the average daily temperature was especially high.

It is important to consider the outside temperature when it comes to steam because the consumption ratio varies significantly depending on the season. The ratios have been calculated for each season and then normalized using the summer consumption:

		Gross Production (kg)	Average steam machine consumption (Tn/day)	Average Ratio (Tn prod/Tn steam)	Difference % versus summer ratio	Difference % average consumption VS summer	Summer value normalized
winter 2023	1/1 a 21/3	294805	516	1,832	20,4%	7,9%	1,08
spring 2023	22/3 a 21/6	306272	486	1,721	13,1%	1,7%	1,02
summer 2023	**22/6 a 21/9**	**311622**	**478**	**1,521**	**0,0%**	**0,0%**	1
autum 2023	22/9 a 21/12	294304	524	1,921	26,3%	9,6%	1,10
winter 2024	22/12 a 21/3	318297	608	2,262	48,7%	27,2%	1,27
spring 2024	22/3 a 6/5	354521	652	1,879	23,5%	36,4%	1,36

Figure 55. Average data in seasons

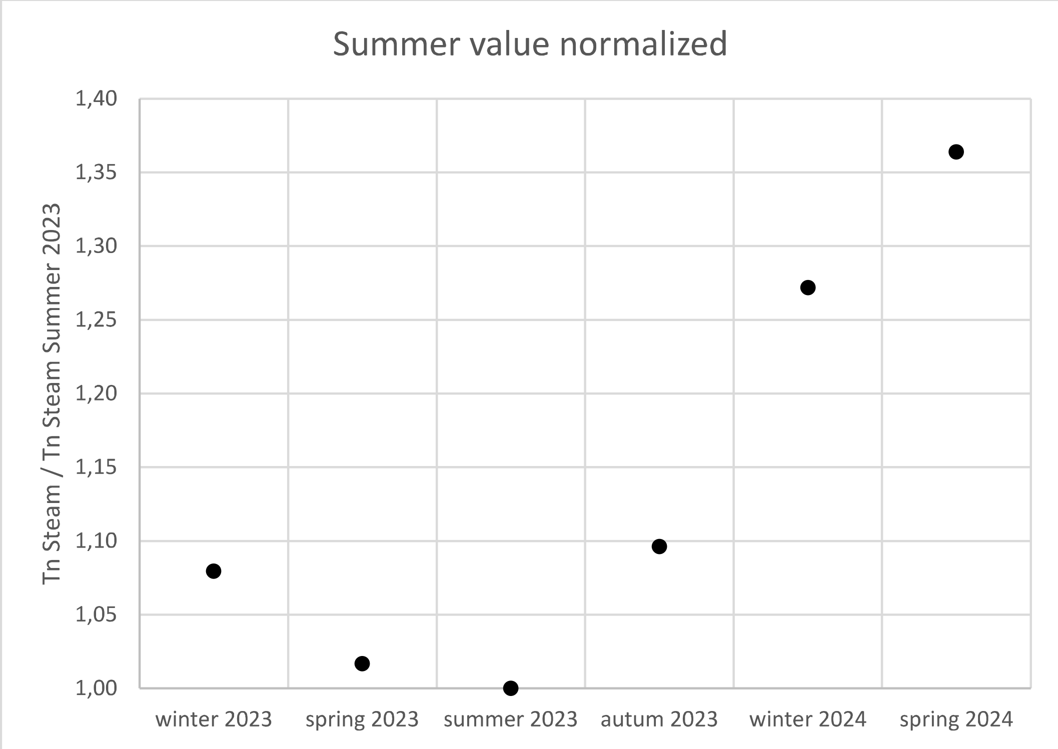


Figure 56. Normalized value with summer

To identify areas for improvement in steam usage, the different steam audits at the Sarrià plant from January 2023 (Valmet) to January 2024 (KADANT) were reviewed, and a list of pending issues was created. Among these, the most frequently mentioned issue was the cleaning of the filters in the steam-air extractors, which exchange heat with the incoming air and direct it to the steam room.

This ventilation system is referring to the next scheme:

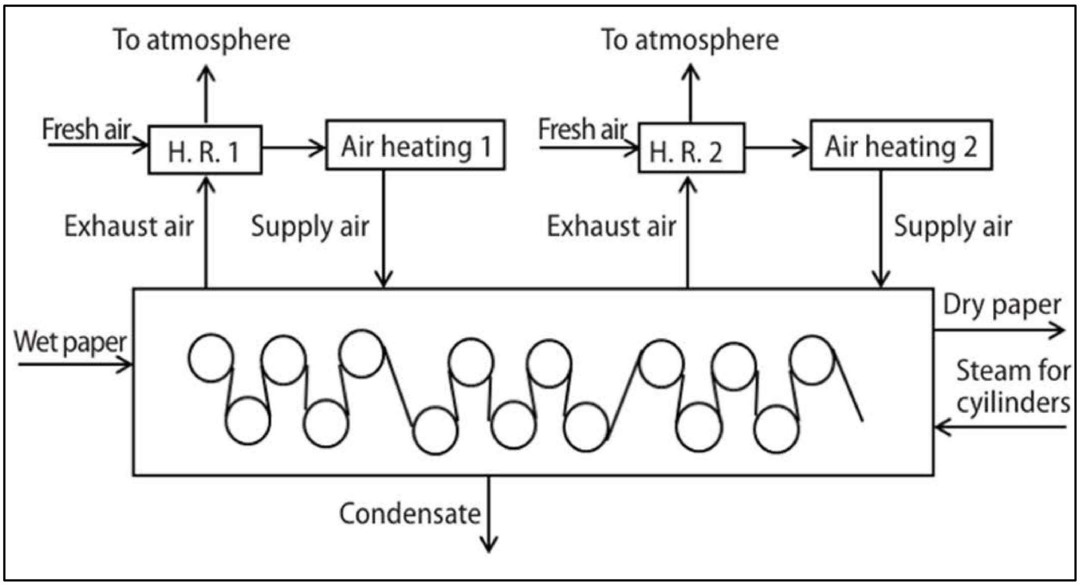


Figure 57. Paper machine drying section and its heat recovery system.

In which the filters that take the incoming fresh air are blocked.

The condition of these filters is shown in the following photos. There are several extractors on the terrace, and all of them were in a similar state to the one shown in the photos:

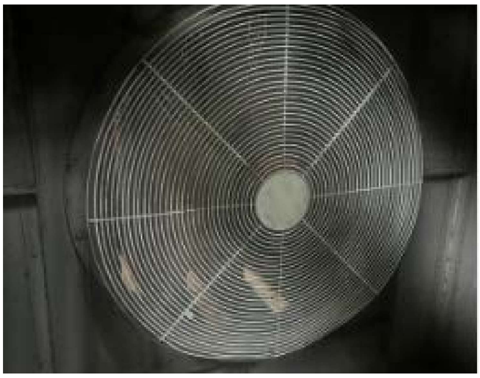
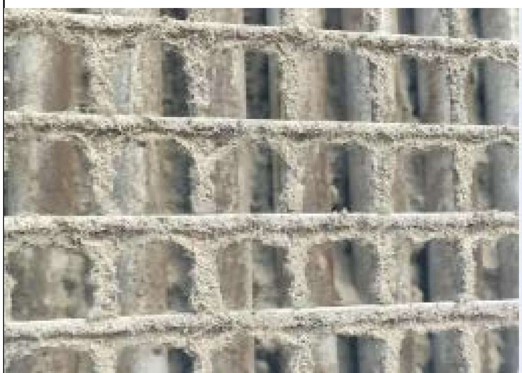
Since January 2023	After May 30, 2024
	
	
	

Figure 58. Filters before and after cleaning

Starting on May 13, the cleaning of these extractors was requested in the daily reports. Finally, on May 30, after two years since the initial audit (Valmet 2023), they were cleaned.

A study has been conducted comparing steam consumption before and after the cleaning on May 30th. To ensure the study's validity, the days selected must have similar characteristics in terms of daily total production, width, grammage, and downtime. However, there weren't many days with matching conditions, limiting the study's precision. Given the variety of conditions before May 30th, the data was filtered based on June's production characteristics, resulting in some important data points being missed for a precise comparison. The study was conducted on June 30th.

To compare the values, three similar days from before June were selected, and their averages were calculated. The steam consumption and the consumption/production ratio from before and after the extractor cleaning were then compared. The tables with the data can be found in the appendix, and a summary table is shown below.

Basis weight (gr/m2)		Average Gross Production (kg)	Steam total consumption (Tn/day)	Ratio Steam/ production (Kg/Tn)	Average T Girona (ºC)
140	before	394691	645	1.64	18.0
140	after	397538	716	1.80	18.6
145	before	325867	621	1.90	21.5
145	after	325404	671	2.06	22.9
145	before	365554	698	1.91	12.4
145	after	366728	671	1.83	22.3
165	before	354774	688	1.94	12.6
165	after	355270	643	1.81	22.9
165	before	315161	645	2.05	11.9
165	after	321240	641	2.00	21.9
195	before	368691	683	1.85	14.2
195	after	360779	690	1.91	21.7

Figure 59. Before and after compared data

Analyzing the results, it was observed that in most cases, the steam consumption ratio compared to production is worse after the cleaning than before. However, there are exceptions, particularly when the average temperature in Girona during the compared days is almost 10 ºC higher than on other days.

This does not necessarily mean that there was no improvement in the factory's steam system after the cleaning or that the cleaning was ineffective. These results can be explained by considering other factors as changes in production management, consequently changes in production and steam consumption during downtime. Also the lack of days with matching conditions limits the study's precision.

To compare the data from before and after the cleaning, it was important that the production characteristics, such as width and weight, were the same. It is important to note that the average production in June was the lowest in all of 2024, as shown in the following table.

Month	Average Gross Production (Tn)	Std. Dev. Gross Production (Tn)	Relative difference production (%)
ene	330	71	-1.33%
feb	326	87	-0.14%
mar	334	84	-2.51%
abr	361	58	-9.88%
may	346	82	-5.77%
jun	326	80	0.00%

Figure 60. Monthly Average gross production

The relative difference in production is referenced to the month of June. The difference has been calculated as (June - the initial month) / June.

The change in the production manager due to paternity leave coincided with June, which was the month with the lowest average production for the year. With the number of production managers reduced from three to two, there was an increase in breakdowns and unplanned downtime. To ensure a minimum number of daily rolls and reduce breakdowns, the average machine speed was lowered, as it is easier to avoid problems and breakdowns at lower speeds. Additionally, higher grammages were produced, which require lower speeds, and there was an increase in SQ production since its quality imperfections do not matter as much because it is the paper that goes inside the cardboard. This combination of factors explains the low production levels in June.

Another reason why the steam consumption ratios after cleaning are not better than before is due to unplanned downtime caused by breakdowns. During these downtimes, the steam sent from the boiler to the machine is released directly into the atmosphere to prevent condensation in the pipes. Otherwise, when the machine restarts and the steam in the pipes has condensed, the steam entering the machine would be wet and could cause problems in the dryers.

To address this issue, installing steam traps has been suggested. These traps would redirect condensate to a designated line, conserving steam during breakdowns and thereby eliminating the need to release unnecessary steam into the atmosphere.

Additionally, the absence of flow meters in the pre-drying and post-drying areas limits understanding the source of overconsumption. Meetings have been conducted with the projects and maintenance teams to finalize budgets for the flow meters, specifying their brand and specifications. Plans are currently underway to install these meters in the pre-drying and post-drying areas, with installation scheduled during the annual shutdown on October 4th.

As a summary: the lack of data with similar average production months, combined with the low production due to the change in the production manager and the excess steam released into the atmosphere during downtimes, makes the analysis imprecise and prevents drawing a definitive conclusion regarding the savings due to cleaning. However, it's important to note that the cleaning was performed at no cost by the factory's own workers, making it a cost-effective initiative.

4. Conclusions

The structured approach used in this project has proven effective. Daily monitoring of energy consumption and comparing it to similar production days has demonstrated that this method helps in finding ways to save energy and identify overconsumption issues early. This allows for prompt action to address problems.
The project has saved at least 24,000 euros, which is enough to cover the cost of hiring a trainee in Spain for 6 months. This shows that the investment in the project has been worthwhile.

Electricity Conclusions:
Energy Consumption Analysis: Typically, good production levels are above 385,000 kg, with efficient energy use around 1,450,000 kWh. Days with very low consumption are about 135,000 kWh, while days with significant overconsumption exceed 149,000 kWh. Staying below 149,000 kWh is challenging, so it is important to keep monitoring energy uses.

Recommendations for Improvement:

- Blower Setpoints: Maintain a low setpoint for Turbo Blowers 1 and 2 to decrease steam usage and improve energy efficiency.

- Need for Additional Analyzers: Additional analyzers are needed in areas where overconsumption frequently occurs but is not well understood. Reports have recommended adding analyzers to the water and wastewater treatment plant to improve monitoring, identify sources of overconsumption, and provide better data for decision-making.

- DAF Solids Management: Review the solids output from the DAF to ensure that the water going to the treatment plant has fewer solids. This will help avoid the need for increased oxygen and reduce overconsumption.

Steam Conclusions:

- Installation of Flow Meters: It is highly recommended to install flow meters in the pre-drying and post-drying sections, as well as in the Umisa boiler with temperature correction. This would be very helpful because without these flow meters, it is impossible to identify where the losses are occurring. This installation will provide better insights into steam usage and help prevent losses.

All of these suggestions align with ISO 50001 standards, which call for reduced steam consumption and the installation of new electrical analyzers. Implementing these recommendations will also help meet European Union requirements, supporting the factory in maintaining its subsidies.

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