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H2020 Work Programme

D5.1 – MONITORING MANAGEMENT SYSTEM

Lead Contractor: CARTIF

Date: 13/05/2022

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1 PU = Public
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Abbreviations

BREF: Best available Techniques Reference Document

CCM: Continuous Casting Machine

CHP: Combined Heat and Power

DB: Data Base

EAF: Electric Arc Furnace

LAF: Electric Ladle Furnace

RES: Renewable Energy Sources

WH/C: Waste Heat/Cold

WtE: Waste To Energy

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Executive Summary

The present deliverable is part of SO WHAT project: Supporting new Opportunities for Waste Heat And cold valorisation Towards EU decarbonization. The objective followed by SO WHAT is to develop and demonstrate at TRL8 an integrated software which will support industries and energy utilities in selecting, simulating and comparing alternatives Waste Heat and Cold (WH/C) exploitation technologies that could cost-effectively. This tool is designed for industries and energy utilities where could be potential waste heat/cold that can be recovered and support them in: auditing the industrial process to understand where energy flows could be valorised, mapping the potential of locally available RES sources to be integrated with WH/C potential

This document represents the Deliverable 5.1 'Monitoring Management System' developed within WP5 - SO WHAT Tool Validation in real industrial demo cases, Task 5.1 - Monitoring Programme for demo cases. The task will be devoted to the validation of the developed tool and its refinement through, the employing it to realise theoretical feasibility studies in the demo sites and encourage replication within and outside the consortium.

The objectives of theWP5 are:

- Define a cloud based monitoring platform, based on the corresponding monitoring networks at the different demo sites, a common database and a data quality strategy.
- Data collection from the system of sensors, actuators, etc. of the different demo sites.
- Validate and fine-tune of SO WHAT tool based on real data from the monitoring platform deployed in the demo cases.
- Demonstrate the techno-economic feasibility of industrial heat/cold recovery.
- Ensure maximized scalability and replicability of results outlining innovative pathways for rapid replication across EU.

In this deliverable, the efforts will be focused on the description of the methodology followed during task 5.1 and includes the process between the comprehension of the demos operation and the reception of the monitored data until end-up in the SO WHAT Tool validation.

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1 Introduction

1.1 Objectives of the Task 5.1

The objective of SO WHAT Task 5.1, "Monitoring programme for demo cases" is to enable pathways to get diagnostic information to feed the SO WHAT tool and eventually track the effectiveness of the actions in terms of energy savings and performance increase. In line with outcomes from T1.2, this task aims to complete the definition of the monitoring network and the identification of strategies and procedures to collect data for mapping and quantifying the potential for waste heat and cold recovery and valorisation and for integration of renewables in industrial contexts. Indeed, Task 5.1 aims to complete the definition of the monitoring network, implement a data quality check module and address instrumentation installation and commissioning.

The outcomes of this Task are articulated into two Deliverables, specifically:

- D5.1 on "Monitoring management system";
- D5.2 on "Report on the instrumentation installation and commissioning".

A detailed description of the methodology followed during the analysis of demo data, will enable the diagnosis information to feed the tool in order to validate it and eventually track the effectiveness of the actions in terms of energy savings and performance increase. The aim is to implement a data quality check module which will be request from the demos. The correct development of dedicated surveillance services will be able to minimize the loss of data and would identify potential problems at different levels related to: communication (problems between monitoring and data base), sensor faults (data outlier, malfunction of the sensor) and equipment malfunctioning (pumps, valves, storage, etc.). This task (T5.1) is broken down into subtasks, but only two of them are involved in the following deliverable.

- Subtask 5.1.1 – Monitoring network – This subtask requires the definition of the architecture of monitoring system including the required sensors, location of them and communication protocols between the management hardware.
- Subtask 5.1.2 – Data analysis and data quality strategy – where, dedicated surveillance services to minimize the loss of data, will be developed and identification of potential problems at different processing levels will be identified.

Objective of D5.1. – Monitoring management system

The main objective is to explain the methodology followed to analyse the available monitoring data of SO WHAT demos in order to simulate possible heat recovery scenarios through the SO WHAT tool.

1.2 Relationship with other activities in the project

Deliverable 5.1 leverage on the outcomes of the previous deliverables:

- **Task 1.2.** Overcoming barriers in data collection and data format required, whose aim is to identify strategies and procedures to overcome barriers and criticalities in the collection of relevant data for mapping and qualifying the potential for WH/C recovery and RES integration.
- **Task 1.1/ D.1.1** [1] Report on Industrial Site Demo Assessment. This deliverable is associated to the assessment on waste heat potential and evaluate which are the main algorithms to model industrial energy processes and those ones related to the evaluation of potential local

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waste heat and cold. This quantification of the WH/C streams at the industrial demo sites are very useful for the demo sites interpretation and to evaluate the data received from the 3 industries.

- **Relation with the D1.4 and D1.5,** where importance of Energy Audit is explained. The deliverable **D1.4** focuses on requirements for data for SO WHAT tool, which globally coincide with data that are required for an energy audit of an industrial plant. It is therefore useful to provide an overview, in this chapter of the energy audit process and of the required input data and **D1.5** introduce this kind of document as a main in the information of every Industrial site.
- **Task 5.1/D5.2** Report on the instrumentation installation and commissioning. It is the deliverable that present the accuracy of the tool and its impact on the demo sites. Deliverable of report format and confidential only for members of the consortium.
- This document is related as well to the **work package 2** (Specification of the tool and common IT framework), where a definition of technical requirements for the SO WHAT Tool is studied.

1.3 Structure of the Document

As said, this document has two main subtasks (Subtask 5.1.1 and Subtask 5.1.2).

Regarding **Subtask 5.1.1**, none of the demos provide the monitoring data through an automatic procedure. IES developed a software tool that can be installed on the demo servers, collects monitoring data and transmits it automatically to a specific software, nonetheless none of the demos authorized the installation of this IES software. The demos that has provide monitoring data, have obtained it through some kind of manual download and export from their existing control and monitoring systems. No software has been developed in charge of dedicated surveillance services for the monitoring data, since the data is provided manually and the process requires a tailored study for each demo.

For this reason, the report focuses on **Subtask 5.1.2**, describing the methodology followed for the analysis of the monitoring data of a possible real production installation. The methodology explains the steps to follow in order to verify the quality of the data received and once verified, it even proposes possible solutions to correct some non-critical defects found in the monitoring data received. The process will always be tailored to the type of industrial facility, the characteristics of the received monitoring data and the amount of information available.

First of all, it will be presented a brief **description of the Industrial sector of the Demo Sites**, while the main recovery points are identified. Then it will be described the **methodology followed** since the detailed understanding of the plant until the reception of software files with the monitoring numerical data. After that it would continue with the data quality and coherence analysis and finally the data adaptation for it later introduction into the SO WHAT tool. The following main aspects has been reported in the deliverable:

- Study of the demo;
- Data analysis and Error correction;
- Adaptation to appropriate formats.

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In this framework, the **potential waste/cold sources in industrial sites** have been identified, in order to take them into account in future projects where this information could be a useful guide. The document will end with **conclusions** reached during this task.

2 Description of SO WHAT validation sites

Whilst there are 11 demo sites in the project, 4 were considered out of scope for this deliverable due to technical limitations. From the 11 demo sites who participate in the SO WHAT project the selected ones are:

- LIPOR Maia Waste-to-Energy plant;
- Pessione Distillery (M&R);
- ENCE Pulp mill (ELEU).
- MPI Steel Industry Research Pilot Plant

The *Table 1* has been taken from the **D1.1 Report on industrial demo sites assessment** (confidential deliverable) of the project, where there is an explanation of why 4 out of 11 demo sites were selected for the implementation of SO WHAT tool validation.

The same ones that in the *Table 1* are coloured in "**Green**". From all the industries, an assessment of WH/C resource through the existing SO WHAT tool could be completed only for the 4 demo sites mentioned. The "**grey**" ones cannot be fully completed the assessment due to insufficient relevant and usable data collected from these demos. Finally, the ones coloured in "**Red**" was not possible due to technical limitation in assessing WH/C resource for district heating and cooling networks or due to partial completion of the demo-site data checklist with thus insufficient collection of relevant and usable data. Therefore, only these first 4 demo sites has been developed in the D5.1.

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Table 1: list of demo sites

Demo site name	Location	Sector	Included into D1.1 WH/C resource assessment?	Comments
M&R Pessione Distillery	Pessione (IT)	Food & Beverage	**Yes**	N/A
MPI Steel Industry Research Pilot Plant	Middlesbrough (UK)	Steel industry		
ENCE Navia Pulp Mill	Navia (ES)	Pulp mill		
LIPOR Maia Waste-to-Energy Plant	Maia (PT)	Waste-to-Energy (WtE), Incinerator		
UMICORE Rare Material Centre	Olen (BE)	High tech manufacturing	**Maybe, up to data processing step**	WH/C resource already assessed by demo site Insufficient relevant and usable data, data mapping complete
ISVAG Waste-to-Energy Plant	Antwerp (BE)	WtE, Incinerator	**Maybe, up to use case identification step**	Insufficient relevant and usable data, use case identified
IMERYS Manufacturing Centre	Willebroek (BE)	Chemical		
ROMPETROL Petromidia Refinery	Navodari (RO)	Refinery	**No**	Data checklist partially completed, insufficient relevant and usable data
RADET Constanta DHN	Constanta (RO)	DHN, WH from local industries		Limitation of existing SO WHAT tool in assessing WH/C resource for District Heating and Cooling Networks (DHN/DCN)
GOTE Goteborg WH DHN	Goteborg (SE)	DHN, WH from refinery and waste incineration		
VAEB Varberg WH DHN	Verberg (SE)	DHN, WH from Pulp Mill		

There will be developed a description of each demos in the following sections of the deliverable and a general and common methodology for any of the 4 case studies without focusing the procedure in any of them particularly. The main objective is to provide a general description of the followed methodology, although as explained in the document, the followed process has to be customized for each demo, since different demos obviously generate quite different monitoring data.

2.1 LIPOR Maia Waste-to-Energy *(LIPOR)*

Located in Maia, a municipality in the Porto Metropolitan Area, **LIPOR Maia** plant is a **WtE** (Waste-to-Energy) facility that incinerates approximately 380,000 tons of municipal solid waste per year.

2.1.1 Process

The process is divided in two treatment lines and operates in a continuous and automatic combustion manner. Energy is produced through a thermal process of combustion and steam production [2]. The

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steam stream generated is fed into a turbine and electrical energy is produced. In sum, the LIPOR plant aims to transform thermal energy into electricity. As said, the fuel used is municipal waste that cannot be used through composting or recycling processes. The recovery centre operates 24h a day, 7 days a week and the duration of annual suspensions for maintenance and upkeep, can range between 1 and 4 weeks, which is important to understand correctly the compiled data. Herein below the productive process will be briefly explained, in order to understand how a Waste-To-Energy plan works.

Parts of the process:

1) Waste reception

Storage in the waste pit after being weighted and separated from possible metal objects.

2) Steam production process

Waste is directed from the pit to the feed hoppers and finally to the boilers. There they burn at high temperatures and the exhaust gases are obtained from this combustion process. The heat from this high temperature stream will be used to produce superheated vapour with heat recovery boilers. In addition, in the turbo-group equipment there are stream extractions that will be introduced in heat exchangers to adjust temperatures of process air currents. At the outlet of the turbine, the steam is condensed through air condensers and reconditioned before being introduced again as water into the boilers.

3) Electric energy production

Superheated vapour from the previous process goes through the turbine that activates the alternator and electric energy is generated. Energy is exported to the electric distribution grid.

4) Exhaust gases treatment

Exhaust gases, before their release to the atmosphere, are treated through neutralization, condensation and filtration processes, in order to minimize emissions.

5) Ashes and Slags evacuation system

Waste combustion processes result and ashes collected will be treated and finally send to a sanitary landfill.

2.1.2 Potential waste cold/heat sources

The following waste/heat sources has been identified:

- Steam boiler exhaust gases **(Exhaust gases in Boilers)**
- Steam-to-water air condensers **(Heat exchange from Condensers)**
- **Cooling system**
  - Turbo-generator turbine oil cooling system
  - Furnace grate oil cooling system
- Water degasser **(Degasser)**

2.2 Pessione Distillery (M&R)

It is located in Pessione, Italy and it is part of the Food & Beverage sector. M&R plant processes require heating and cooling and work in a range of temperatures between -8 and 60ºC.

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2.2.1 Process

In Martini & Rossi's Pessione industrial site the company produces: Martini, sparkling wines and liquors, following their recipes. This demo site has been selected as particularly relevant for the project as the stabilization of sparkling wines requires low temperatures, which are achieved via glycol-based refrigerators.

The cooling production is of about 10 GWh/year employed in the different parts of the plant: considering the amount of low temperature fluids, M&R is searching potential benefits related to waste cold recovery. The plant is classified as a "Food & Beverage" category that uses numerous heat processes.[2]

In the plant low temperature waste heat is produced (as a consequence of refrigerating power) by evaporative condensers which accounts for 15 GWh/year. Another waste heat stream in the cooling circuit is located in the air compressors, which are cooled in an evaporative tower. M&R is an optimal test case for the analysis of RES integration and its direct impact on the production. The development of a calibrated building energy simulation model for the Pessione Distillery, including HVAC systems would allow to capture and control more accurately the energy flows between HVAC systems and the demo-site processes and to investigate opportunities for RES integration.

2.2.2 Potential waste cold/heat sources

The following waste heat sources has been identified:

- **Loads (Natural Gas CHP)**
    - Cogeneration of heat and power **(CHP Unit)**
    - Refrigeration loads
    - Other loads
- **CHP electricity generation, heating station heat generation, CHP heat generation**

2.3 ENCE Pulp mill *(ELEU)*

It is located in Navia in Spain and it is part of the Pulp mill sector. This is the mill with the largest production capacity belonging to ENCE Group and the most efficient pulp mill on the eucalyptus market in Europe.

2.3.1 Process

Ence Pulp mill has a production capacity of aprox. 950,000 ton/yr of eucalyptus pulp obtained from their raw material, wood from Navia (Asturias) and Pontevedra (Galicia). Additionally it has a power generation capacity of 220 MW using biomass as a fuel. Processes based in the procedure of pulp mills are similar to each other and they are usually organised in 3 different lines:

1) Fibre (pulp fibre line)

Reception of the raw material and procedure of the pulp extraction from the wood

2) Recovery Line

Process of recovery of chemicals and the reuse of energy in the pulp line

3) Effluent treatment line

Treatment of the production, monitoring and control of all the currents

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An especially significant part of ENCE is the generation of renewable energy (since the used fuel is basically wood and biomass). The cooking liquor is retrieved and reused in the process. Lignin, which is an excellent renewable and natural biofuel, is also used to generate more energy in the form of steam through more than 95% energy-efficient recovery boiler. Steam produced is then supplied to both the pulp manufacturing process and to generate RES electrical power through a backpressure turbine.

2.3.2 Potential waste cold/heat sources

The following waste/heat sources has been identified:

- Biomass dryer hot air extraction fan (**Fans for drying processes**)
- **Bleaching effluents**
  - Treatment outlet
  - Cooling tower outlet
- Biomass boiler exhaust gases **(Exhaust gases in Boilers)**
- Recovery boiler exhaust fumes **(Exhaust gases in Boilers)**

2.4 MPI Steel Industry Research Pilot Plant

It is located in Middlesbrough (UK) and one of the main areas of expertise is in melting, alloying and casting of semi-finished product, produced at the Institute's production facility. MPI is specialized in challenging processes, particularly those involving high temperatures, hostile environments and high specification materials. It operates pilot and demonstration steel industry plant including electric arc furnaces and continuous casting plant.

2.4.1 Process

The furnace and casting processes involve liquid steel at temperatures of approximately 1600°C which generate large quantities of radiant heat at all stages in the process, also several defined cooling water streams, which make this demo site an ideal candidate for an estimation of potential WH/C resource through existing tools.

1) Primary steelmaking

With an electric arc furnace (EAF)

2) Secondary steelmaking

With an electric ladle furnce (LAF)

3) Steel to ingot or sand mould and continuous casting machine (CCM)

Allows continuous casting of either square billet

4) Gas-fired ladle pre-heat station and then all units are cooled

From a common water main header fed from a large water storage tank.

5) A fume extraction system draws exhaust fumes

From both the EAF and the LAF furnaces

2.4.2 Potential waste cold/heat sources

The following waste/heat sources has been identified:

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- Water cooling systems heat recovery
- **Exhaust fumes**
  - EAF
  - LAF
- Ladle gas-fired pre-heater exhaust fumes
- Continuous caster tundish gas-fired pre-heater exhaust fumes
- Casted steel air cooling heat recovery
-

3 Methodology

The 4 demos selected for the analysis are different in terms of their installations, besides they belong to different industrial sectors, e.g. an urban waste incineration plant is not comparable with a pulp mill, a refinery of wine or distillates factory.

In any case, one common characteristic for all of them is that they are real production facilities whose main priority is to carry out their main industrial activity, they are not test facilities focused on testing new technologies or processes. Therefore, existing monitoring data are usually oriented towards the installations control and obviously not for hypothetical heat recovery detection.

That is why, on several occasions, the sensors needed for the objective of the project will not be available and data will be less than needed to measure energy efficiency or even for the simulation of energy models.

Logically, the different processes and treatments to be carried out with the monitoring data of the demos must be particularized for each demo. Both the processes involved and the quantity and quality of the monitored data will present great differences between them. In any case, a general methodology can be established in three main steps: first, a study and understanding of the demo, then a stage of data analysis and error correction, and finally a stage of adaptation to the required formats. The next figure shows a schematic representation of the 3 main steps of the followed methodology.

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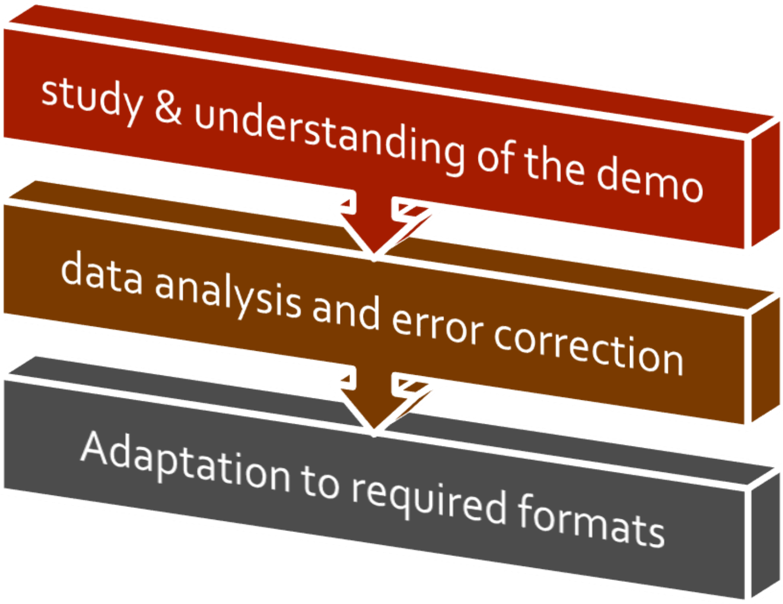

Figure 1: SO WHAT data monitoring methodology main steps

Throughout the process of explanation of the methodology, **figures and graphics by way of example** have be introduced for a better understanding of each section, always bearing in mind that it is a **public deliverable** and all the demos information have been presented without disclose confidential information.

3.1 Study & Understanding of the demo

Although it may seem obvious, it is wise to note that before proceeding to analyze the data and correct errors, a demo study and understanding exercise is going to be required. It will be difficult to perform a good fault detection on the received monitoring data if the physical system associated with the received monitoring data is not fully understood.

However, the demos considered are not relatively simple isolated machines. The demos are complex industrial plants whose friendly and detailed description (understood as the description of their facilities and their way of operating) might not be always available. For this reason, a methodology is proposed for this study and understanding that includes multiple suggestions on how to proceed with this study and what possible sources of information to consider.

As with the whole process in general, this study and understanding process must be customized for each specific case depending on multiple factors such as:

- the quality and quantity of the explanatory documentation provided together with the monitoring data;
- the level of complexity of the demo installations;
- the standardization that be it the production process of the demo;
- the professional background of the people in charge of the study.

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3.1.1 Description of existing facilities in previous deliverables

SO WHAT **D.1.1 Report on Industrial Site Demo Assessment** has been taken into consideration; it reports assessment on waste heat potential and evaluates which are the main algorithms to model industrial energy processes and those ones related to the evaluation of potential local waste heat and cold. The takeaways of D1.1 were above all:

- Detailed description of Demo Sites to be assessed;
- WH&C potential resource assessment of the demo sites;
- High level study of potential waste cold/heat sources which calculations were based on **flow rate** for the estimation of annual WH/C resources. The contents of this study were:
  - ✓ Potential source,
  - ✓ Expression for the WH/C resource calculation (if it can or cannot be calculated),
  - ✓ Annual operational schedule,
  - ✓ Annual WH/C energy (MWh).

3.1.2 Energy audits

The main objective of a company is the benefit it can achieve and therefore, correct energy management will turn into greater productivity and better competitiveness of the company. **Energy audits** are studies that allow the company to have a good understanding of its energy situation and detect which operations within the processes can contribute to the savings and efficiency of the energy consumption. This is related directly to the objective of the project, the identification of potential heat/cold recovery sources.

The **2012 / 27 / EU Directive of the European Parliament and of the Council** [3], of 25 of October of 2012, concerning the energy efficiency, creates a common frame to promote energy efficiency inside the European Union, and among other prescriptions, establishes the obligation for non-SME companies to undergo an energy audit at least every four years.

In this context, obligated companies must undergo an energy audit every four years from the date of the previous audit, covering at least 85% of the total final energy consumption of all the facilities located in the territory that are part of the industrial, commercial and service activities that these companies and groups manage in the development of their economic activity.

The basis that defines the procedure for the energy audit required in the **EU Energy Efficiency Directive** is the ***EN 16247-1*** [4] according to which an energy audit consists of the examination and analysis of the energy use of a plant, organization, etc. with the aim of identifying and documenting the potential energy savings in energy efficiency. Requirements:

- the company must appoint an energy representative, internal or external, as the contact and coordinator of the energy audit,
- the public administration will check by random sampling that these rules are being followed and that the energy auditor has the necessary qualifications;
- energy audit considers all parts of a company and its location, with the goal of representing at least 90% of the total energy consumption.

The policy of energy audits is not the same for every country in the EU but, in those related to the Demo Sites studied in this document, there are similarities such as: the mandatory of its application, the benefits that its good development entails, reach the highest potential energy saving.

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As said, energy Audits (of the demo sites) are very precise documents for these applications and, as far as possible, it would be interesting to consult them for an adequate evaluation of industrial processes. A disadvantage in this source of information could be the language in which the document is written. Obviously, the energy audit documents are written in the local language of factory location and not in English.

3.1.3 Flow diagram elaboration

Apart from the documentation mentioned in the previous section, there is another effective procedure that can be helpful to understand an industrial process, the generation of **Flow Diagrams**.

A Flow Diagram or flowchart, is a specific type of activity diagram that communicates a sequence of actions or movements within a complex system. A flow diagram is a powerful tool for optimizing the paths of people, objects, or information and they can create visual representation of processes that, although is often quite time consuming, it can help to easily understand the plant and have a global idea of every part and connection of the system. In the applications that concerns this project, it may be faster to locate potential waste heat/cold sources. In sum, the **potential benefits** of this method: visual clarity, effective analysis, problem solving and simplifying difficult procedures.

Among the wide variety of software for creating diagrams, it can be used online pages like, Diagram Paradigm Online [5] (*Figure 4*) or those that require installation on the computer that present a greater variety of options like, Microsoft office Visual Basic. Below it is presented an example of a flow chart, not very detailed, and applied to an industrial process.

Usually the first phase of these flow diagrams elaboration starts with a very simple "big boxes model or Block diagrams" (*Figure 3*) where the main sections of the industrial process are represented as simple boxes in order to identify the interconnection of the different steps and the inlets and outlets of the manufacturing process. And after that, more detailed flow charts are elaborated taking into account the different flows of material and energy (including thermal energy flows). As an example, Figure 3 shows a more detailed flow diagram of the demo waste-to-heat plant where the different material flows have been drawn including all the steam and water loops from the boilers to the turbines, the condensers and back to the boilers.

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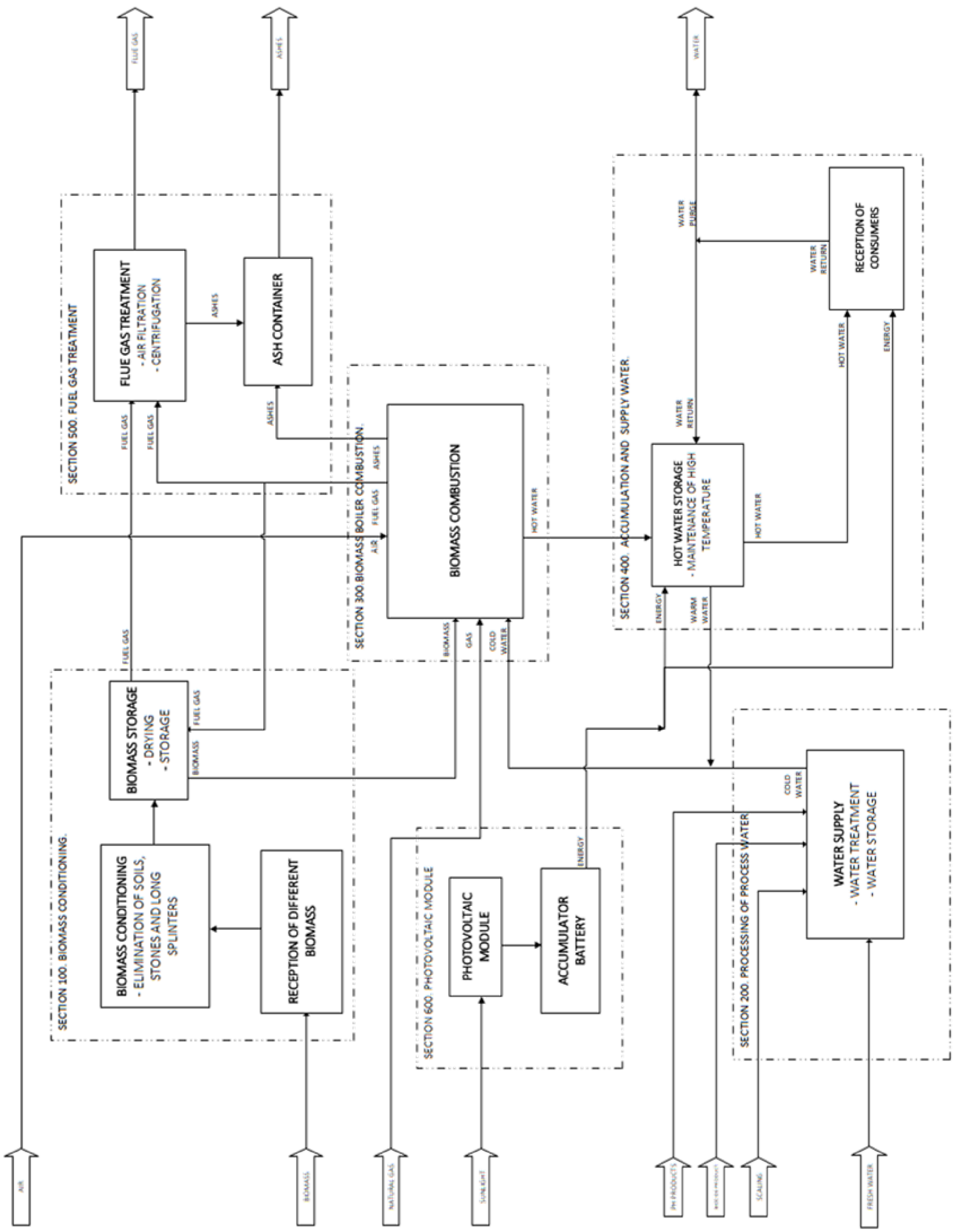

*Figure 2: Example of a preliminary **Block Diagram** from a Biomass Plant*

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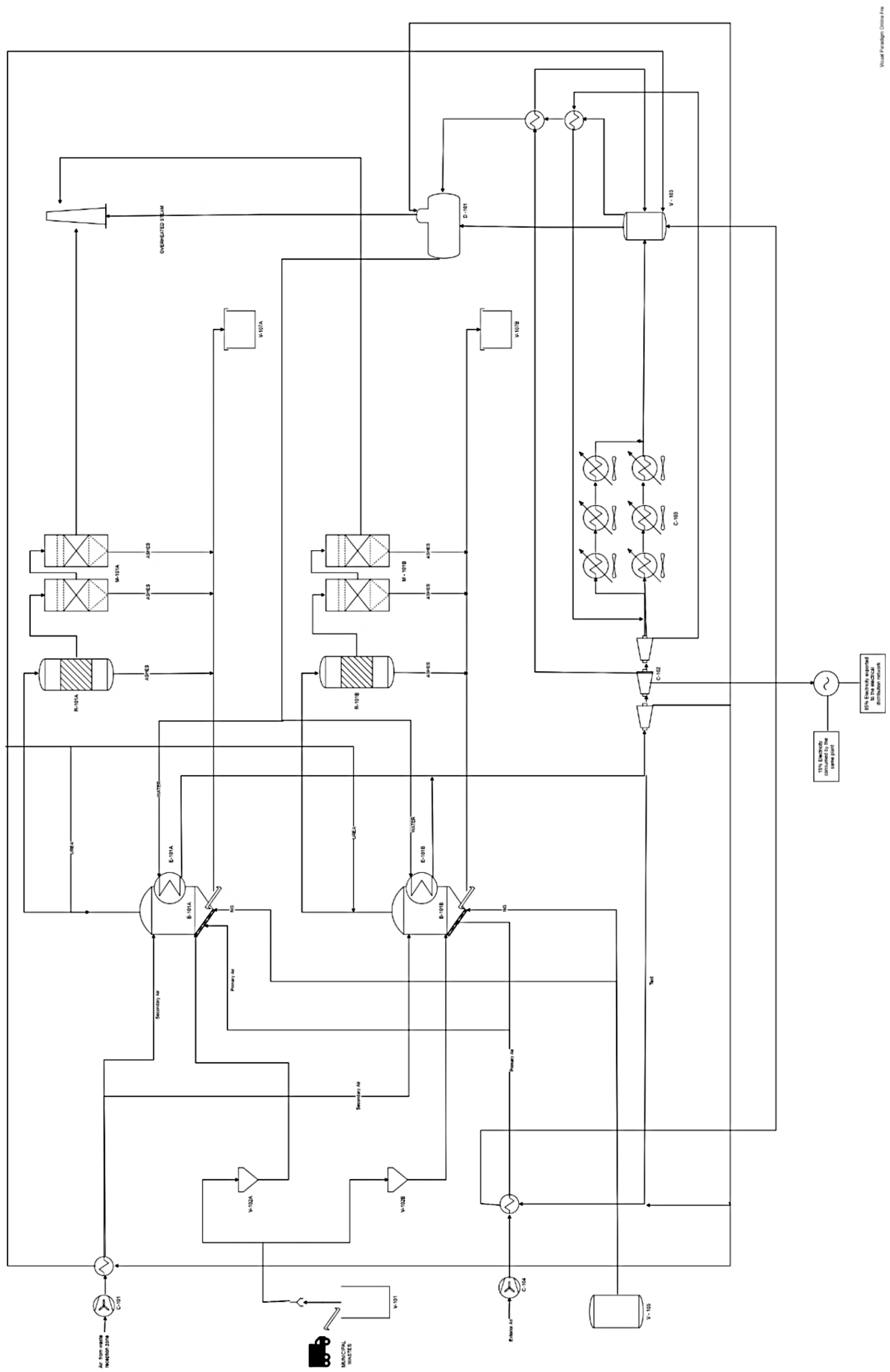

*Figure 3: Example of a **FlowChart** from a Waste-to-Heat plant*

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3.1.4 Sankey diagram elaboration

Sankey diagram is a very useful tool in order to represent an entire input and output energy flow that can be done in any energy equipment (boilers, fire heaters, furnaces…) or in complete process to have a general view.

The application of this kind of diagrams, in aims like the one in this deliverable, is very successful because it allows to locate potential sources of residual heat precisely and easily way (once the necessary calculations have been made and the industrial process is known in detail). The Figure 4 is an example of a Sankey diagram of a boiler where the power provided by each current is represented in percentages.

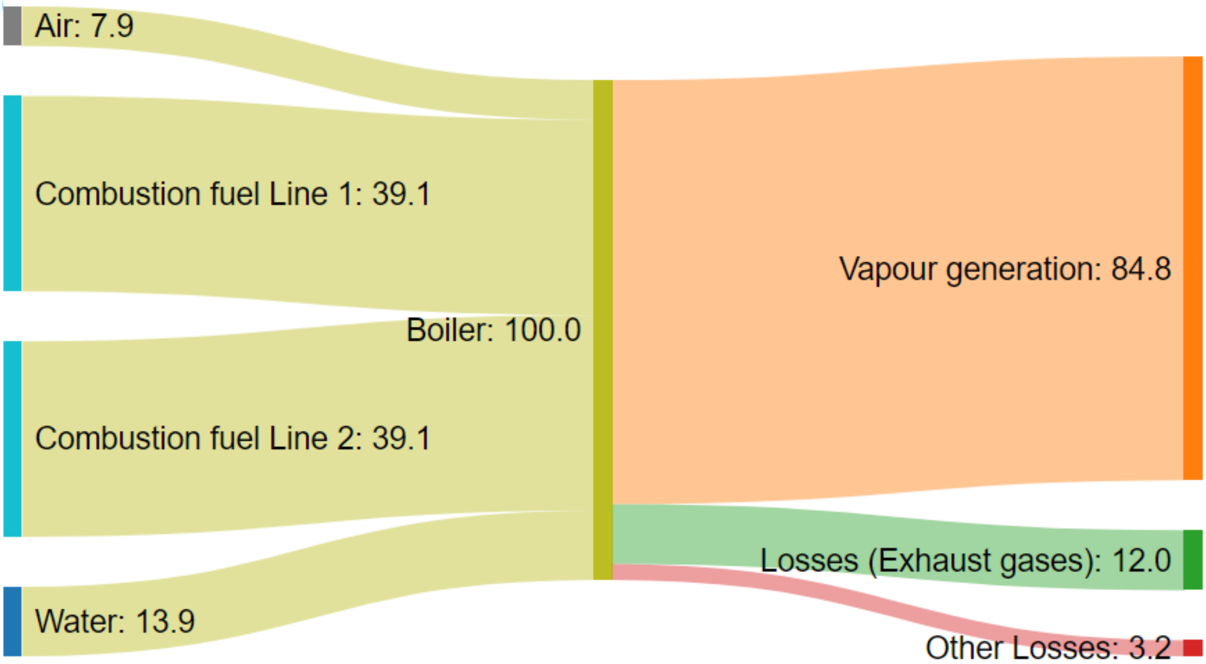

*Figure 4: **Sankey Diagram** of the power proportion (%) in a Boiler for vapour generation* [6]

3.1.5 Other public sources of information

This section is an optional stage if the internal information of the facility is not detailed enough or if it is only available in a language that is difficult to translate. There are other sources of information that could be consulted.

In the public domain, there an extensive information base with **public descriptions of production processes**, e.g. the manufacture of paper, the distillation of hydrocarbons, the incineration of waste, etc., are relatively standardized processes. Nowadays, there is abundant information describing the generalities of these processes.

Every EU project has an **official website** [2] where detailed public documentation is uploaded, in order to promote knowledge of the project and update the monitoring of the process. In this particular case, the official project website, is a very useful source to understand the description of the processes and have additional information of every demo site.

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In addition, EU JRC BREF [7] (Best Available Techniques Reference Documents) are a useful source in order to inform from an specific topic in this reference documents of the European Union, developed through an exchange of information between industrial sectors.

4 Data analysis and Error correction

As explained earlier, once (and not before) it is reached a certain understanding of the demo in both the description of the facility as the description of the way of operation, then it is the moment to jump into the data analysis and error correction of the monitoring data.

The data analysis and error correction step is so critical. It must be taken into account that there is not a valid format for all the demos (different hardware, software, language, methodology). The procedure followed can be structure in the following sections.

4.1 Definition of the format in which the data is received

This means, the definition of the monitoring data dump process. The data is originally generated in some type of SCADA (characteristic of each industry) or software programs in the same line. The process usually follows the same steps: data is collected in some Data Base (DB and then it is exported from there in a manual or automatic way. In some cases the exportation is done directly from this SCADA and this can cause problems such as:

- the ease of understanding the data written;
- the number of variables and the frequency in which they are recorded, this can lead to a very large file size for some software (special attention to the selection of the program used for the analysis);
- computer file format (potential data in DB format).

4.2 Establishment of an operation schedule

Before entering into the monitoring data interpretation is so important to establish the **particular industry operating schedule** in order to easily locate not only annual suspensions for **maintenance** and **upkeep** stops, but also work regime (shifts) and stops that occurred during the period of time associated with the data like, **Holidays** or **vacations**.

	Process working continuously
	Process with a stop in the line

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boiler Steam production Line 1 [T/h]												
Duration of the stop in Line 1 [h]	0	0	0	44	83	18	350	0	0	107	0	142
Boiler Steam production Line 2 [T/h]												
Duration of the stop in Line 2 [h]	0	0	0	0	68	9	277	125	0	0	0	0
Duration of the stop in BOTH LINES [h]						3	113					

Figure 5: analysis of the duration of the stops in a process

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In the *Figure 5* it can be seen a study of the stops in a process that works in continuous 24/7, and it can be placed the duration of the stops in order to understand if there was any problem during that period that could disable the data or if, on the contrary, the industry provides data for a correct operation of the process.

In the analysis a **qualitative definition of seasonality** must be included and obviously the data must respond accordingly to it. For example the demand for hot water for space heating should be much higher in the winter months or the cooling demand of a refrigeration process should be much higher during the summer.

This gives weight to the previous documentation section (preliminary knowledge of the operation calendar) where useful information should be gather before. However, if this information is not available, **monitoring data** will have to be interpreted because they **will reflect** these operation schedules. In other words, the study of the monitoring data will allow stablishing the operation calendar, but in some cases it will be difficult to distinguish between unexpected stop situations and lack of data situations.

4.3 Adaptation and standardization of the frequency of monitoring data

Depending on the sensor, technology or equipment you required to monitor, the frequency of the recorded data would be higher or lower and even more, not all variables will need to be recorded with the same sampling frequency: variables with high variability are usually recorded more frequently compared to slower variables.

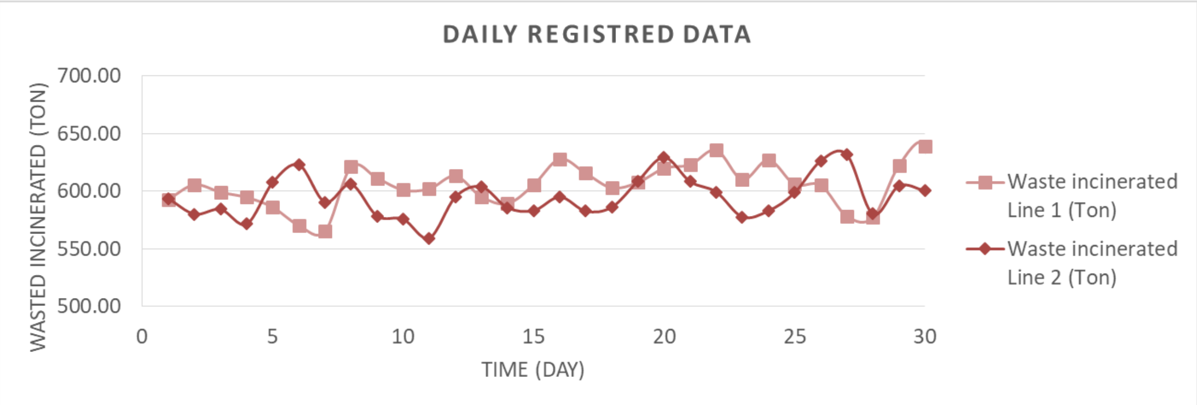

Figure 6: variable with low variability (recorded with lower frequency)

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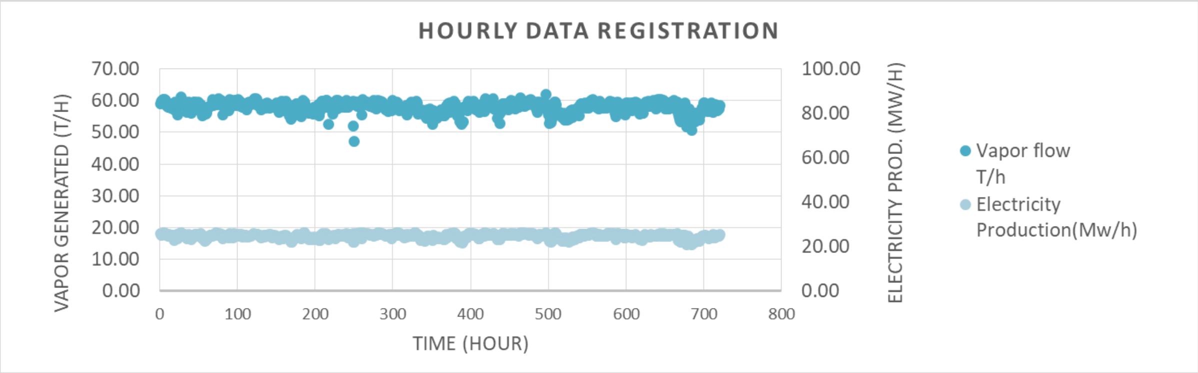

Figure 7: variable with high variability (recorded with higher frequency)

For example, the input of fuel (into the boilers for steam production), such as municipal waste, are very large loads that do not require very high data collection frequencies (Figure 6), that is why the data has a total daily record, while the value of steam that is introduced into a turbine to produce electricity in a power generation plant will require a higher registration (Figure 7).

An adaptation of the data to a homogeneous frequency will favour its analysis, otherwise the sections of quality preliminary analysis and data consistency will be more difficult to develop.

4.4 Quality Preliminary analysis of the data received

Before checking if the data are consistent and valid to be used in the tool, it is of vital importance to carry out a preliminary quality study for a first check of the monitored data.

In this case, value range evaluation for every variable was compared with the audit information in order to identify potential errors in the variables. It is important to develop a first variability check of each of the variables, recording the maximums and minimums to check for significant imbalances. This would show if the data have different orders of magnitude (that do not coincide with the expected response, taking into account the seasonal time and operational schedule) and negative values where it does not make sense.

Talking about an analysis of numerical values, another tool that is very useful for a quickly analysing of variability of the data (apart from maximums and minimums) is the application of **colour scales** to long list of different variables values. With this procedure it can be located proportional relations between variables, sudden changes in the list, values that are not in appropriate range, etc.

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Table 2: colour scale applied to a list of numerical data

Period of time	Vapour flow Line 1	Vapour flow Line 2	Electricity production	Pressure Turbine	Equip. Inlet Tª	Equip. Outlet Tª	Ambient Tª	Outlet liq. Flow
Hourly	T/h	T/h	Mw/h	bar	ºC	ºC	ºC	T/h
07-04-2020 21:00:00	59.65	58.57	24.94	0.17	59.59	59.31	20.85	128.31
07-04-2020 22:00:00	60.00	59.85	25.47	0.17	58.62	58.41	19.94	130.57
07-04-2020 23:00:00	59.71	60.12	25.65	0.16	57.69	57.49	19.28	120.73
07-05-2020 00:00:00	60.89	59.50	25.80	0.16	57.14	56.91	18.89	119.86
07-05-2020 01:00:00	59.97	57.56	25.08	0.15	55.70	55.48	18.49	121.84
07-05-2020 02:00:00	60.00	54.67	24.28	0.14	53.59	53.38	18.05	123.08
07-05-2020 03:00:00	59.98	53.44	24.39	0.14	53.54	53.37	17.89	124.24
07-05-2020 04:00:00	58.52	56.29	24.74	0.14	53.28	52.96	17.53	124.05
07-05-2020 05:00:00	56.85	31.03	17.31	0.13	51.01	50.93	16.72	93.57
07-05-2020 06:00:00	56.73	4.77	10.06	0.16	57.08	52.71	16.47	61.41
07-05-2020 07:00:00	58.09	0.00	9.97	0.18	60.20	55.90	18.41	61.75
07-05-2020 08:00:00	58.00	0.00	10.11	0.16	56.96	55.09	22.72	60.76
07-05-2020 09:00:00	59.64	0.00	9.78	0.20	62.91	62.31	27.71	61.63
07-05-2020 10:00:00	58.07	0.00	10.11	0.16	57.77	55.92	30.70	60.86
07-05-2020 11:00:00	59.15	0.00	10.25	0.16	58.72	58.52	32.92	61.80
07-05-2020 12:00:00	59.41	0.00	10.68	0.14	55.87	55.65	32.42	62.50
07-05-2020 13:00:00	56.46	0.00	10.01	0.12	51.88	51.73	34.40	58.75
07-05-2020 14:00:00	58.29	0.00	10.23	0.14	56.35	56.17	38.70	60.87
07-05-2020 15:00:00	58.96	0.00	10.30	0.14	56.55	56.51	37.68	61.03
07-05-2020 16:00:00	57.78	0.00	10.08	0.14	56.49	56.45	36.79	59.95
07-05-2020 17:00:00	57.62	0.00	9.82	0.14	55.58	55.53	33.25	58.61
07-05-2020 18:00:00	58.83	0.00	10.31	0.13	55.10	55.06	31.77	60.39
07-05-2020 19:00:00	59.59	0.00	10.34	0.13	54.40	54.28	29.92	60.85
07-05-2020 20:00:00	57.09	0.00	10.18	0.12	51.61	51.52	26.87	59.14
07-05-2020 21:00:00	57.82	0.00	9.94	0.13	52.99	52.74	23.55	61.74
07-05-2020 22:00:00	58.20	0.00	9.69	0.15	56.03	51.73	21.19	60.55
07-05-2020 23:00:00	58.95	0.29	10.01	0.13	53.95	51.49	20.48	63.09
07-06-2020 00:00:00	58.28	9.52	9.80	0.13	52.60	50.71	20.29	62.05
07-06-2020 01:00:00	58.75	16.07	13.47	0.13	51.07	50.98	19.48	76.96
07-06-2020 02:00:00	58.80	21.59	14.96	0.14	54.07	54.13	19.25	83.85
07-06-2020 03:00:00	57.85	27.03	16.48	0.14	53.44	53.61	18.42	89.31
07-06-2020 04:00:00	57.75	43.42	20.95	0.14	53.62	53.35	17.72	107.94
07-06-2020 05:00:00	58.39	52.90	23.92	0.14	52.63	52.45	17.40	120.61
07-06-2020 06:00:00	56.28	51.90	23.26	0.13	51.29	51.12	17.17	117.12
07-06-2020 07:00:00	55.23	55.59	23.67	0.14	53.75	53.39	18.82	120.55
07-06-2020 08:00:00	57.40	57.34	24.17	0.17	58.77	58.49	21.48	124.96
07-06-2020 09:00:00	57.04	57.38	23.11	0.20	62.18	62.01	24.81	121.75
07-06-2020 10:00:00	57.74	56.90	23.15	0.23	67.25	66.98	27.53	124.56
07-06-2020 11:00:00	56.86	56.72	23.28	0.20	63.46	63.29	25.06	121.85
07-06-2020 12:00:00	56.55	57.77	23.13	0.22	65.75	65.55	27.09	123.07
07-06-2020 13:00:00	57.45	58.56	22.94	0.28	70.99	70.72	33.28	125.05
07-06-2020 14:00:00	56.72	57.71	22.38	0.29	72.34	72.13	37.56	123.44
07-06-2020 15:00:00	56.64	56.64	22.08	0.29	72.53	72.33	37.38	122.00
07-06-2020 16:00:00	57.88	58.42	22.73	0.30	73.70	73.39	36.97	125.28

Another common problem that should be controlled in the data received could be the corresponding to systems that use cumulative type counters, this data will have to be transformed into average values corresponding to the period between two consecutive values of the original counter type variable. These adaptation processes should be included in this preliminary analysis. This cumulative type counters could encounter problems such as:

- Periods without reading with constant accumulated value, time ranges in which the sensor were not recording so that monitoring data does not exist in the data base until the next measured point;
- Periods without reading with variation of the accumulated value, in this case the sensor was reading correctly the process but the system has not registered these intermediate values;
- Zero crossing of the counters. Upon reaching the maximum value in the accumulation register, the counter is reset and begins to increase from the zero value.

There are several examples that could happen in any industrial process, for which this step (quality preliminary analysis), before data consistency analysis is necessary.

4.5 Data consistency analysis

Once the data analyser has reached this section, data will be found that, taking into account all the previous considerations, are technically correct. Due to errors in the computerized recording of the monitoring data (or human factor), data can be presented as formally correct registers but unfortunately without consistency with each other (e.g. corresponding wrong column of the data, duplication of data etc). This inconsistency can appear permanently, in which case it will be easy to detect. This situation could be a reflection of faulty sensor or a bad implemented software

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registration. On the other hand, this can appear in certain time periods of data and then, it will be more difficult to detect. This issue is usually due to an error in the data dump.

Condensate flows

Caudal de Condensados T/h	Caudal de Condensados T/h
127.97	-139189.95
116.78	-139128.47
123.05	-139067.00
125.88	-139005.52
123.75	-138944.05
117.02	-138882.58
123.79	-138821.09
125.83	-138759.63
125.37	-138698.16
125.72	-138636.67
127.94	-138575.20
128.84	-138513.73
128.67	-138452.25
127.48	-138390.78
128.08	-138329.30
124.52	-138267.83
122.55	-138206.36
120.39	-138144.88
123.10	-138083.41
124.44	-138021.94
125.20	-137960.45
126.60	-137898.98
127.16	-137837.50
119.01	-137776.03
123.54	-137714.56
125.21	-137653.08

Figure 8: localization of wrong order of magnitude (right) compared to the correct range (left)

In the situation of the *Figure 8* the detection of wrong order of magnitude data was detected in certain months of the year (certain time periods) and correctly showed thanks to the preliminary analysis where it was developed a first variability check of each of the variables, recording the maximums and minimums to check for significant imbalances. This would show if the data have different orders of magnitude. The detection of the error was not difficult at all due to the high error that presented the correct value of the erroneous. This is thought to be due to a failure or breakage of the measurement sensor in that period of time.

Another issues to take into account in this data review process is the **homogenization of the measurement units** of the monitored data. Carefully review that the recorded values correspond to the correct units of measure, in other words, the detection of variables that could have been measured in different units because it has been used different sensors. All this situation should be considered, knowing that the monitoring data comes from real industrial sites and day to day problems could appear. Thanks to the detailed study of the demo, the data could be analyse with an industrial point of view, and interpret the data related to the industrial processes:

- Study of the consistency in the data between actions in the process that occur simultaneously or actions that are dependent on others (e.g. if a boiler burns more waste, the production of steam will be greater and consequently it will also be the electrical energy produced in the turbine).

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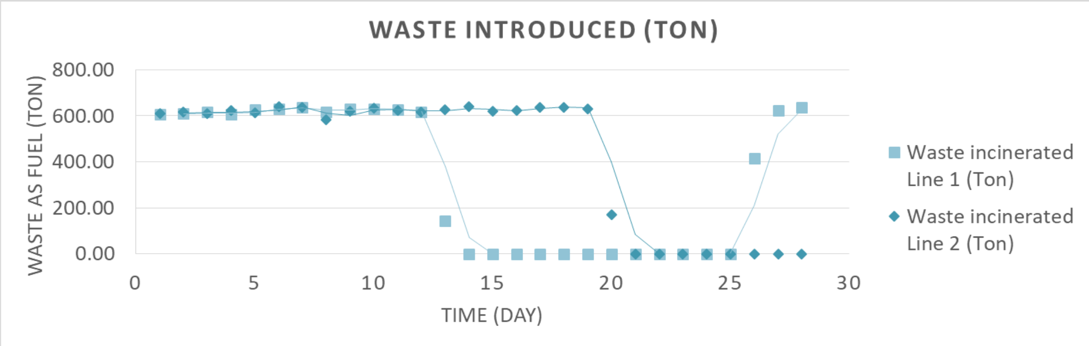

Figure 9: waste as fuel for vapour generation in the two lines of the process

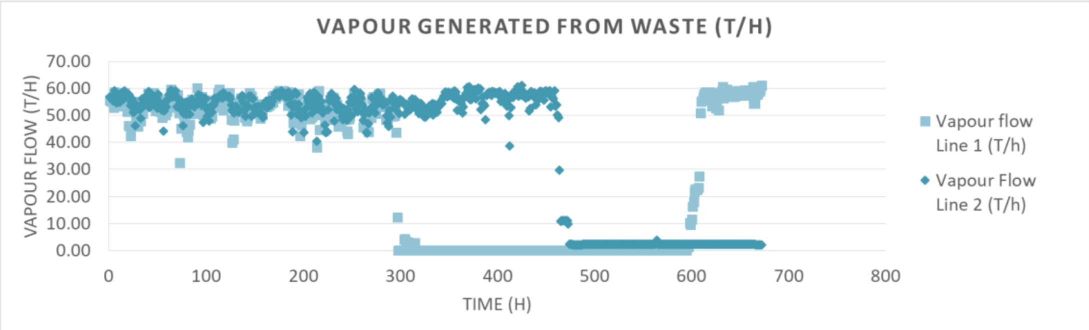

Figure 10: vapour generated from wastes in the two lines of the process

An example, to explain better this section, is showed in the comparison between *Figure 9* and *Figure 10.* These two processes are one dependent on the other, and the monitoring data should reflect the changes with coherence. In this case, there is a stop of the fuel (for reasons of maintenance, due to a stop of the demand…) and what is expected of the data in subsequent process sections is that they respond accordingly (as it reflects *Figure 7*)

- Consistency in the inlets and outlets flows;
- Understand and pay attention to the trends of related variables (e.g. energy produced and consumed);
- Special attention to the seasonality (summer vs. winter) this is important to understand if the process and the monitoring data are valid for the aim of the project.

4.6 Error correction

Knowing the possible errors that can occur when analysing the monitored data of a system, the errors will be corrected in order to continue with the use of the tool or the procedure followed to solve the problems presented.

- For those errors that have been due to the manual process of exporting the database, the first step will be **to re-request a dump of that data**, because it will have been an error when taking or writing that data in the sent file. Another option would be to ask for **another period of time** if it is available. In the end, the objective is usually to work with a year of monitoring

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data and it is not necessary for it to be from January to December of that same year. The important key is to have all the data for every month or the frequency required;

- In the hypothetical situation of missing data of a sort period of time, the approximated correction could be solved **filling in empty data** with data that is available. For example, if a week is missing (for whatever reason) it can be copied the data from another week (as close as possible) to occupy that blank space;
- When two variables are related, one with correct data and the other with erroneous data during a section, the missing information can be obtained with the equation of relation between both variables. The trend of the correct data of one variable against another (not including those that are not correct) will be obtained and an equation will be obtained that can be used in the section for which adequate information is not available;

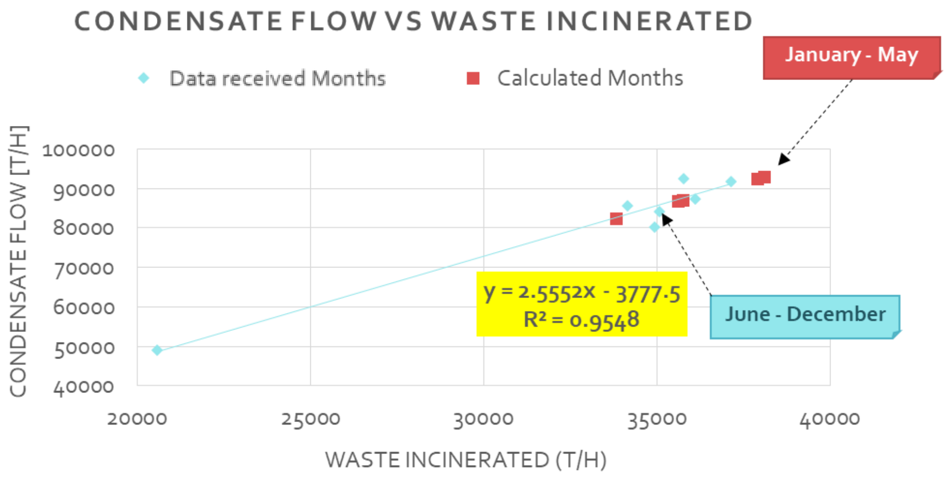

Figure 11: substitution of wrong data variable with another correct variable

The *Figure 11* represents the substitution of wrong data variable with another correct variable. For the problematic variable (in this example, the condensate flow) the values, related to the months from **January to May,** have to be **calculated** and the rest of the annual monitoring data is correct. On the other hand, the other variable (waste incinerated) has all the monitoring data correct. With the equation of relation between the both variables in the months from **June** to **December** it can be calculated the holes with a relation operation;

- **Construction of simulated data from other variables** to fill in gaps. Sometimes, as mentioned before, there are not enough sensors to calculate all the variables in order to calculate the potential sources of heat recovery, but there will be other variables that, by means of mathematical methods, consistent assumptions or thermodynamic and physical equations, will be able to find these lost variables.
  For example, the heat generated is not available, but the electrical energy produced or the amount of fuel (municipal waste, biomass, gas) consumed is available. Another example could be that the number of pieces produced in that industry is available and the average energy cost per piece can be extracted (from other periods) in order to do an estimation of the consumption from the production data.

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4.7 Adaptation to appropriate formats

Once it has been analysed that the values of the monitoring data have coherence it has to be translated into the correct format and prepare them to be the data imported to the SO WHAT Tool. The adaptation of the data must be presented in the form:

- Correct monitoring data frequency (daily, hourly, minute, etc.);
- Transformation to the universal system or the one needed in the tool;
- With all the errors fixed;
- With correct format of decimal or thousand separators;
- Valid name of the variables in order to be read by the tool.

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5 Conclusions

This document describes the actions carried out when implementing the data monitoring system within Task 5.1 of WP5. Specifically, all the procedures followed to carry out a data analysis and review of its quality for its subsequent use in the validation of the SO WHAT tool.

The main objective of the SO WHAT project is to develop and demonstrate an integrated software which support industries and energy utilities in selecting, simulating and comparing alternative Waste Heat and waste Cold exploitation technologies that could cost-effectively balance the local forecast heating and cooling demand also via RES integration. Within the project, the demos are mainly industrial facilities in charge of providing their production process monitoring data that is related with possible sources of waste heat to be used in the various validations of the SO WHAT tool.

As explained in previous deliverables of the project, the different demos are enormously different from each other in terms of their facilities and manufacturing machinery. There will obviously be few similarities between the facilities of a refinery, a wine and spirits factory, a waste incineration plant, a thermal plant, a pulp mill or a carbon black and graphite factory.

Although, on the other hand, there is a common feature in all of them and that is the fact that they are real production facilities whose main priority is to carry out their scheduled industrial activity and they are not pilot test facilities focused on testing new techniques or machinery. This can also influence (although there are always exceptions) on the quality and quantity of the monitoring data. Existing monitoring data is often thought and implemented towards facility monitoring rather than providing data for energy efficiency studies.

As this deliverable is a public document, it cannot contain the specific and detailed data of the operation of all the demos. Instead, it has been preferred to focus the document on the description of the methodology followed in the analysis of the monitoring data. This methodology can be summarized in three main stages: First, a study and understanding of the demo, then a stage of data analysis and error correction, and finally a stage of adaptation to the required formats. These three stages are common for all the possible monitoring data of the demos, but the different sub-stages must be implemented in a completely personalized way depending on the particularities of each industrial facility and the available monitoring data.

The order of the three stages is critical. It is important to remind that before proceeding to analyse the data and correct errors, a demo study and understanding exercise is going to be required. It will be really difficult to perform a good fault detection on the received monitoring data if the physical system associated with the received monitoring data is not fully understood.

In the description of the different sub-stages, all the possible errors and difficulties that may appear in the monitoring data and possible solutions or corrective treatments have been described.

Finally, it is important to note that in this activity no calculations are made of the potential values of residual heat recovery. This activity verifies that the monitoring data is correct from a qualitative and quantitative point of view. It is precisely in the rest of the WP5 tasks where the SO WHAT tool developed to propose the different heat recovery scenarios and simulate and calculate the energy

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and economic results of this possible heat recovery implementations is used. However, in the initial study and understanding of the demo, some actions were devoted to identify possible sources of waste heat. This is due because it could happen that the dumped monitoring database contains all the possible monitored signals. In this case, it would be necessary to understand the demo facilities to filter to the right signals required for the waste heat calculations in the SO WHAT tool.

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