H2020 Work Programme

D6.1_LESSONS LEARNT FROM SO WHAT – ENVIRONMENTAL AND TECHNICAL BENEFIT OF WHC AND RES INTEGRATION

Lead Contractor: ENVI

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Executive summary

The deliverable is under the WP6 activities focused on SO WHAT impact analysis and maximisation of lessons learnt. The main WP6 objectives are to conduct the impact analysis of the industrial WH/C recovery and RES integration solutions promoted by the SO WHAT tool and project and to compile the derived conclusions into a set of lessons learnt and useful recommendations. In particular D6.1 is strictly connected to the objectives of the Task 6.1:

- Gathering and evaluation of the environmental and technical benefits in each industrial demo site
- Elaboration of guidelines for the different pilot typologies to complement the simulation platform outputs in terms of environmental impact and energy efficiency

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Abbreviations

BHKP: Bleached Hardwood Kraft Pulp

DAF: Dissolved Air Flotation

DHN: District Heating Network

ECF: Elementary Chlorine Free

GDPR: General Data Protection Regulation

KPI: Key Performance Indicator

PFC: Pipe flow calculation

RES: Renewable Energy Sources

TES: Thermal Energy Storage

TRL: Technology Readiness Level

WH/C: Waste Heat/Cold

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1 Introduction

The environmental benefits found in each industrial demosite, in terms on energy and GHG savings, are gathered and evaluated. To this aim, outputs from the software simulator are considered as primary source of information, complemented by external studies and calculations as well as best practices and protocols, specialized databases and literature. After the analysis stage, final guidelines are produced applying the knowledge and expertise acquired during industrial demosites stage, for the different pilot typologies. The main objective of these guidelines is to complement the environmental impact and energy efficiency outputs of the simulation platform. These guidelines will detail the steps to achieve a high positive environmental impact and will be applied together in future commercial exploitation of SO WHAT's simulation platform.

The deliverable reports a brief description of the scenarios identified by the Clusters and summarize the main benefits in terms of energy efficiency, energy saving and CO2 emissions saving implementing technologies to recover heat and cold waste thanks to the use of SOWHAT tool.

2 Environmental&technical benefits based on the simulation results for each demo

2.1 Italian demo

2.1.1 General description

The Italian Cluster is coordinated by ENVI and RINA-C with the involvement of the demosite Martini & Rossi's (M&R). In Martini & Rossi's (M&R) Pessione industrial site all the products of company are produced: Martini, sparkling wines and liquors, following their recipes. M&R demosite has been identified as particularly relevant for the SO WHAT project as the stabilization of sparkling wines requires low temperatures, which are achieved via glycol-based refrigerators.

The overall cooling production is of about 10GWh/year employed in different areas of the plant: considering the remarkable amount of low temperature fluids related to this production M&R is interested in analyzing the possibility and potential benefits related to waste cold recovery. As a consequence of the refrigerating power, in the plant it is produced a large amount of low temperature waste heat which is rejected in evaporative condensers and it accounts for about 15GWh/year and which potential has already been identified as interesting. Moreover, another waste heat stream has been identified in the cooling circuit of air compressors, which is currently cooled in an evaporative tower but it could be otherwise employed for about 170MWh/year. Finally, M&R is committed in employing Renewable Energy Sources (RES) and the installation of solar thermal panels for process purposes is planned in the framework of SHIP2FAIR

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H2020 project: for the present reason, M&R is an optimal test case for the analysis of RES integration and its direct impact on the production.

2.1.2 Scenarios identified to use in the tool trial

Three scenarios are identified as possible trials for SOWHAT tool.

2.1.2.1 Sparkling wine process optimization: "ASTI"

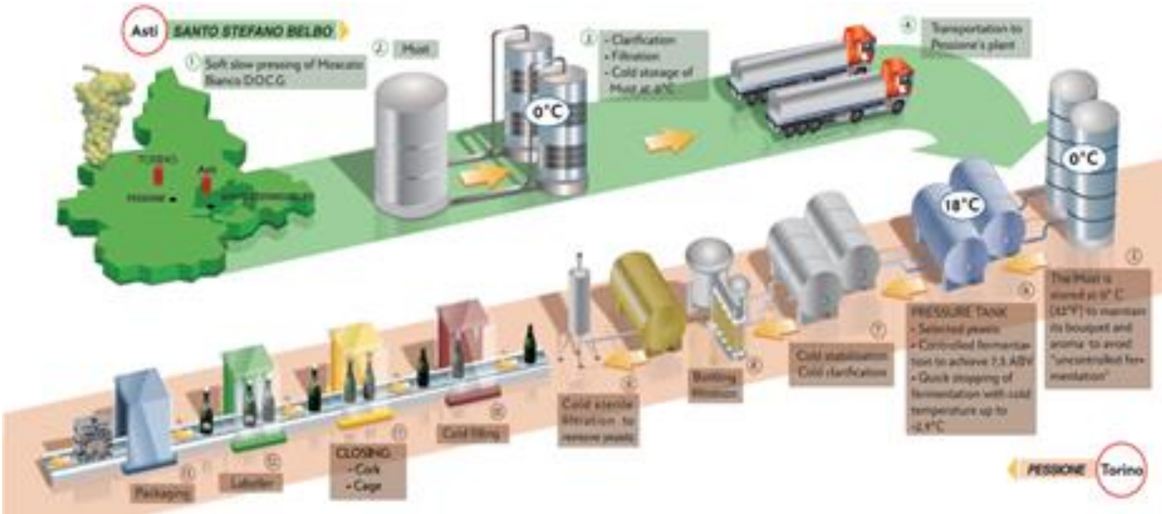

Figure 1 Sparkling wine process at M&R

The process consists on:

- Must be kept at 0°C from harvesting (September) to the bottling time during all the year in the M&R plant and others suppliers
- Must be heated to 20°C for the fermentation step, to allow the fermentation
- Sparkling wine refrigerated to 0°C to control the fermentation (ABV of 7%) and kept at 0°C
- Sparkling wine bottled at 0°C
- Bottle heated to 20°C for labelling and packaging purpose

Volume: 28 Ml/year.

Technology used to recover heat: heat exchangers.

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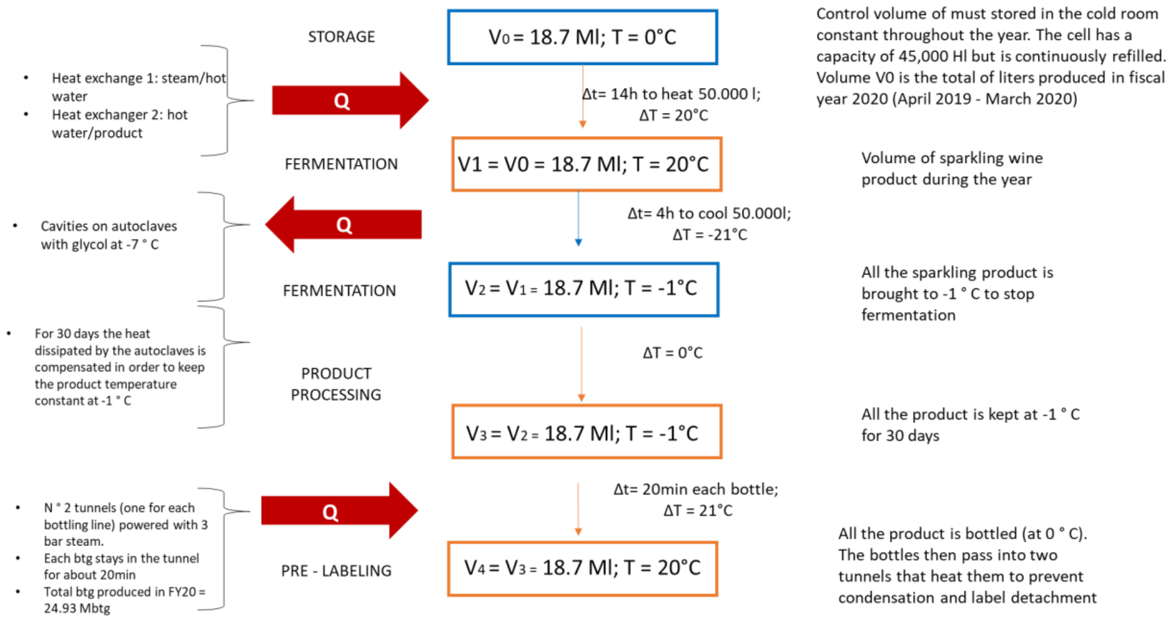

Figure 2 Sparkling wine process

2.1.2.2 Heat recovery from rooftop condenser of cooling plants for process

The process consists on:

- Heat recovery from rooftop condenser of cooling plants for process
- Cooling plant using R507 gas, typical Kelvin cycle process
- T of condensation: 35°C
- 10 condenser, Condenser model: Baltimore VXC (185-576)

Technology used to recover heat: heat exchangers for the sparkling wine process. Heat exchangers, to be used as water-cooled organic fluid condensers. Potentially recoverable heat: 1,848 MWh (only "sparkling wine" line). The project will produce hot water, consequently reducing natural gas consumption of boilers and CHP plant for the production of the same amount of hot water. Installation size: 1450 kWt. Investment costs around 50-100 €/kWt.

Figure 3 Heat recovery from rooftop condenser of cooling plants for process

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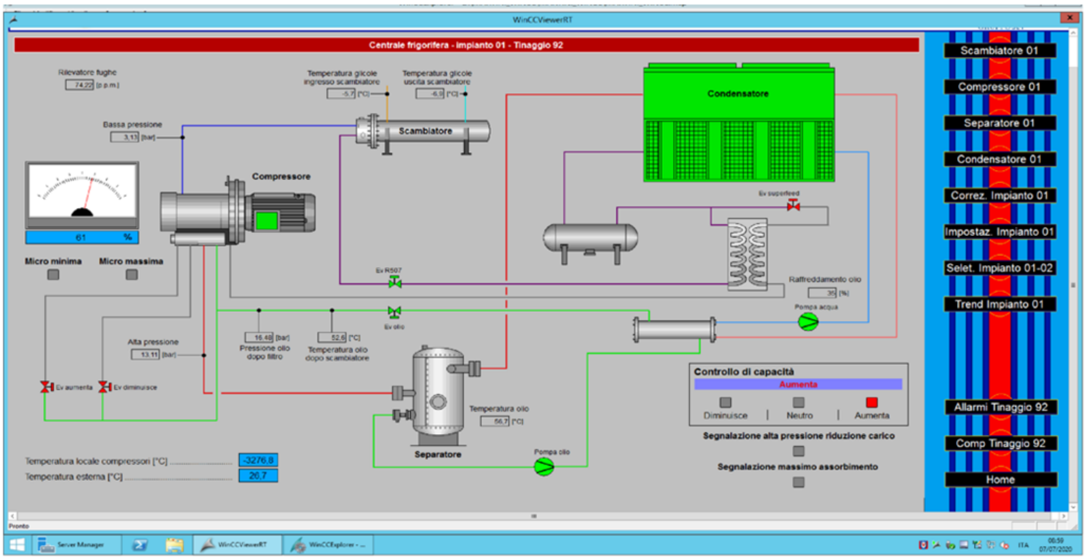

Figure 4 Refrigerated plant in the brewing plant

Compressor electrical power	128	kWe
Compressor cooling capacity	350	kWfr
COP cold production	2,73	
COP hot production	3,73	
Compressor thermal power	**478**	kWth
Compressor outlet refrigerant temperature	70	°C
Cooling tower outlet refrigerant temperature	25	°C
Coolant temperature after heat recovery	35	°C
ΔT useful coolant	35	°C
Useful percentage of usable heat refrigerant	78%	
Useful percentage of usable heat refrigerant	372	kW

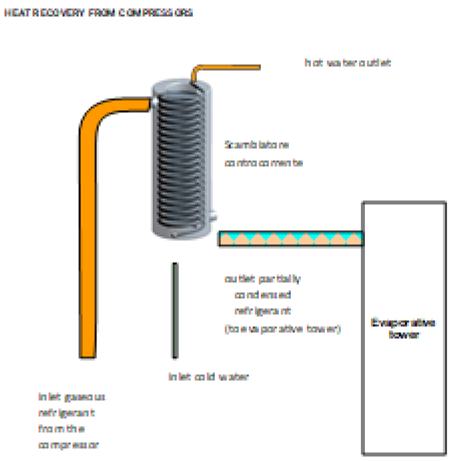

Figure 5 main characteristic process data and the energy flows implemented through the installation of the heat exchanger

The figures above show the main characteristic process data and the energy flows implemented through the installation of the heat exchanger.

The refrigerant leaves the compressor with a temperature value of 70°C and after passing through the evaporative condenser its temperature is reduced to 25°C.

The idea is inserting between the compressor and the condenser and intermediate HE that will reduce the temperature of the refrigerant from 70°C to 35°C while producing an outlet flow of hot water.

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2.1.2.3 Solar field installed in SHIP2FAIR project

During the weekends in summer period, no much steam needed in M&R processes. It is possible to use the thermal energy produced by solar field to heat two existing warm water tanks (70°C). In this way it could be easier to bring the water inside the tanks at this level of temperature at the beginning of the processes on the following Monday.

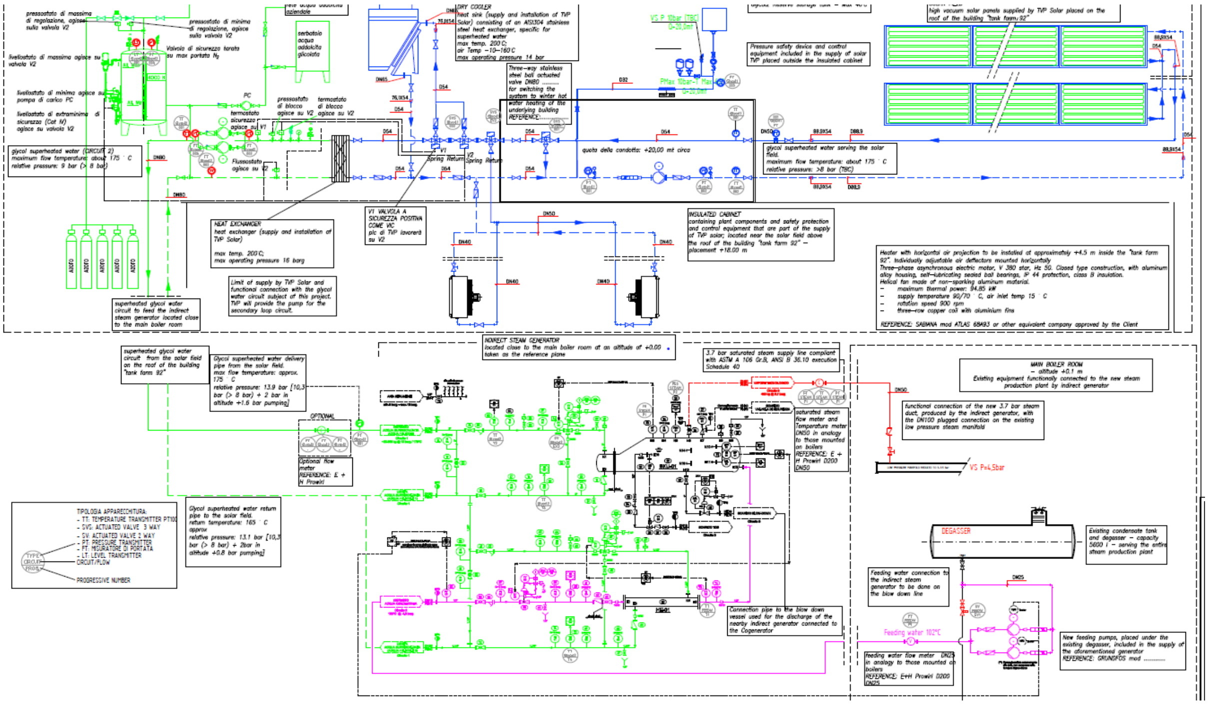

Figure 6 Solar field scheme

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Figure 7 Solar field process

2.1.3 M&R tool trial results

In particular, the evaporative condenser was chosen as case study useful for the trial. The aim of this scenario is to use the heat produced in the compression phase to heat the environment next to the cooling system. It will also partially condensate the refrigeration gas before it reaches cooling towers. So as to obtain savings in term of both thermal and electric consumptions.

Figure 5 reports the simplified scheme: hot gas from the compressors recovered through the heat exchanger before it flows into the tower.

The first step of this analysis was focused on the definition of the main quantities to be measured in the various step of the refrigeration cycle. Starting from the electrical power of the compressor and its COP, it was possible to find the potential heat production equal to 478 kWth. This value represents the maximum thermal power that can be used by the compressor. In calculating the annual usable energy, it was considered a utilization factor of 78%, and an additional utilization factor limiting the operation of the entire system to the winter period and the days where heaters are actually turned on.

With the second step it was targeted the thermal energy demand of the building in the winter period. The heat sent to the environment must cover the losses from both refrigerated wine tanks and building.

The potential heat recovered from this system was thus calculated considering the annual operative working hours of the compressor and the average temperature of the hot gas exiting the compressor, before reaching the condenser, so it was possible to obtain a waste heat recovery of 351 MWh/y. This value is different from that found in the preliminary analysis described in Section 2.1.2.2, which was 1,848 MWh. That because in the initial stages, it was considered the possibility to recover the energy

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produced by all the compressors serving the sparkling wine production. In the specific case, only one compressor was investigated.

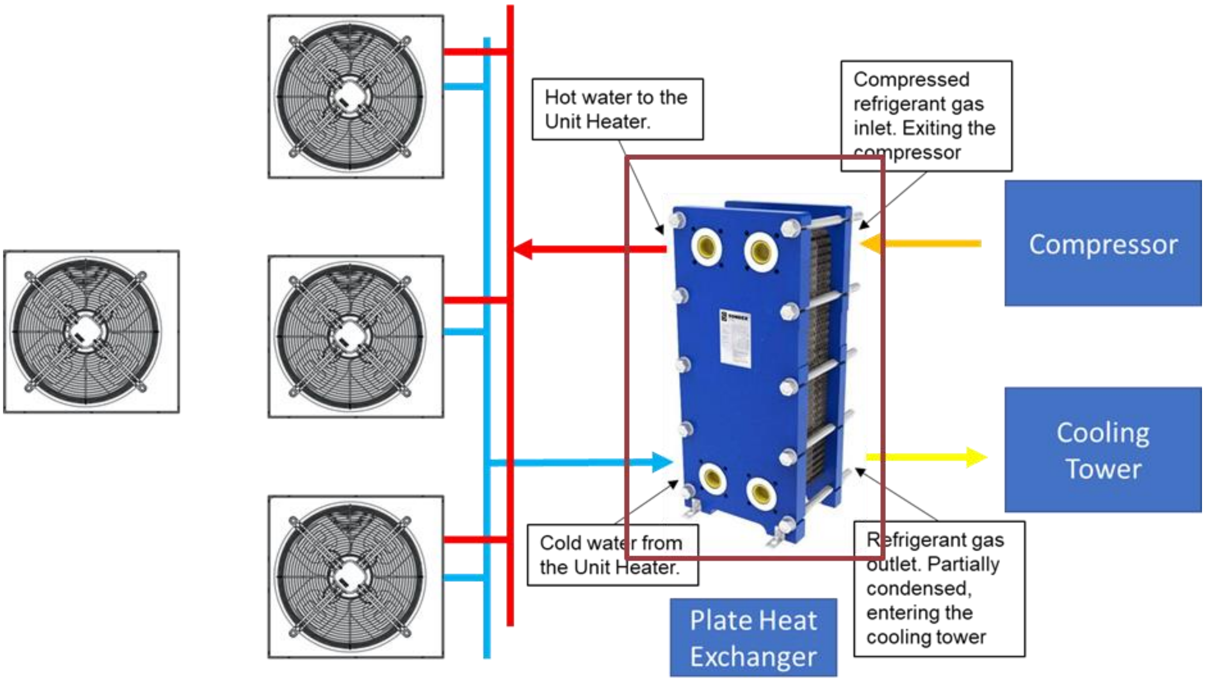

Figure 8 Scenario identified: evaporative condenser

This value, combined with a reduction of natural gas use, allows to meet a CO2 reduction of 71ton/year, that in our assumption considering a technical life of 20 years correspond to 1418ton/runtime life.

Even if from both economic and energy perspective this scenario looks very interesting, there are many other aspects to be taken into account. All the technical aspects related to the resulting differences in refrigerant gas pressure and temperature. The likelihood of significant changes in the standard system working cycle and how to adapt it. Another aspect is linked to the quality of the air sent to the environment and the analysis on where to install the unit heaters and to drive the flow.

2.2 Spanish demos

2.2.1 General description

The Spanish cluster of the SO WHAT Project is made up of the following five companies:

- **CARTIF:** Applied research centre. Legally is a private non-profit foundation, which emerged from the University of Valladolid, whose mission is to offer innovative solutions to companies to improve their processes, systems and products, improving their competitiveness and creating new opportunities of business.
- **ELEUKON:** Engineering company focused on energy efficiency services, industrial engineering, energy production and industrial digitization.
- **ENCE:** The business model of ENCE is based on the sustainable use of natural resources (wood and biomass) for the eco-efficient production of pulp and renewable energy.
- **SUSTAINABLE INNOVATIONS:** Communication company focused on innovation management services, business development and capacity building.

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* **FAEN:** FAEN ("Fundación Asturiana de la Energía"), as the Principality of Asturias Energy Management Agency, studies the energy needs of the region (Asturias) in order to try to satisfy them in the most efficient way possible. To achieve this, it works in accordance with the proposed objectives and the international commitments that Spain must comply with.

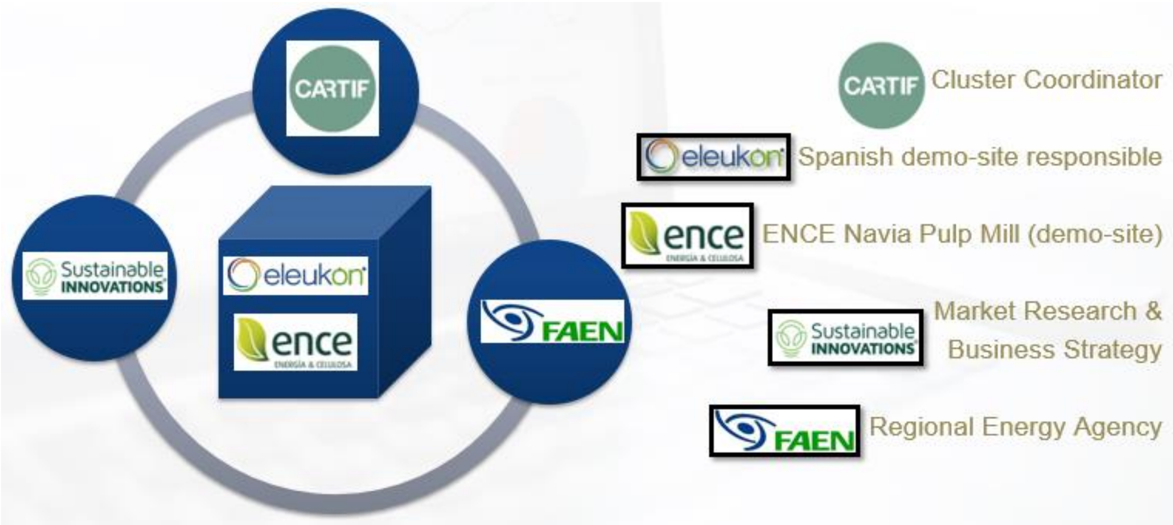

Figure 9: Overview of the Spanish Cluster

ENCE, with an installed capacity of 1.2 million tons distributed in its two bio-factories in north-western Spain, Navia (Asturias) and Pontevedra (Galicia), is one of the largest European producers of short fibre pulp (BHKP) based on eucalyptus wood purchased in the environment of its bio-factories and from certified responsible sources, which guarantee sustainable forest management.

Through its 51% stake in MAGNON GREEN ENERGY, ENCE is also the largest generator of renewable energy with agroforestry biomass in Spain, with an installed capacity of 266 MW distributed in eight independent plants located in southern Spain.

Navia pulp mill (Spanish SO WHAT demo-site) is the centre of ENCE with the largest production capacity. After the recent expansion and improvement of its facilities, it has positioned itself among the leaders in the European eucalyptus market. The current production capacity of the bio-factory is 685,000 tons/year of high-quality ECF (Elementary Chlorine Free) eucalyptus cellulose. This capacity has been increased in 2019 after the execution of the "Navia 80" Project, which entails an expansion of capacity of 80,000 tons in the factory.

Figure 10: ENCE Navia pulp mill (Spanish SO WHAT demo-site)

2.2.2 Scenarios identified to use in the tool trial

Three scenarios were identified as possible trials for the SO WHAT tool.

2.2.2.1 Biomass Dryer

ENCE Navia installed a biomass dryer in 2019 in order to increase the calorific power of the biomass burnt into the biomass boiler (biomass savings).

Figure 11: ENCE Navia biomass dryer facility

In this scenario the waste heat is recovered from the process flow of the bleaching stage through a water/water plate heat exchanger ("BIOMASS DRYER HEAT EXCHANGER" in Figure 12) installed in parallel of the principle line. The heat recovered at this point does not affect the process, because the recovery point is located at the end of the process line before the flow is sent to the effluent treatment. The heat is recovered from the dilution fluid (inlet temperature of around 80ºC) of the bleaching stage and send to a water (outlet temperature of around 70ºC) closed circuit which is connected directly to the biomass dryer, in where through water/air heat exchangers and fans the recovered heat is used to generate a hot air stream used to dry the biomass which flows through a conveyor belt.

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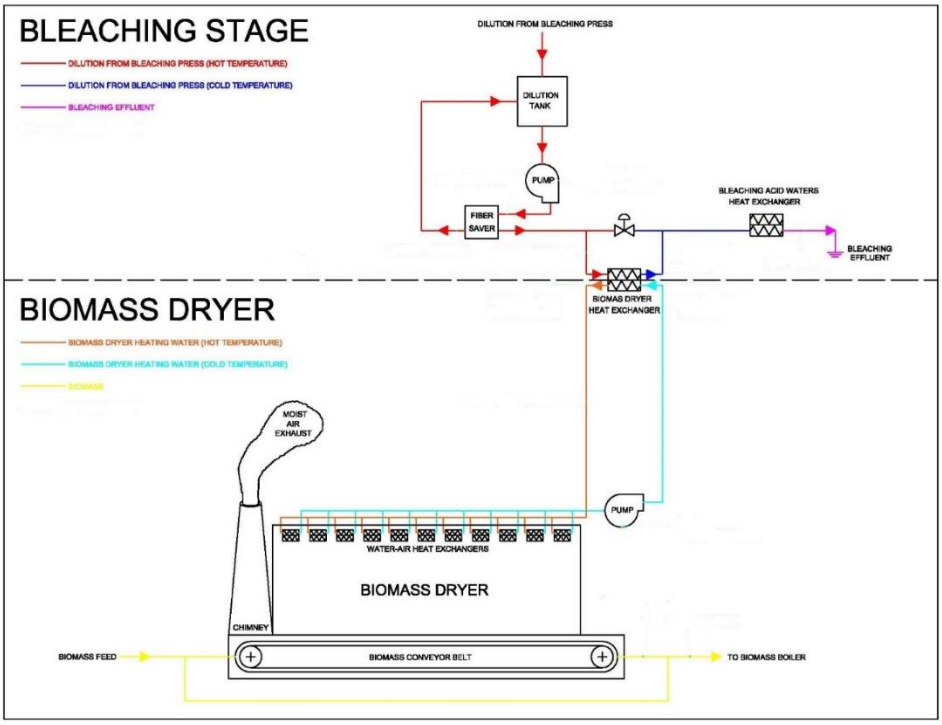

Figure 12: Biomass Dryer waste heat recovery flow diagram

2.2.2.2 Lime Kilns

In this scenario, the waste heat would be recovered from the exhaust gases of the lime kilns (causticizing stage), which are at a temperature greater than 300ºC, through a gas-water heat exchanger. The recovered heat would be used to further increase the temperature of the water (working fluid) used in the biomass dryer, thus increasing the drying capacity of the facility.

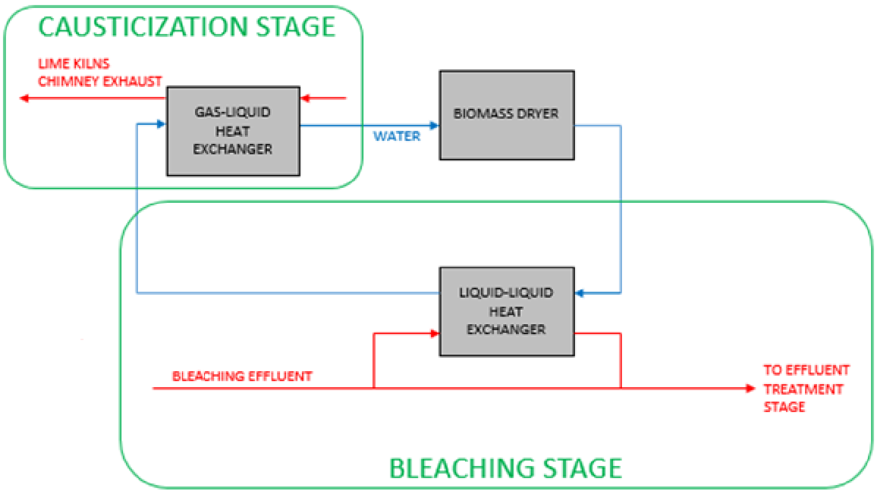

Figure 13: Lime Kilns waste heat recovery flow diagram

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2.2.2.3 Effluent Treatment (DHN)

In this scenario, the waste heat would be recovered from the effluent during its treatment stage through plate heat exchangers, to take advantage of it through a district heating network that would be connected to public buildings in the town of Navia (town hall, swimming pool, etc.), which is located less than 2 km away from the factory. Currently there is a need for cooling in the effluent treatment process between the DAF (Dissolved Air Flotation) and the decanters, which is carried out through two cooling towers. The implementation of this measure would imply a reduction in the electrical consumption of cooling towers.

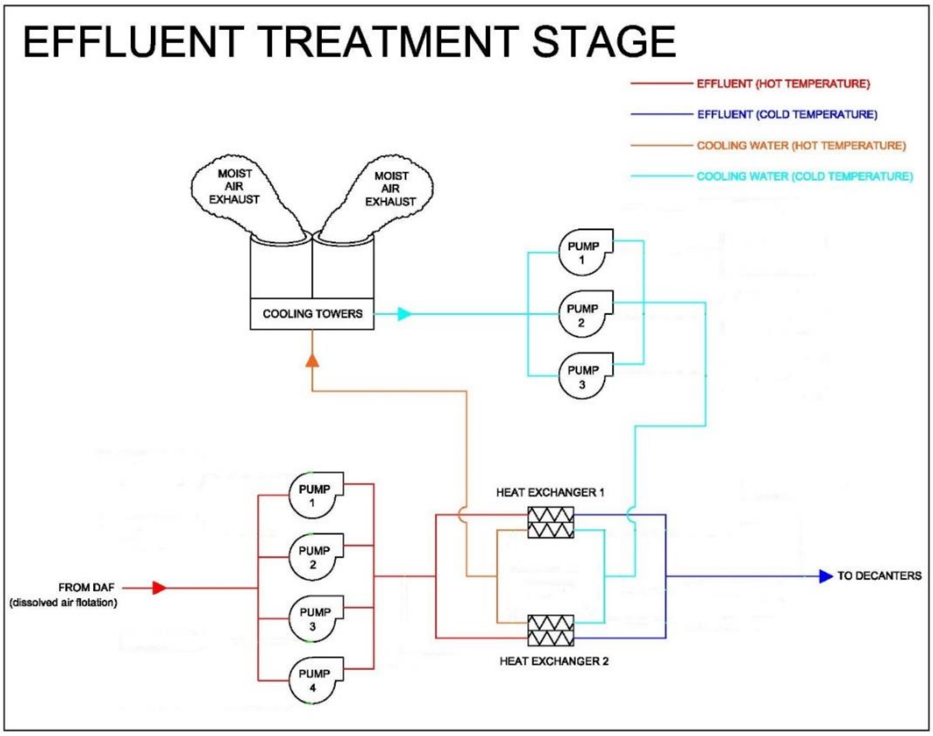

Figure 14: Effluent Treatment flow diagram (cooling between DAF and decanters)

2.2.3 ENCE tool trial results

Finally, it was decided prioritize the use the Biomass Dryer scenario for the testing of the SO WHAT tool due to the following main reasons:

- The facility was real and operational, providing the opportunity to collect data before and after its construction.
- The facility was fully monitored and integrated into the monitoring system of the plant.
- The plate heat exchanger had all the necessary sensors installed (flow, temperature and pressure).

First of all, the data from the facility was gathered through the monitoring system of the plant. The sampling period was five months, between December 2019 and April 2020, the most critical months of the year in terms of biomass humidity. The temporal resolution of the data chosen was only one minute, due to the fact that the operation of the facility was not very stable, taking into account that a learning process must be overcome until the process is stabilized. This small sampling period

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allowed for a very precise data cleaning to be performed, removing periods of downtime or malfunction. After this process the data was uploaded to the SO WHAT tool platform (see an example in the Figure 15)

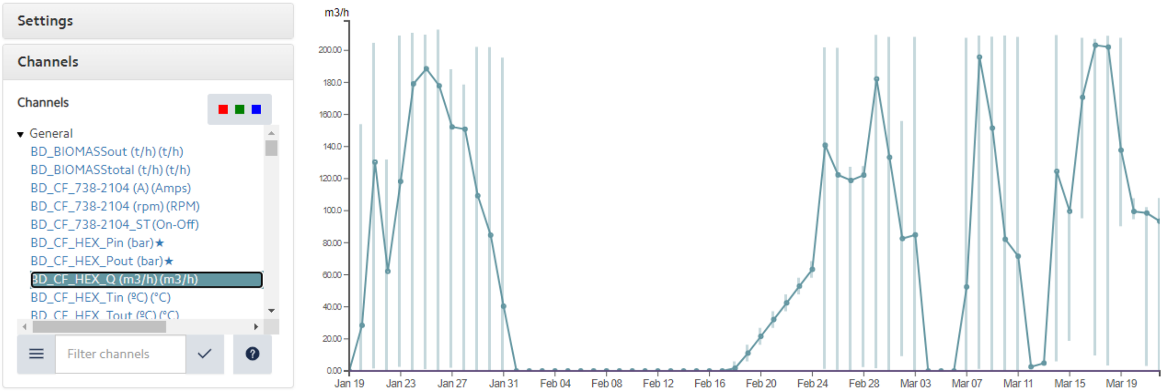

Figure 15: Biomass Dryer data into the SO WHAT tool platform (water flow of the cold focus in m³/h)

Next, the facility was modelled in the SO WHAT tool. In the Figure 16 there are two blocks, the bigger one represents the Bleaching Stage (where the waste heat is recovered) and the smaller one represents the Biomass Dryer (where the recovered waste is reused).

Figure 16: Implementation of the Biomass Dryer facility within the SO WHAT tool

Finally, the connection between the generation of waste heat (Bleaching Stage) with the demand for heat (Biomass Dryer) was made through a plate heat exchanger (see Figure 17).

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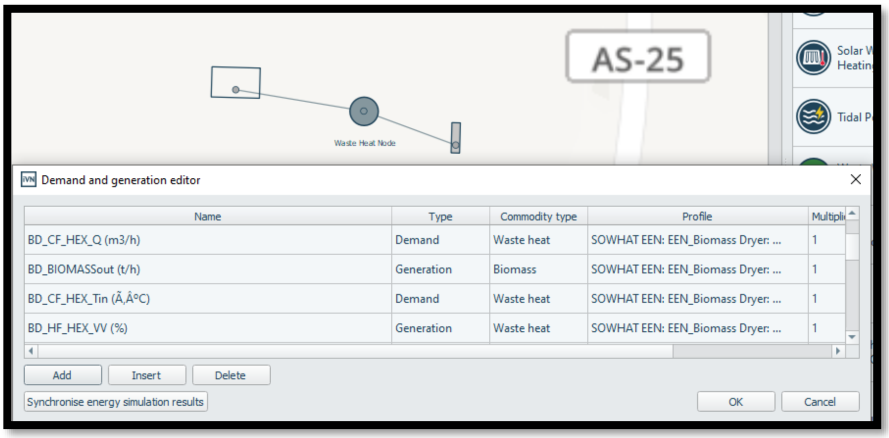

Figure 17: Connexion of the waste heat generation to the heat demand in SOWHAT tool

Extrapolating the data from the sampling period (five months between December 2019 and April 2020) to a whole year, an annual saving of around 50,000 ton/year of biomass is obtained. To obtain this result, the following considerations have been taken into account:

- 8,500 hour/year of operation of the Biomass Dryer have been considered (taking into account one annual maintenance stop of about ten days and without taking into account stops due to facility breakdowns).
- Losses in the heat transfer capacity of the plate heat exchanger due to fouling (fibres of the hot working fluid) have not been taken into account (4,717 constant thermal kW).
- It has not been taken into account that the extrapolation of the sampling period (the most critical months of the year in terms of biomass moisture percentage) to the rest of the year is not entirely accurate.
- An electrical consumption for the operation of the biomass dryer of 2,337 MWh/year has been considered (this consumption is mainly due to the fans, the cold working fluid pump and the conveyor belt).
- The increase in electrical consumption of the hot working fluid pump (increased pressure loss due to the heat exchange) has not been taken into account.
- The reduction in consumption (both electricity and fossil fuels) of biomass handling equipment derived from the biomass saving has not been taken into account.

Regarding the CO2 and GHG (Greenhouse Emissions) savings, the biomass is considered neutral in CO2 emissions The combustion of biomass is considered neutral in carbon emissions because the CO2 that is released is part of the photosynthesis cycle of the trees, a process in which they absorb it to continue growing. This process is continuous and, therefore, guarantees the sustainability of the raw material (see **Errore. L'origine riferimento non è stata trovata.**).

Figure 18 The Carbon Cycle

2.3 Belgian demos

2.3.1 General description

Demosite 1: Umicore Olen

Figure 19 Umicore Olen_demo 1

- Core: Recycling of metals
- Reinforced sustainability objectives of the company (also due to geopolitical situation)
- Umicore requested studies to explore recuperation of waste heat via on site district heating network, and thus reducing the use of steam
  - Possible sources for waste heat
  - High temperature processes that could be transformed to low temperature processes
  - Connection of high temperature processes to low temperature waste heat, using heat pumps
  - Use of deep geothermal energy as extra source
- Democase of Umicore has been used to develop and test the tool to assess (financial/economical) feasibility
- Democase of Umicore has been used for testing So What tool.
- Difficulty encountered during testing So What tool: heat demand in this demo case is mainly process heat, and no building heating.

Demosite 2: Isvag

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- Core: waste incineration plant
- Issues related to the permitting/licenses: not only for the construction
  of the new incineration facility, but also for the existing.
- However, willingness to continue to develop existing district heating net (Terbekehof) and to investigate new connections
- Democase of Isvag has been used to develop and test the tool to assess (financial/economical) feasibility

Figure 20 Isvag_demo 2

- Democase of Isvag has been used for testing So What tool
  - Analysis based on existing plant
  - Scenario: provide waste heat to near located Atlas Copco plant
- Difficulty encountered during testing: with current software it is difficult to analyse a large DHN as the radius is limited. Therefore, we limited the scenario to Isvag – Atlas Copco (otherwhise the connection with Antwerp University could have been tested)

Demosite 3: Imerys Willebroek

- Core: production of graphite and carbon
- Increased production
- Decision taken to use waste heat for heat to power installation. Imerys found partner to dvelop heat to power.
- There might still be waste heat, but no certainty on amount and temperature.
- Discussions with POM Antwerp and Imerys on involvement in So What and outcome was to use existing information.
- Testing of the So What tool based on Imerys democase is on hold.

Figure 21 Imerys Willebroek_demo 3

2.3.2 Scenarios identified to use in the tool trial

2.3.2.1 Scenario Umicore

Within the Umicore group, Umicore Olen wants to be a forerunner in achieving the sustainability goals. In light of this vision, the feasibility of the realisation of a heat net on the industrial site in Olen was studied.

The feasibility study was executed by Kelvin Solutions, who after an earlier study in 2019 confirmed the possibility of a profitable transition to lower temperatures. Today a more detailed study results in the connection of the waste heat recuperation on the flue gases of the CHP (Combined-Heat and

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Power) which supplies 18 users. A great deal of work was devoted to the identification, selection of processes and the confirmation of the possibility to transform a user from steam to hot water.

The situation right now is a completely gas-fuelled steam production consisting of two CHP's and 2 back-up steam boilers. The goal of the project is to implement a recuperation on the residual waste heat that is still present in the flue gases from the exhaust of the CHP's. This will be done by placing a heat exchanger to further cool down the flue gases. The aim is to demonstrate within the current heat production that switching process users to hot water is already profitable with the current heat sources. If the basic investment in the heat network and conversion of heat users is already feasible, this gives reason to investigate the sustainability of the heat source in second instance.

Because in this project there is no clear substitution of power, but only a decrease in steam production it is difficult to mention an estimated substituted power. In this case only a very rough assessment of the to be installed heat exchanger, based on a simulation of the boiler house, can be made. An estimated power of three heat exchangers of 2,5MW, 2,0MW and 0,25MW might be installed.

The heat net drawn in Figure 1 will be placed in solid ground from the boiler house to the nearest pipe rack and will have a total length of 881m in the first phase. The length describes only the meters trench and is limited to the backbone, the whole network on the other hand will consist of a 3-pipe-system in which one high temperature flow, one low temperature flow and one medium temperature low where both flows combine. This means that in total 2643 m of piping back bone will be constructed.

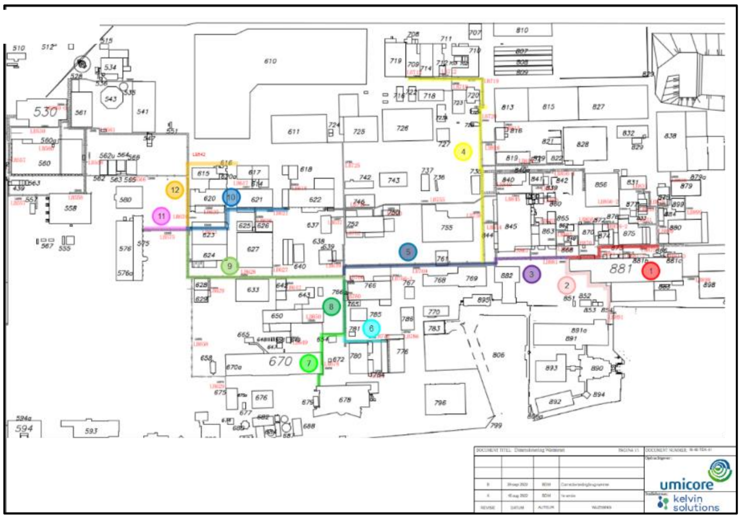

Figure 22 Layout of the Heat net fed with waste heat

Below you can find the 'as-is' and 'to be' situation according the scenario.

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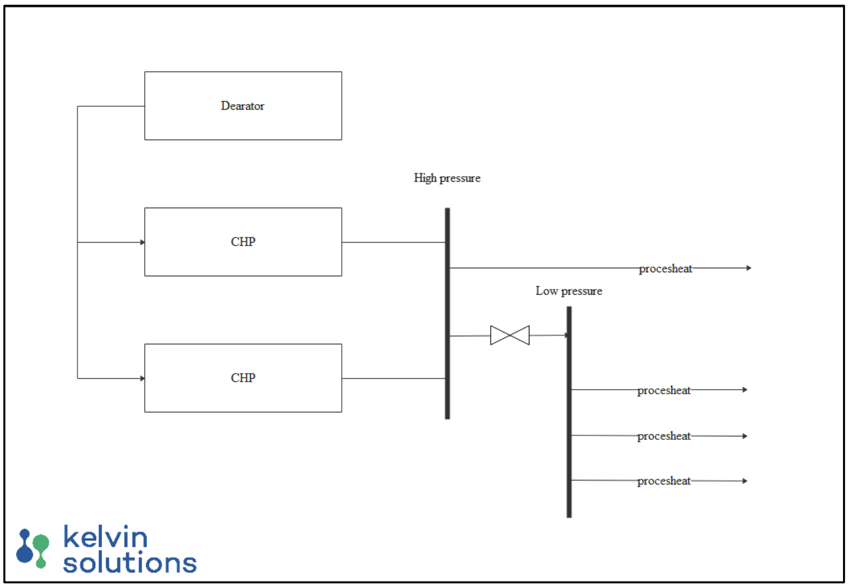

Figure 23 Electricity and steam production as is today

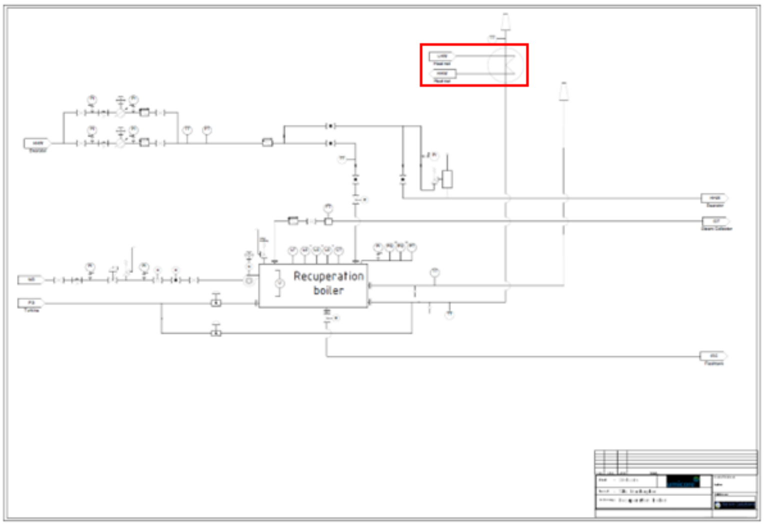

Figure 24 Future waste heat recovery from the flue gases of the recuperation boilers

2.3.2.2 Scenario Isvag: Valorisation of waste heat by industrial user

Today, a limited part of the available residual heat of incinerator Isvag is already being used to provide the neighbouring heat network "Terbekehof" with residual heat. A highlevel study, executed in 2019, confirmed the possibility of a profitable valorisation of additional residual heat by constructing a district heating grid to big industrial users nearby. Within the So what project, the link with Atlas Copco air compressors was investigated. Atlas Copco has a significant heat demand to heat its production areas. If we take 2021 as the reference year, the simulation of the SoWhat tool comes to a total heat demand for Atlas Copco of 8.52GWh. Historically, these are older buildings that can be renovated to a limited extent.

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Below you can find the as is and the to be situation of the scenario.

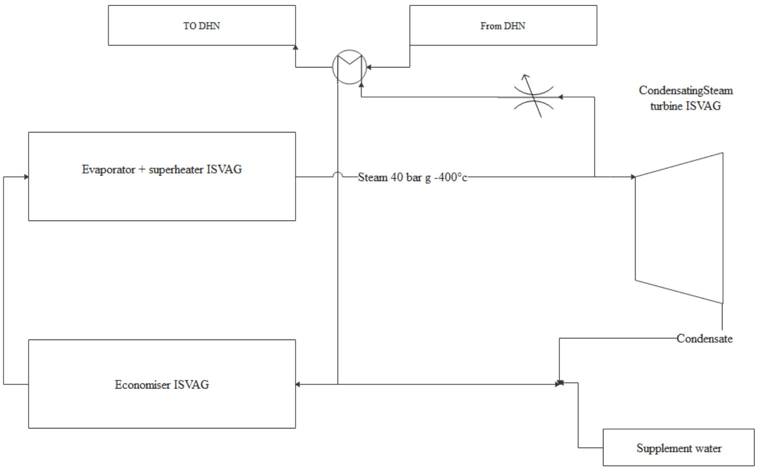

Figure 25 Electricity and heat production as is today

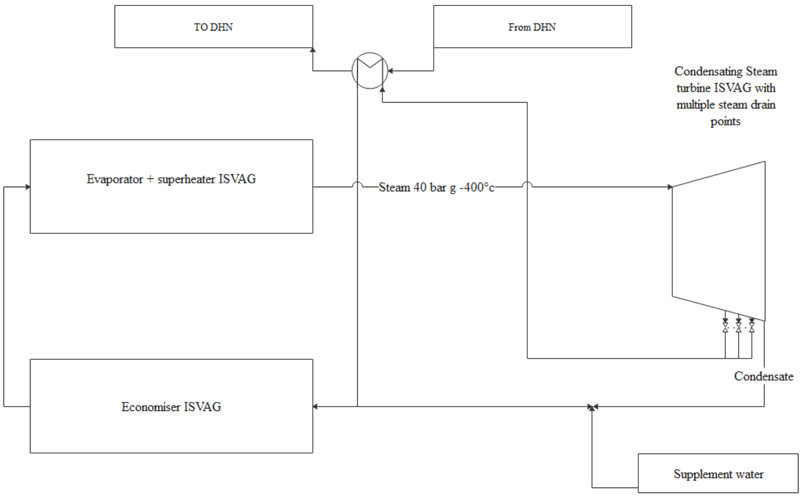

Figure 26 Future waste heat recovery from the expanded steam within the steam turbine

2.3.3 Demos tool trial results

2.3.3.1 Results Isvag

Due to the recuperation of waste heat, a potential energy reduction of 10.023 MWh is possible. This is the part of the heat demand of Atlas Copco that replaced by waste heat from the DHN.

1. Energy reduction /Energy replaced by Waste Heat (WH) or Renewable Energy Source (RES)					
ID	Vector	Energy content (GJ primary/unit)	($kg\ CO_2$ / GJ_primary)	Potential energy reduction per year	Vector to heat efficiency
1	Natural gas (MWh-LHV)	4	56	10.023	85%

This corresponds to gross savings of 2,024 tons CO2 per year. This differs from the Nett avoided emissions because party of the steam-energy will not be used to produce electricity, but to generate hot

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water. In the worst case this transfer from electricity production to heat production means that this 'difference' needs to be compensated for with 'grey electricity'.

Gross Avoided CO_2-emissions [ton/year]		Total Gross avoided CO_2-emissions [ton/runtime model]
2.024		38.056
Nett Avoided CO_2-emissions [ton/year]		Total Nett Avoided CO_2-emissions [ton/runtime model]
1.667		44.774

The proposed project is dimensioned for the future, so that a robust basic infrastructure can be constructed on a part of the site that can be expanded in the future. This means that future new heat users would also be climate neutral at a low-cost heat.

2.3.3.2 Results Umicore

Due to the recuperation of waste heat, a potential energy reduction of 38.044 MWh can be saved. Because it concerns heat demand for processes, only a part of the steam demand can be transferred to a hot water-solution.

Energy reduction /Energy replaced by Waste Heat (WH) or Residual Heat (RES)					
	vector	Energy content (GJ primairy/unit)	(kg CO_2 / GJ_primair)	Potential energy reduction per year	Vector to heat efficiency
1	Natural gas (MWh-HHV)	3	56	38.044	85%

This corresponds to gross savings of 6.938 tons CO2 per year. This differs from the Nett Avoided emissions because natural gas is converted to steam and electricity in a CHP. Because the steam demand will decrease by implementing the hot-water system electricity production will decrease. This means that this decrease has to made up with 'gray electricity'.

Bruto Avoided CO_2-emissions [ton/year]		Total avoided CO_2-emissions [ton/runtime model]
6.938		128.354
Netto Avoided CO_2-emissions [ton/year]		Total Netto Avoided CO_2-emissions [ton/runtime model]
2.798		205.358

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2.4 Romanian demo

2.4.1 General description

The Constanta RES Pilot Case has been developed based on a partnership between DH utility company Thermoficare and Ovidius University of Constanta and it has been demonstrated the possibility to convert the classical re-heating station is local RES Power plants (Figure below).

Figure 27 Local RES power plant

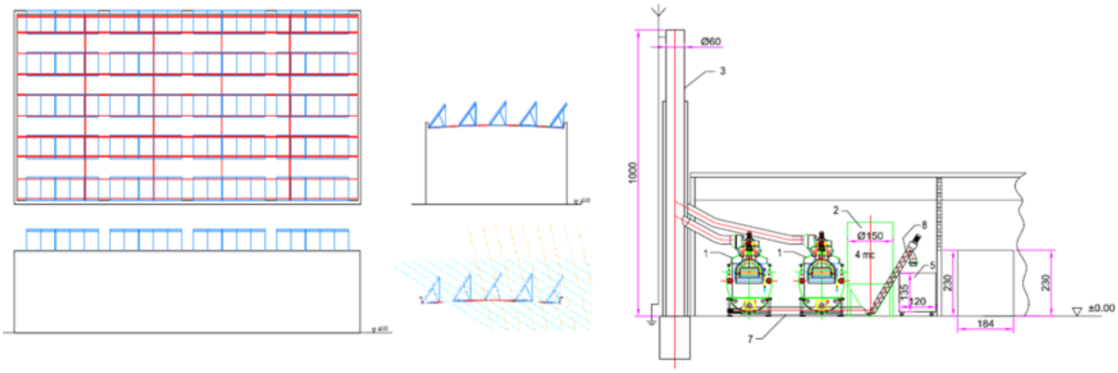

Figure 28 re-heating stations, Faleza Nord district

One of the re-heating stations located in the district "Faleza Nord", that is suppling hot water for heating and warm water for daily use for an impressive secondary network of dwellings in apartments blocks has been selected for a pilot project.

The aim of the project was to define a concept of pilot plant using solar energy by installing solar-thermal panel on the roof-top of the building without additional structural changes as an alternative thermal energy source, sustainable but, at the same time assuring the quantity and quality thermal energy for the end-user customers in the frame of the legal provisions for thermal energy distribution in Romania.

To develop the concept of the pilot plant, between 2016 and 2018 there were carried out studies of evaluation of demand side characteristics by drafting the energy consumption plots for the existing customer structure as the daily statistical demand side curve for summer and winter season. There were taken into consideration also the yearly variations due to weather conditions.

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The solar thermal installation has been dimensioned by correlating the thermal energy demand and the available surface on the roof top of the PT31 building. The solar thermal installation is composed of 100 solar thermal panels, serial connected in groups of 5 panels, and the series are connected in parallel for a section of 25 panels. The sections of panels are operated by 4 recirculation stations of the working fluid. As it may be observed from the P&ID diagram, the thermal energy is stored in storage tanks with a total capacity of 10 m3.

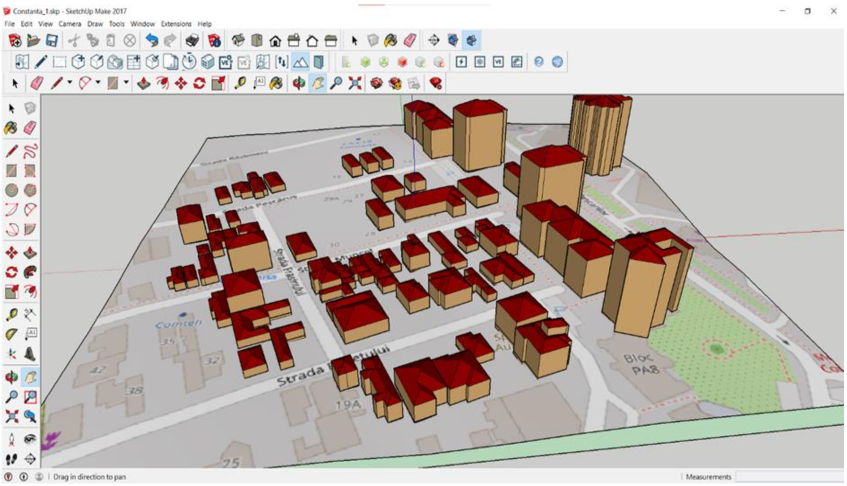

Figure 29 P&I_thermal energy

The station is preparing the hot and warm water streams based on the primary thermal energy stream from the cogeneration plant. Due to the very high costs of the thermal energy, many dwellings shifted to individual gas fired boilers. In October 2018, about 100 end-user dwellings were still connected to the secondary distribution network.

The concept of the pilot plant has been conceived as during the summer season, the solar-thermal panels to be able to cover the entire energy demand and working together with the energy accumulation system to be able to cover the morning and evening daily picks.

The pellet boilers are manufactured by Ecohornet Ltd that is a Romanian manufacturer of highly performant boilers working with pelletized waste biomass. The boilers are fully automatic, integrating up-to-date digital technologies for monitoring the parameters and dynamic adjustment to the operating conditions.

2.4.2 Scenarios identified to use in the tool trial

For the reduction of the environmental impact of the supplied thermal energy to the end-users, there were identified 2 scenarios as followings, both are implemented simultaneously:

Scenario A – the substitution of the thermal energy supplied from the Power Plant with the thermal energy obtained from solar panels

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Figure 30 Solar thermal panels

The solar thermal installation is composed of 100 solar thermal panels, serial connected in groups of 5 panels, and the series are connected in parallel for a section of 25 panels. The sections of panels are operated by 4 recirculation stations of the working fluid. The thermal energy is stored in storage tanks with a total capacity of 10 m3. The installed capacity of the solar panels is 230 kWt.

Scenario B – the substitution of the thermal energy supplied from the Power Plant with the thermal energy produced with the pellet boilers

In the second scenario it has been considered the situation of installing in the re-heating station of pellet boilers. The pellet boilers are considered as neutral from the point of view of CO_2 emissions because the fuel is obtained from biomass by appropriate processing.

The combustion processes are on grade with some specific features for assuring the high temperature combustion above 1200 °C.

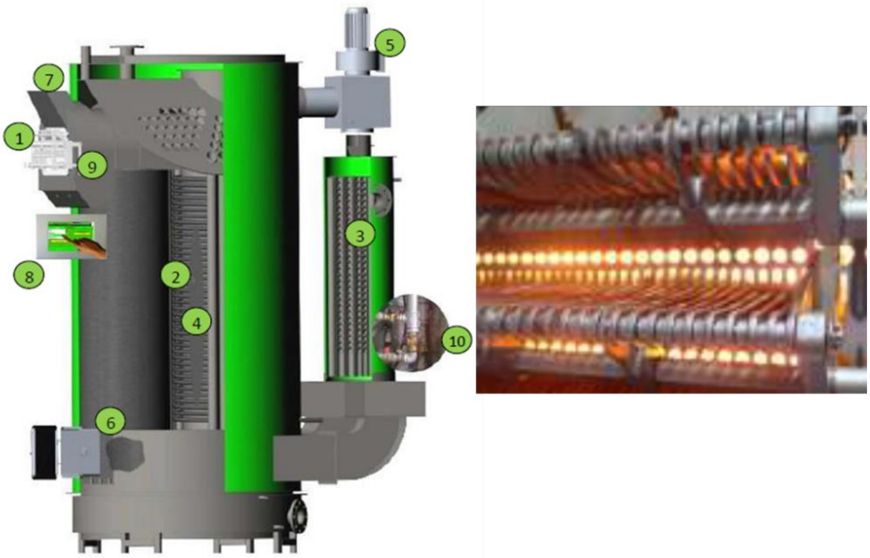

Figure 31 Pellet boilers to be used in scenario B

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2.4.3 Demos tool trial results

Taking into consideration the modelling of the connected blocks of apartments, there were initialized the parameters for each building and weather conditions and the simulation results are presented in the followings.

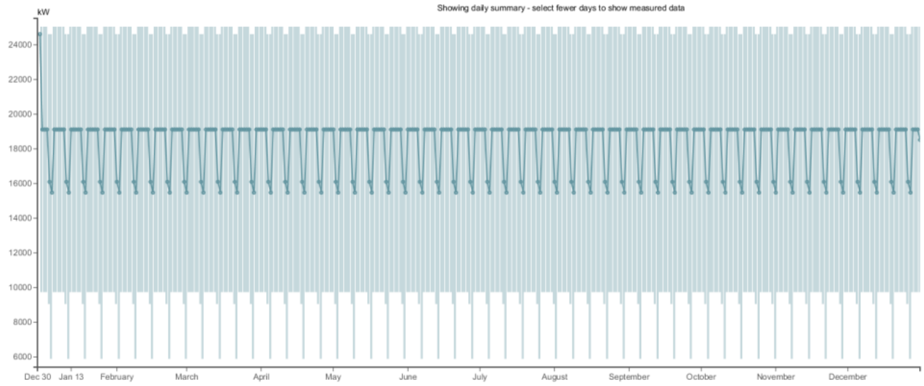

Figure 32 Calculated hot water demand

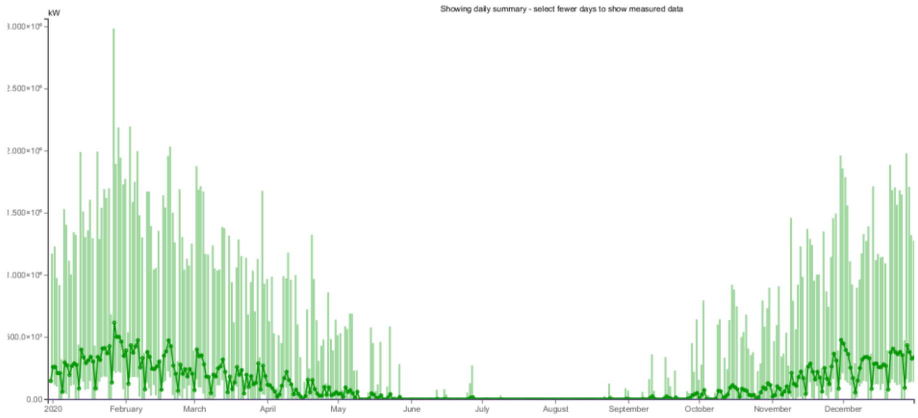

Figure 33 Calculated heat demand

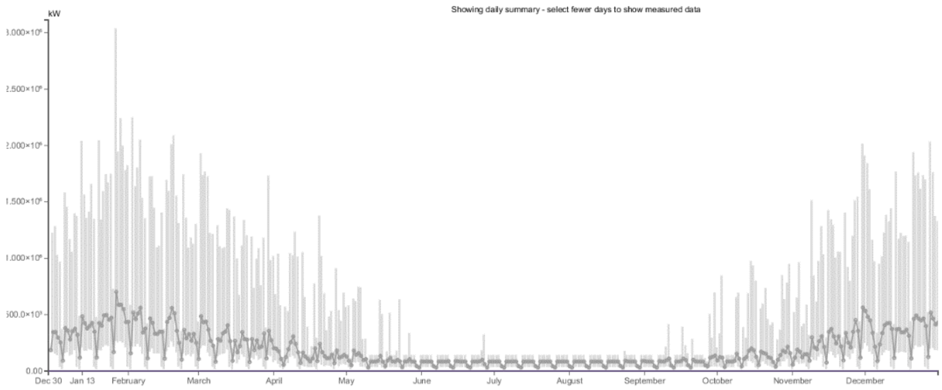

Figure 34 Calculated total energy demand

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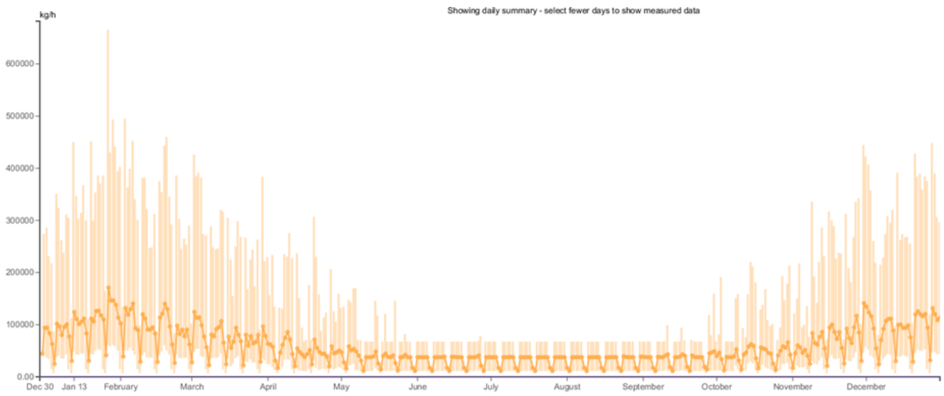
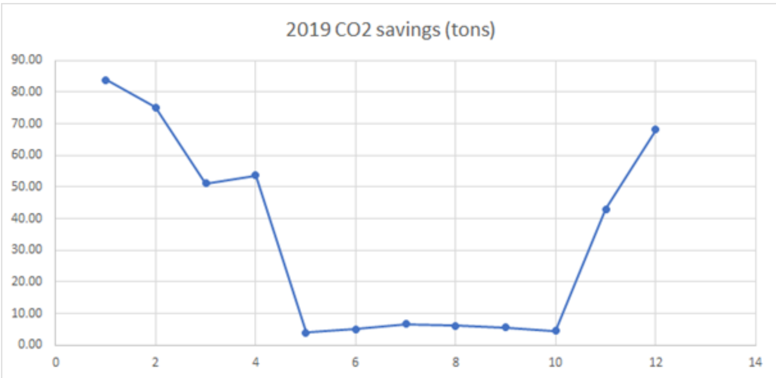


Figure 35 Calculated total CO2 impact

Takin into account the results obtained by simulation it has been possible to evaluate the impact of the selected scenarios.

The total estimated reduction of CO2 emissions is presented in the following diagram, the total annual value is 407,12 ton/year referred to 2019. This reduction is cumulating the savings of the losses at the Thermal Power Plant, the transport of thermal energy to the re-heating station and the change of the heat source with the RES.



Month	2019 CO2 savings (tons)
January	83.88
February	75.19
March	51.15
April	53.70
May	4.09
June	5.11
July	6.65
August	6.14
September	5.63
October	4.60
November	42.96
December	68.02
Total	407.13

Figure 36 CO2 savings monthly trend (referred at 2019)

2.5 SWEDISH demos

The Swedish lighthouse cluster comprises of two demo sites located in the cities of Gothenburg and Varberg on the Swedish west coast. IVL Swedish Environmental Research Institute (IVL) coordinates the work of the cluster. The two demo sites are presented briefly in the following sections. Due to the existing waste heat collaborations with industries in Gothenburg and Varberg, the lighthouse cluster has the role to inspire the other demo sites and share their experiences of waste heat collaboration, both with regards to technical aspects, challenges, success factors, business models and contractual arrangements

2.5.1 General description

Göteborg Energi's multiple waste heat and district heating and cooling networks in Gothenburg, Sweden

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Göteborg Energi (GOTE) has a world-class district heating network, covering 90% of the heat demand of the city of Gothenburg. Only 5% of the heat production is based on fossil fuels; the vast majority of energy production is based on excess heat (80%), originating from waste incineration, oil refining and electricity production, and from biofuels (15%). The waste heat is primarily delivered from Refinery ST1, PREEM refinery and waste incineration (Renova). GOTE has used waste heat for district heating since the 1970's. In addition, GOTE is offering district cooling based on absorption chillers driven by waste heat from industries which in summer months could not be exploited for heating due to low heat demand. In parallel, free-cooling (cooling towers or river water) and compressors are employed to offer a reliable service. GOTE is acting as lighthouse partner for the SO WHAT project, but it also benefits from it for its next development forecasted activities. By 2021, they will need to expand cooling production by another 20 MW to meet the sales forecast. The demo will be under investigation and today they are looking at two types of absorption machines. They also look at utilizing low temperature heat for district heating networks (i.e. server halls, data test cells, etc.).

Varberg Energi Pulp and Mill industry Waste Heat District Heating Network in Varberg, Sweden

The demosite in Varberg is represented by Varberg Energi (VEAB), a municipality owned energy company providing district heating and other services to the area. As a municipality owned company they have been given the directive to invest in sustainable energy resources on a local market and, following it, they identified waste heat from a pulp mill situated about 20 km from the city as a promising source of waste heat to be fed into the district heating network. Before the construction of Varberg district heating network, the pulp mill was forced to cool away heat and release it into the surroundings. Waste heat is the main source for the district heating network (85%), but to integrate it and diversify and secure the network conventional heating systems based on wood chips, biogas and bio-oil are available. VEAB is acting as lighthouse partner for the SO WHAT project. VEAB and the pulp mill are currently investigating the possibility to increase the amount of waste heat injected in the network through action both at heat exchanger level and at customer level (i.e. lowering the return temperature). Furthermore, they are currently investigating the possibility to provide district cooling during summer via absorption chiller exploiting local waste heat.

2.5.2 Scenarios identified to use in the tool trial

Two different scenarios were used to test the functionality of different parts of the SO WHAT tool. These scenarios are presented briefly in this section.

Scenario 1: Increased use of waste heat. VEAB and the pulp mill SCV are currently investigating the possibility to increase the amount of waste heat injected in the network through action both at heat exchanger level and at customer level (i.e. lowering the return temperature). The tool was tested for the Varberg demo site using input data for hourly average heat demand for the city of Varberg (MW). The idea was to test how district heating demand could be matched by the excess heat from the pulp mill Södra Cell Värö (SCV) to make use of more of the excess heat.

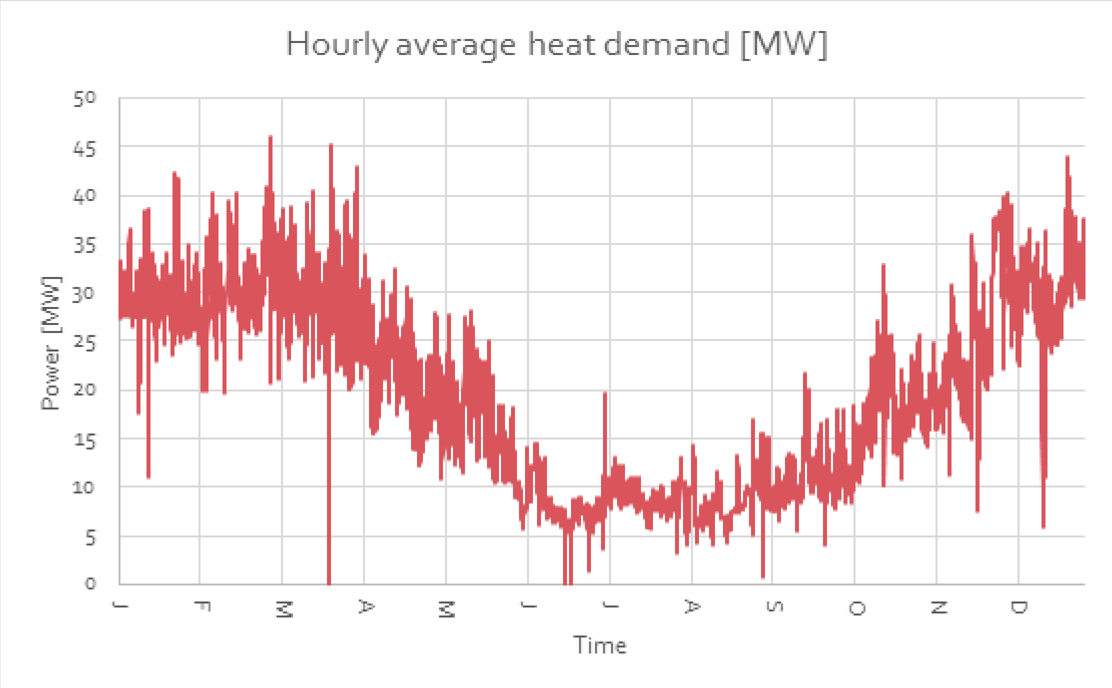

Figure 37 The input data for hourly average heat demand used in the tool trials for Varberg demo site

Scenario 2: Provision of district cooling. VEAB are also currently investigating the possibility to provide district cooling during summer via absorption chiller exploiting local waste heat, combined with free cooling from the sea. VEAB has investigated the possibility of expanding the technical supply in the city of Varberg with district cooling. IVL used this scenario to compare VEAB:s own study with the results of the Power BI tool developed within SO WHAT.

Today, each property has its own cooling installation that uses environmentally harmful refrigerants and electricity. The aim is to minimize the use of refrigerants and free up electricity in the power grid for more appropriate purposes. A positive side effect is that the number of existing outdoor cooling units and coolant in the city centre can be reduced, which in this way reduces noise.

The production plant for the district cooling is planned to be ready in 2026 and is based on the utilization of free cooling from the cold seawater during the winter half-year, while the residual heat from Södra Cell Värö produces the district cooling during the summer half-year when the temperature of the seawater is too warm. The total capacity of the district cooling network will be 13 MW. Approximately 13,000 MWh cold per year will be distributed. This will replace electric chillers in each customer's building and thereby reduce the annual electricity demand by 2,300 MWh.

The pipeline network will be built in two separate main pipelines:
A northbound line connecting properties in Lassabacka, Susvind, Kvarnagården and Holmagärde.
A southbound line that runs via Västerport, the city center and finally connects to the central hospital.
District cooling is mainly applicable to larger properties such as malls, industries, department stores, restaurants, hotels and hospitals, but the basis lies in the need for cooling and a separate cooling system inside the properties.

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Figure 38 Map over Varberg city. Red line is the pipeline for district cooling.

2.5.3 Demos tool trial results

The demo tool trials were focused on testing the functionality of the tool, and no specific results were attained for energy efficiency nor environmental impact.

However, as part of the So What project an ex-ante Cost-Benefit Analysis (CBA) of the investment in a district cooling system in Varberg (Scenario 2) was performed[2]. The CBA assessed the net social welfare of the technologies, taking into account the impacts on human health and the environment. With the method used, a drastic decrease in emissions was identified. However, given a high investment cost for the district cooling the costs exceeds the benefits and the project turns out to be sub-optimal in a societal perspective. In order to get a positive result, the investment cost would have to drop a 30-40%.

[2] Gariboldi, Gaia, *Cost-Benefit Analysis under the EU SoWhat Project Framework – Case Study of a District Cooling System in Varberg, Sweden. Final Dissertation in Resource Valuation and Decision-Making Methods.* Università di Bologna: School of Economics and Management. Cited 2022

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2.6 PORTUGUESE demos

2.6.1 General description

The Portuguese Cluster is coordinated by 2GO OUT Consulting with the involvement of the demosite LIPOR and AdEPorto – Energy Agency of Porto.

LIPOR is responsible for the management, recovery, and treatment of 380.000 tons of municipal waste in eight associated municipalities.

In 2021, 74% of the municipal waste sent to LIPOR's waste-to-energy (WtE) plant was used for energy recovery generating approximately 182,8 GWh of electricity. Nearly 88% of the electricity produced is sent to the grid, while the rest is consumed internally.

LIPOR waste-to-energy plant produces steam for electricity production and the excess heat is released at the condenser (55 – 60ºC) is not yet exploited.

2.6.2 Scenarios identified to use in the tool trial

The LIPOR demosite base scenario considers the recovery of excess heat from the WtE, to be delivered at the Porto Airport (2 km away from LIPOR's WtE), where it will be used for space heating and cooling (nowadays gas boilers for heating and electrical chillers for cooling are used), creating a new district heating network.

Figure 39 Lipor Waste-to-Energy Plan in Maia (Portugal)

In this scenario 40,8 GWh of waste heat will be recovered from the waste to energy (WtE) and shared with Porto Airport. The heat will be used for space heating and space cooling at the airport (26,8 GWh of thermal energy needs).

For this purpose, the investment planned considers: 1 heat pump (in WtE, COP 4.6) to increase the temperature of the supplied heat in the network, absorption chillers at Porto Airport for cooling purposes, heat exchangers, circulation pumps and 4 km of a new district heating network piping.

The total initial investment cost is estimated to be of 6,9 M€.

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It was considered an additional scenario, for replication purpose, in which it was included two new potential users: a brewer factory and a business hub with more than 100 companies and more than 5.000 employees.

Both new users are located at less than 4 kms away from LIPOR's WtE.

2.6.3 Demos tool trial results

For the SO WHAT tool tests, we tried to follow a step-by-step logic for the characterization and validation of the existing situation, so that later it was possible to simulate energy efficiency and emission reduction solutions. Having overcome the whole issue of installing and acquiring a license for the various components of the software, the process began by gathering and analyzing existing information.

iSCAN – The first component of the tool used was iSCAN, which allowed to compile, postprocess, import and export data regarding the demosite and also the potential waste heat users. Using iSCAN's capabilities of post processing data, it was possible to estimate de total waste heat available at the plant and its profile.

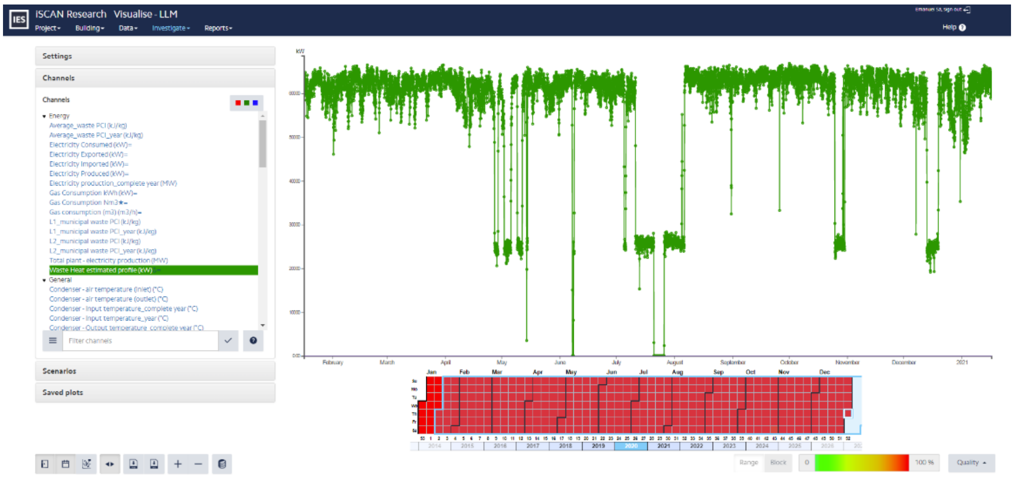

Figure 40 – iSCAN information regarding Lipor's data. Estimation of the waste heat profile

iCD – For the estimation of the waste heat demand for potential user, the Portuguese cluster used the iCD tool, which allows to select the area of interest from an *Open Street Map* and then proceed with the characterization and energy demand estimation for the desired buildings of interest in the area.

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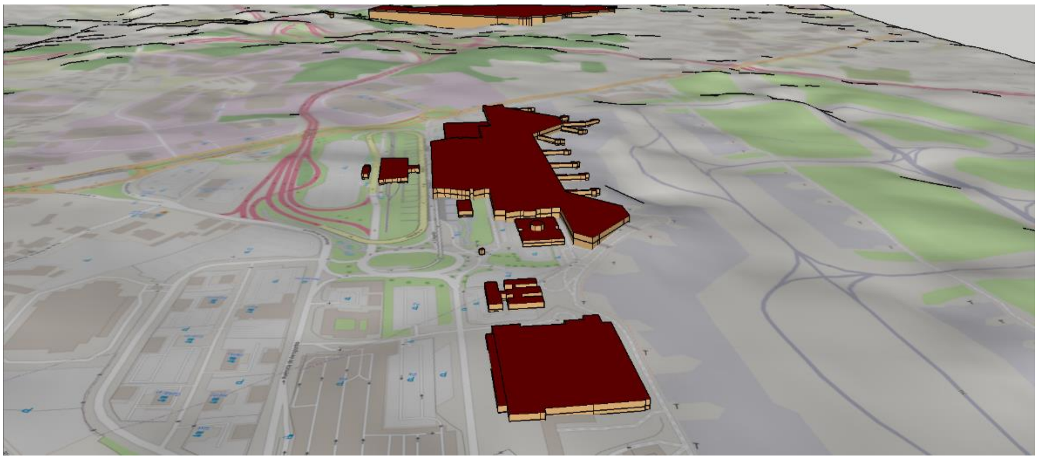

Figure 41 – iCD tool showing Porto airport and its premises.

The tool for importing information on buildings and facilities from the "open street maps" immediately allowed a significant advance in the initiation of the energy needs mapping work. In the specific case of the Portuguese study, and since it was of interest to know as many potential customers of the heat network as possible, an area of about 15 km² around the demosite, Lipor, was imported. The sealing of this area resulted in the survey of hundreds of buildings, proving to be impractical to maintain the model in such detail, both in terms of necessary information and in terms of graphic and computing resources.

For this reason, the number of existing buildings in the model was reduced to those that were identified as being strictly necessary.

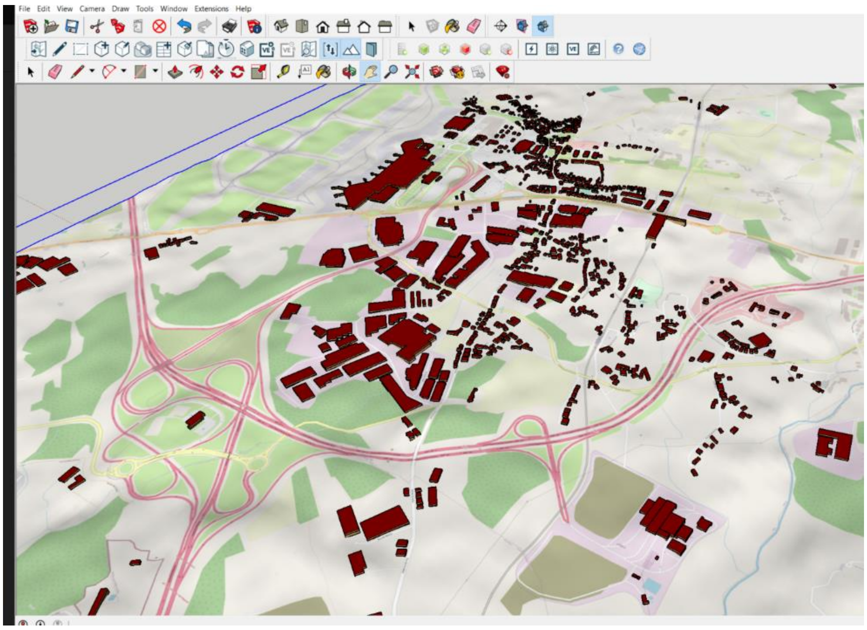

Figure 42 – Image of the initial model that was discarded

The following figure shows the image of the model with only information on the buildings identified as having relevant interest for this phase of the work. In the Portuguese case, and due to contact with

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several well-known stakeholders in the vicinity of the demosite, there was already some knowledge of energy consumption in buildings and respective hourly profiles. In a particular case, there was a dynamic simulation executed in another software (EnergyPlus) whose results were able to be exported and integrated in the iSCAN tool for later use in the various components of the SO WHAT tool, thus making its use much more flexible.

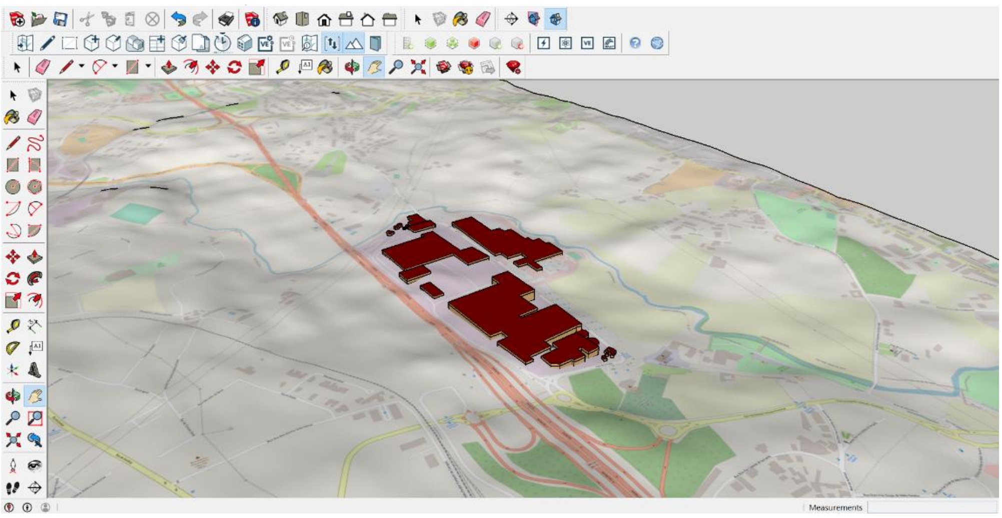

Figure 43 – iCD tool other buildings of interest in the area (used for replication studies D5.5)

iCIM – After this initial phase of surveying and characterizing the buildings around the demosite, the iCD tool was linked with the iSCAN tools for acquiring and processing information, and the iCIM tool for sharing and visualizing results and scenarios.

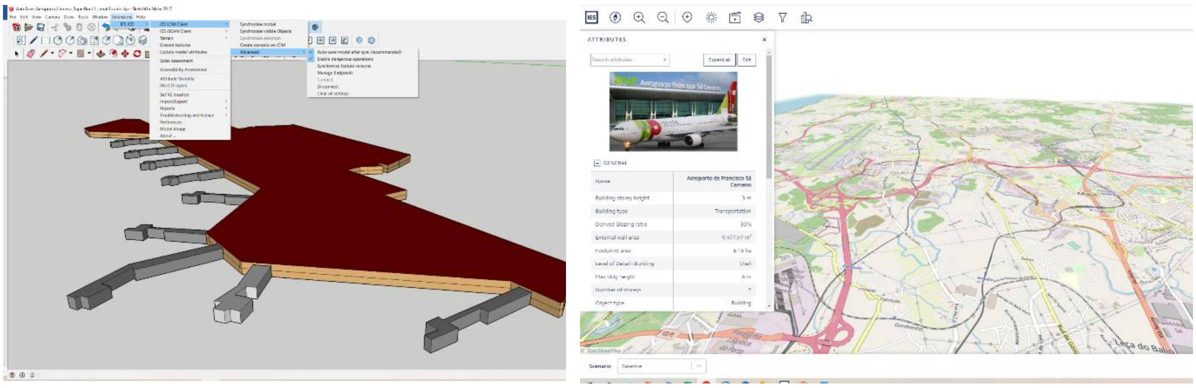

Figure 44 – Connection to iCIM and iSCAN (left). iCIM exported model (right).

After making this connection between the various modules of the So What tool, it was possible to import the 3D model previously developed in iCD to the network simulation tool, iVN.

iVN – The iVN tool also allows obtaining data from iSCAN, allowing to import hourly profiles of energy needs as well as supply and availability of resources, such as the residual heat profile.

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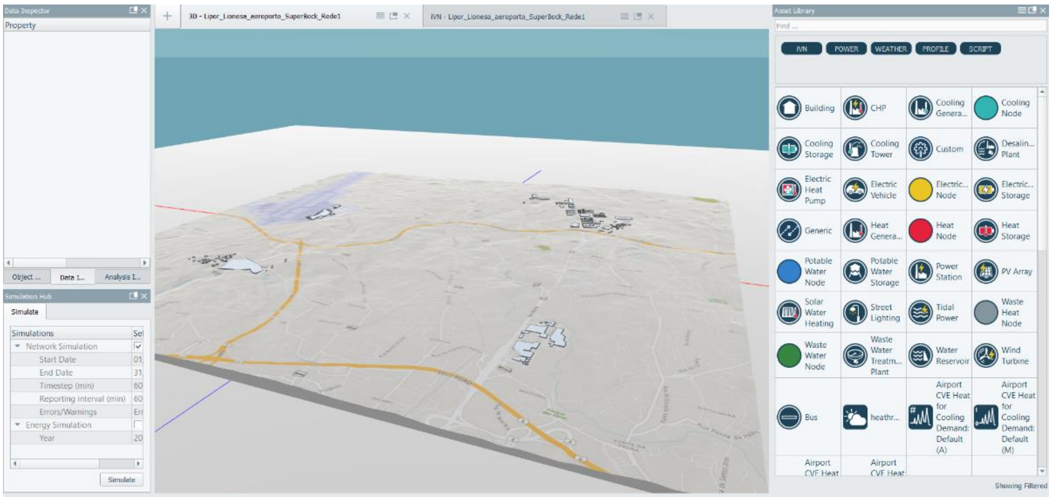

Figure 45 – iVN tool showing the imported 3D model from iCIM

The construction of the network model in iVN took place in several iterations, being necessary in an initial phase to use the different components of the network step-by-step in order to mitigate errors and inconsistencies. The figure below exemplifies one of the more than ten models tested with the iVN software using several scripts developed within the scope of this project, as well as pre-existing modules.

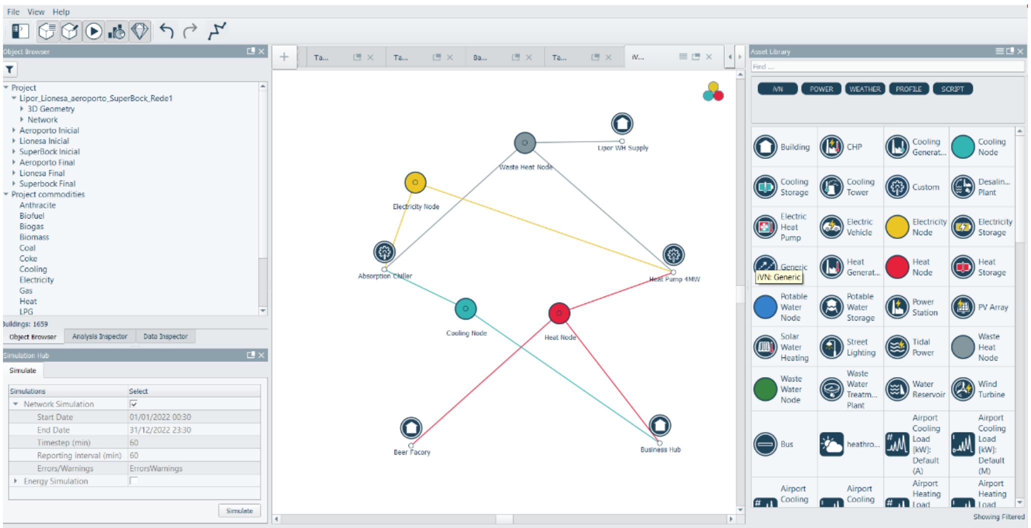

Figure 46 – Scenario modelling in iVN

Given the specificity of the Portuguese cluster case study, the iVN tool was the one that required the most effort, since the heat network modelling was the center of this case. For this, more than 10 scenarios were created and simulated in this software and several different technologies were tested for modelling waste heat technologies for both heating and cooling purposes.

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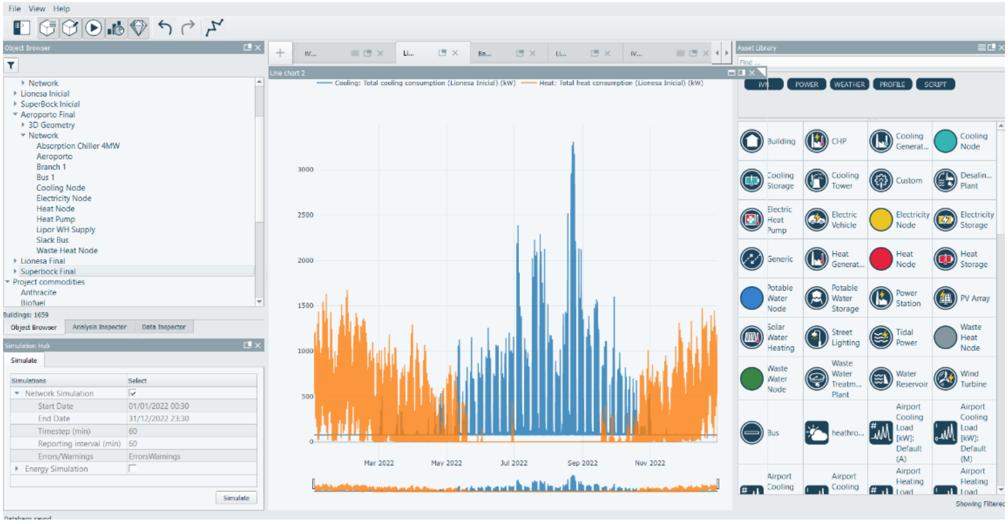

Figure 47 – Results from the simulation in iVN

The use of Python scripts was a challenge because it requires technical knowledge in terms of modelling the technology in question as well as the interpretation of the code developed for this modelling. The interaction with the partners involved in the development of these scripts proved to be fundamental to obtain results and be able to complete the modelling with an understanding of all the assumptions involved in the process.

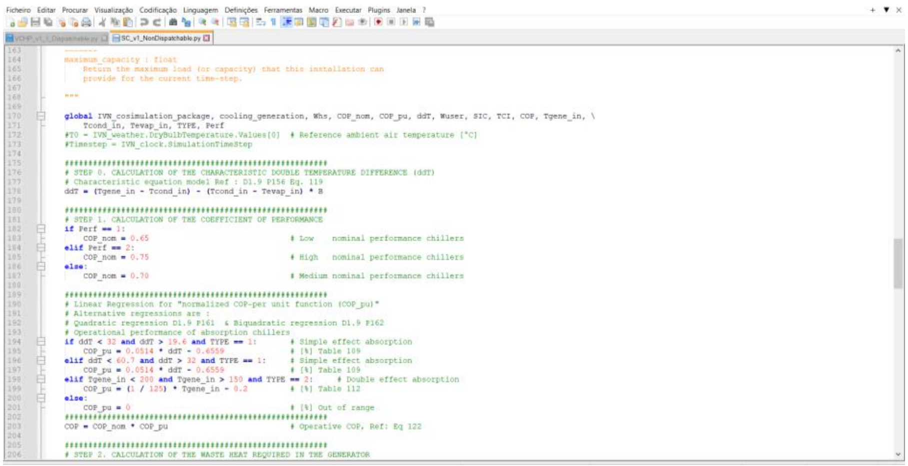

Figure 48 – Use of the Python Script for sorption chiller

Final results – *Due to the recuperation of waste heat, a potential energy reduction of 12,0 GWh/h* (referred to conventional energy) *per year can be saved. This corresponds to gross savings of 2483 tons CO_2 per year. Technical considerations: the ability to test different technologies and scenarios in a fast and intuitive way*

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2.7 UK demos

2.7.1 General description

The Materials Processing Institute is an independent not for profit research and technology organisation located in the North East of England, UK. It is a centre for innovation, development and commercialisation of technology for advanced materials, industrial decarbonisation and the circular economy.

The Institute houses a number of pilot facilities the largest of which are a 7 tonne electric arc furnace, ladle arc furnace and continuous casting machine. These facilities allow the development of new steel alloys, raw materials and steelmaking practice.

The overall energy use of the site is approximately 1400 MWh of electricity and 400 MWh of gas per year. This includes energy used by site tenants.

One of the biggest uses of gas at the Institute is natural gas used for domestic heating, i.e. heating of office and laboratory space.

2.7.2 Scenarios identified to use in the tool trial

The scenario identified for analysis at the Materials Processing Institute was to model the use of a heat pump to upgrade heat from the cooling water bulk tank on the site for use in domestic heating. A diagram of the proposed scenario is shown in figure1.

The SO WHAT tools were also be used to estimate the amount of energy required to heat the buildings to determine how the required amount of heat compares to that available from the cooling water.

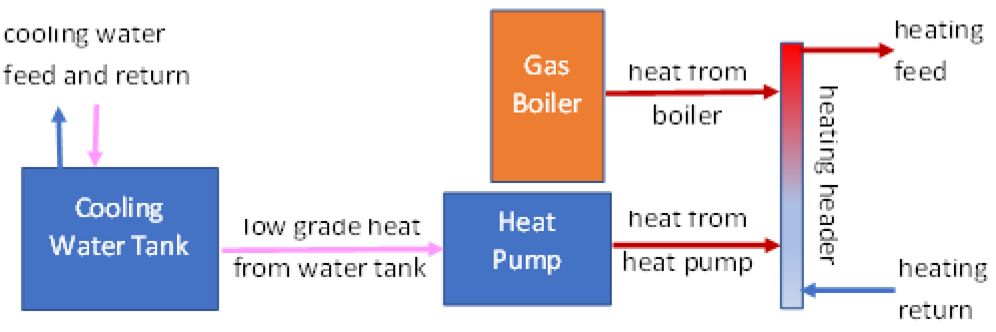

Figure 49 diagram of Materials Processing Institute heating system with proposed heat pump

2.7.3 Demos tool trial results

The SO WHAT tool was used to build rapid models of the main buildings at the Institute and to estimate the heat demand from the Blue and Green buildings as these are the two buildings heated by natural gas boilers.

The SO WHAT model estimated energy demand from the buildings every 10 minutes. This data was processed to calculate the average daily energy demand (figure 2) and compare it to the daily energy demand calculated from the metered gas use of the two buildings.

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The simulated heat load for the coldest month of the year is within 12% of the measured gas use of the Green building for the years 2018, 2019 and 2020.

The measured gas use for the Blue building is 50 to 60% higher than that simulated. The heating boilers in the Blue building are known to be close to end of life and are not working at good efficiency. This may explain the discrepancy between measured gas use and modelled demand.

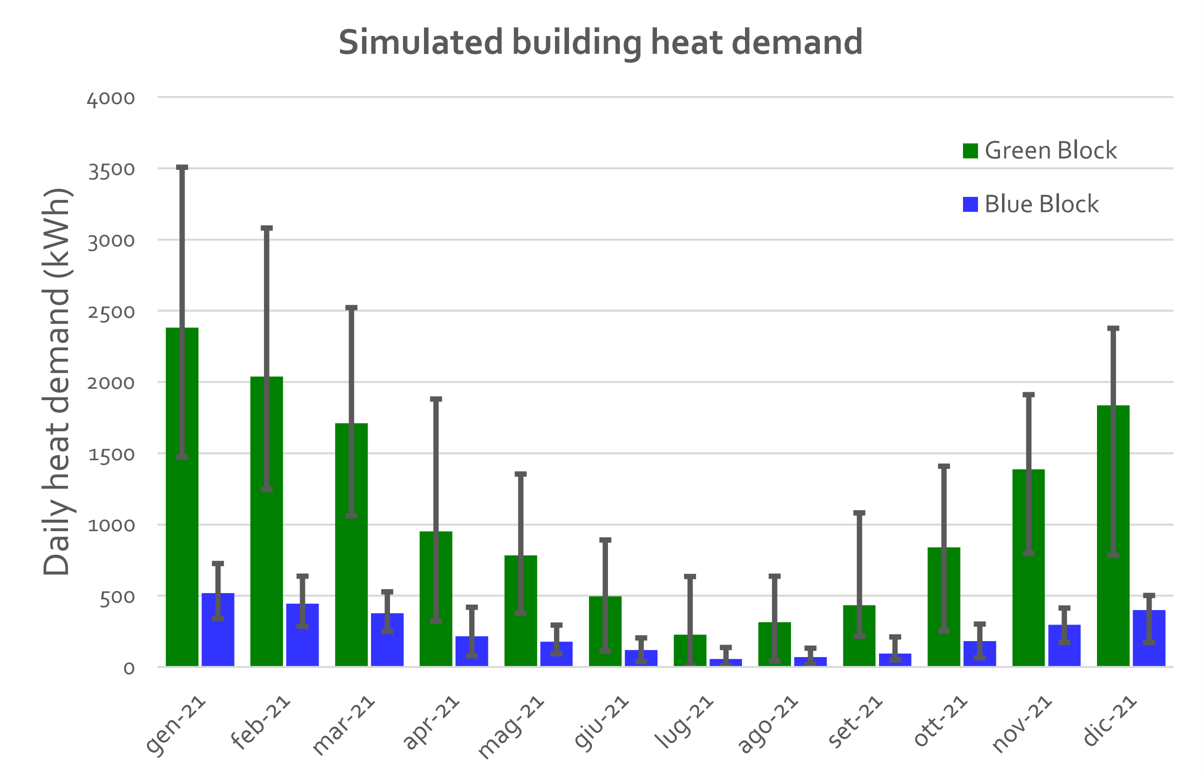

Figure 50 simulated heat demand of buildings at Materials Processing Institute

At current levels of activity there is on average one melt of steel each week in the arc furnace. There are normally 4 weeks per year when the furnace does not run due to holiday periods and shutdowns. There are approximately 8 weeks per year where domestic heating is not required as the ambient temperature is higher in summer. For assessing the potential use of waste heat we can assume that waste heat is available from the furnace and useful for approximately 40 weeks per year.

It was calculated from data that an average of 540 kWh of useful waste heat is available from the cooling water after each steel melt. If this heat is available and useful for 40 weeks per year this gives approximately 21.6 MWh of heat per year. It is anticipated that production capacity of the site may double in the next 2 years, to 2 melts per week, which would double the amount of waste heat available to 43.2 MWh.

Replication of this heat matching calculation was not possible in the SO WHAT tool due to issues with heat pump model algorithm not being able to link to the heat stored in the cooling water tank at varying temperature. To implement this scenario would require significant custom coding of the SO WHAT model.

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If a heat pump with a COP of 4 were used to upgrade this heat for domestic heating, then, based on current UK CO2e values for natural gas and electricity, use of the heat pump would save approximately 3.7 tonnes of CO2e per year.

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