H2020 Work Programme

D6.5- SO WHAT LESSONS LEARNT AND RECOMMENDATIONS
Lead Partner: CAR

Date: 30ᵗʰ November 2022

Project title			
Supporting new Opportunities for Waste Heat And cold valorisation Towards EU decarbonization			
Project acronym	SO WHAT	Start / Duration	June 2019 (42 months)
Coordinator	Rina Consulting S.p.A. – RINA-C		
Website	www.sowhatproject.eu		

Deliverable details			
Number	D6.5		
Title	SO WHAT Lessons learnt and recommendations		
Work Package	6		
Dissemination level[1]	PU = Public	PU = Public	PU = Public
Due date (M)	M42 – 30.11.2022	Submission date (M)	M42 – 30.11.2022
Deliverable responsible	Fundación CARTIF – CAR		

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[1]   PU = Public
       CO = Confidential, only for members of the consortium (including Commission Services)

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Document History			
Date	Version	Name	Changes
04/11/2022	1.0	Francisco Morentin	Initial ToC and chapters brief description
14/11/2022	2.0	Paula Serrano, Icíar Bernal	Design and preliminary version
24/11/2022	3.0	Icíar Bernal, Paula Serrano and Francisco Morentin	Review and updates from Demonstrators
30/11/2022	4.0	Icíar Bernal, Paula Serrano, Francisco Morentin	Review and final design

Supporting new Opportunities for Waste Heat And cold valorisation Towards EU decarbonization

LESSONS LEARNT

PROJECT ID

Duration: 42   42 months
Partners: 20 partners from 8 countries
                  (Belgium, Ireland, Italy, Portugal, Romania, Spain, Sweden, United Kingdom)
Coordinator: RINA-C
Call identifier: H2020-LC-SC3-EE-2018
Topic: LC-SC3-EE-6-2018-2019-2020
                  Business case for industrial waste heat/cold recovery

The following partners made up the SO WHAT consortium: RINA CONSULTING SPA, IES R&D, FUNDACION CARTIF, THE UNIVERSITY OF BIRMINGHAM, SUSTAINABLE INNOVATIONS EUROPE SL, IVL SVENSKA MILJOEINSTITUTET AB, SUSTENTEPOPEIA UNIPESSOAL LDA, ADEPORTO - AGÊNCIA DE ENERGIA DO PORTO, KELVIN SOLUTIONS, FUNDACION ASTURIANA DE LA ENERGIA, PROVINCIALE ONTWIKKELINGSMAATSCHAPPIJ ANTWERPEN,ASOCIATIA CLUSTER PENTRU PROMOVAREA AFACERILOR SPECIALIZATE IN ECOTEHNOLOGII SI SURSE ALTERNATIVE DE ENERGIE -MEDGREEN (REGIUNEA SUD-EST SI REGIUNEA BUCURESTI ILFOV), MARTINI & ROSSI SPA, SERVICO INTERMUNICIPALIZADO DE GESTAO DE RESIDUOS DO GRANDE PORTO, GOTEBORG ENERGI AB, VARBERG ENERGI AB, REGIA AUTONOMA DE DISTRIBUTIE A ENERGIEI TERMICE CONSTANTA, MATERIALS PROCESSING INSTITUTE, ELEUKON GLOBAL SL, PARCO SCIENTIFICO TECNOLOGICO PER LAMBIENTE ENVIRONMENT PARK TORINO SPA

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TABLE OF CONTENTS

1 Preface

SO WHAT aimed to develop and validate, through different sectors and countries, real industrial test cases, an integrated software for auditing industrial process, planning and simulation of waste heat and cold (WH/C) valorisation systems towards the identification of economically viable scenarios where WH/C and renewable energy sources (RES) cooperate to match local demand.

The SO WHAT tool has been built following a participatory approach involving both clusters from Spain, Portugal, Belgium, Sweden, Romania and external stakeholders since the very beginning of the development, in order to have wide, clear and structured promotion of WH/C also thanks to a robust training campaign and policy oriented dissemination actions.

SO WHAT Kick-Off Meeting, 4-5 June 2019, Dublin, Ireland.

Our consortium has worked with great efforts towards these objectives in an unbeatable environment of mutual support, trust and continuous learning, which we hope is reflected in the following pages. Enjoy reading!

Arianna Amati (RINA-C)

SO WHAT Project Coordinator

2   Introduction

2.1   Conventional and non-conventional sources of waste heat

Waste heat can be classified in to categories: **conventional** and **non-conventional** waste heat:

Conventional Waste Heat	Non-Conventional Waste Heat
It includes energy intensive industries, where waste heat is usually available, easy to identify and has a high temperature level.	It includes data centres, metro stations, buildings (e.g. hospitals, offices or shopping malls), waste heat from power-to-gas processes, and sewage channels and waste water treatment plants

The SO WHAT project is focused on this type of waste heat, and it analyses several industrial sectors, including the following:

This type of waste heat has been further analysed in several projects, such as in the ReuseHeat Project.

- Ion & Steel
- Non-ferrous metals
- Non-metalic mineral
- Chemical
- Food & beverage
- Wood & Textile
- Paper, pulp and print
- Other

ReuseHeat Project is focused on advanced, modular and replicable systems enabling the recovery and reuse of excess heat available at the urban level.

2.2   Waste Heat Global Figures

The yearly potential for several countries worldwide [1] is shown in the following figure:
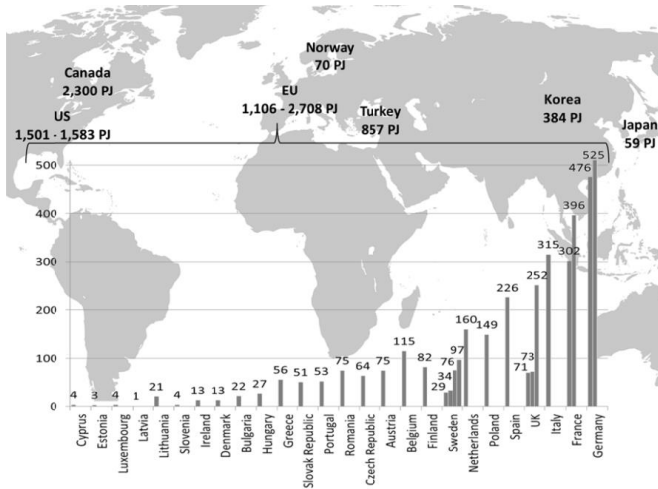
Analysing the data for these countries:

- ◯ In general, the more energy consumed by the country and/or by the industry, the more industrial waste heat (IWH) potential.
- ◯ Most of the countries have a similar percentage of IWH potential from Energy Intensive Industries: the average share of IWH coming from Energy Intensive Industries on the Energy Consumed by the Country is 73.6%.

IWH per Energy Consumed by the Industry (%)
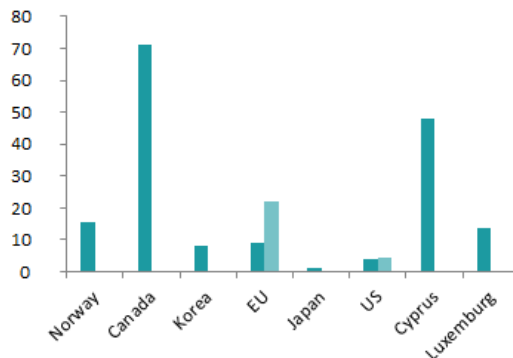
2.3   Estimation of Waste Heat Potential across the EU

Several studies estimate that between 20 and 50% of the industry energy consumption ends as waste heat. And between 18 and 30% of this waste heat could be used [2].

In the SO WHAT project, two methods have been used to calculate the waste heat potential in the EU:

Method 1: a top down calculation that estimates heat use and waste heat from national and industry studies.

Method 2: a bottom up calculation that estimates surplus energy output from industries based on the technologies they employ.

The calculated recoverable waste potential is 187 TWh per year for method 1 and 167 TWh per year for method 2:

Method 1   187 TWh/year

Method 2   167 TWh/year

The following figure shows the estimated recoverable waste heat potential per industry for the EU in 2017:

Waste Heat Potetnial per Industry for EU 2017
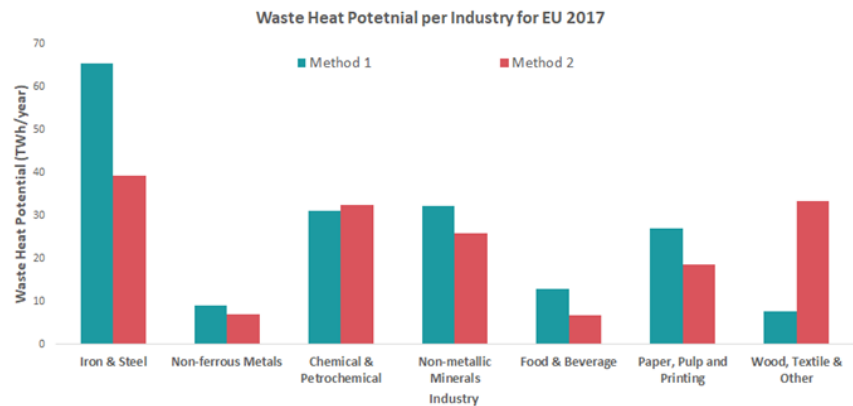
More detailed information about WH/C potential in the EU can be found in the Deliverable 1.2: First Release of SO WHAT industrial sectors WH/C recovery potential.

2.4 Waste Heat Recovery definition

Waste heat recovery consists of the capture and reuse of the waste heat. All the thermal and mechanical processes always produce waste heat, and the idea behind its recovery is to try to recuperate maximum amounts of heat in the plant and to reuse it.

The mechanism to recover the unused heat depends on the temperature of the waste heat fluids and the economics involved. As long as its recovery and use become technically and economically feasible, the waste heat may represent an important source of possible energy.
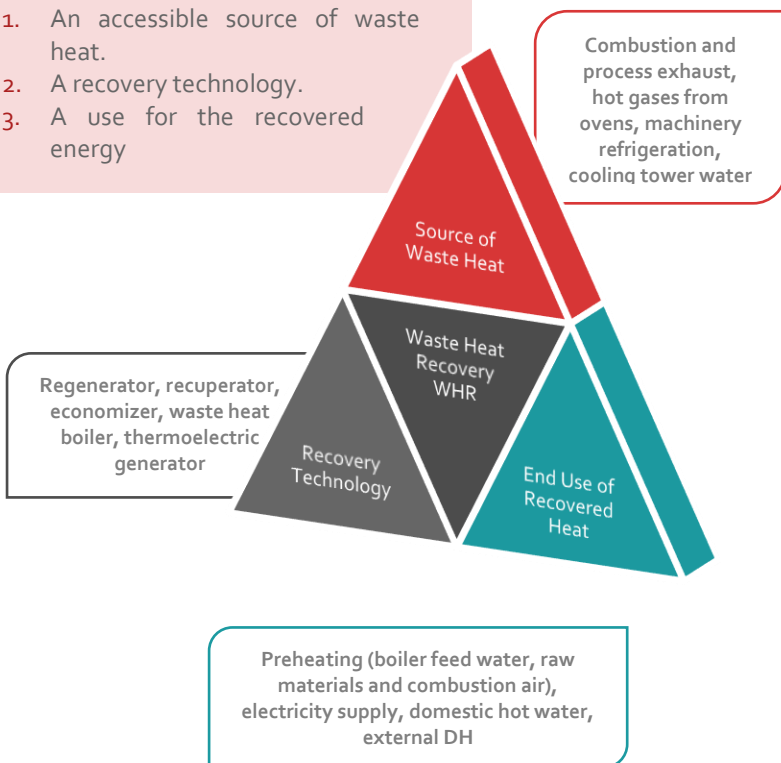
As described in the Deliverable 2.1: Report on end-users' current status, practices and needs in waste H/C recovery and RES integration, the essential components which are necessary for waste heat recovery are namely:

1. An accessible source of waste heat.
2. A recovery technology.
3. A use for the recovered energy

Combustion and process exhaust, hot gases from ovens, machinery refrigeration, cooling tower water

Source of Waste Heat

Waste Heat Recovery WHR

Regenerator, recuperator, economizer, waste heat boiler, thermoelectric generator

Recovery Technology

End Use of Recovered Heat

Preheating (boiler feed water, raw materials and combustion air), electricity supply, domestic hot water, external DH

2.5   Energy Cycle and Waste Heat sources

Waste heat is generated along the industrial processes as a by-product in different forms like: combustion gases released into the atmosphere, heated water discharged into the environment, heated products at the industrial processes output and also heat transfer through the hot surfaces of the factories equipment and machinery.

The sources of residual heat differ among themselves in the physical state (mainly fluids or gaseous), the temperature ranges, their type of occurrence (constant or periodic) and the power thermal available.

Three stages are considered within the **energy cycle**:

Energy conversion	→	**Energy distribution**	→	**Energy use**
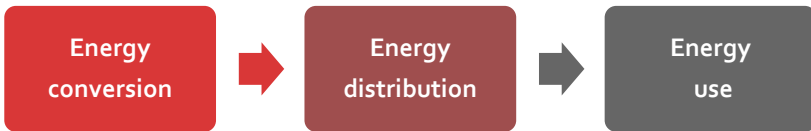
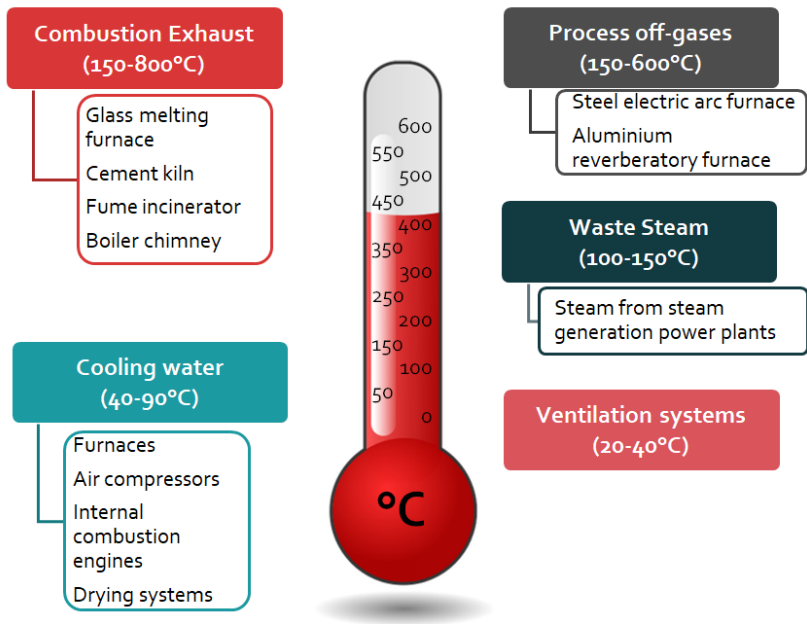Where the **possible sources for waste heat** are:

- ○ <u>Conversion losses</u>, such as all the possible waste heat that is produced in steam boilers, air compressors or water chillers.
- ○ <u>End-user losses</u>, such as all the different types of waste heat that are produced in manufacturing furnaces.

Energy cycle and waste heat sources
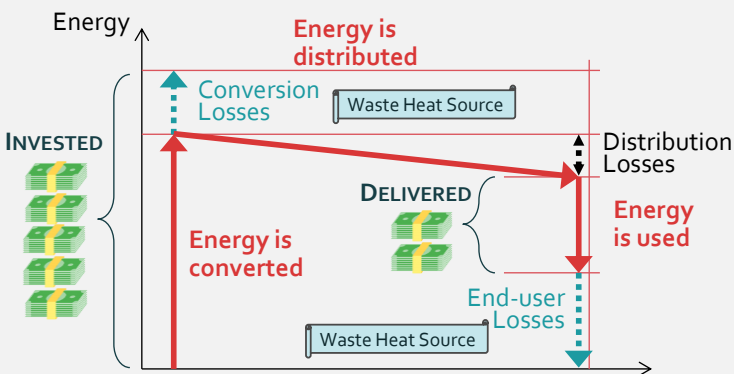
Most waste heat recovery devices transfer heat from a higher temperature effluent stream to another lower temperature inlet stream. It is possible both to increase the temperature of the inlet flow and also to transform the state of the inlet flow from liquid to steam, as in a boiler. These devices can be broadly named as heat exchangers. On the other hand, waste heat can be used by passing hot gases or stream through a turbine to generate electricity. Therefore, as a general rule, it can be considered that the "utility" of a waste heat will be determined by its temperature; the higher its temperature value, the higher its quality value.

Combustion Exhaust (150-800°C)
- Glass melting furnace
- Cement kiln
- Fume incinerator
- Boiler chimney

Cooling water (40-90°C)
- Furnaces
- Air compressors
- Internal combustion engines
- Drying systems

Process off-gases (150-600°C)
- Steel electric arc furnace
- Aluminium reverberatory furnace

Waste Steam (100-150°C)
- Steam from steam generation power plants

Ventilation systems (20-40°C)

Deliverable 2.1: Report on end-users' current status, practices and needs in waste H/C recovery and RES integration
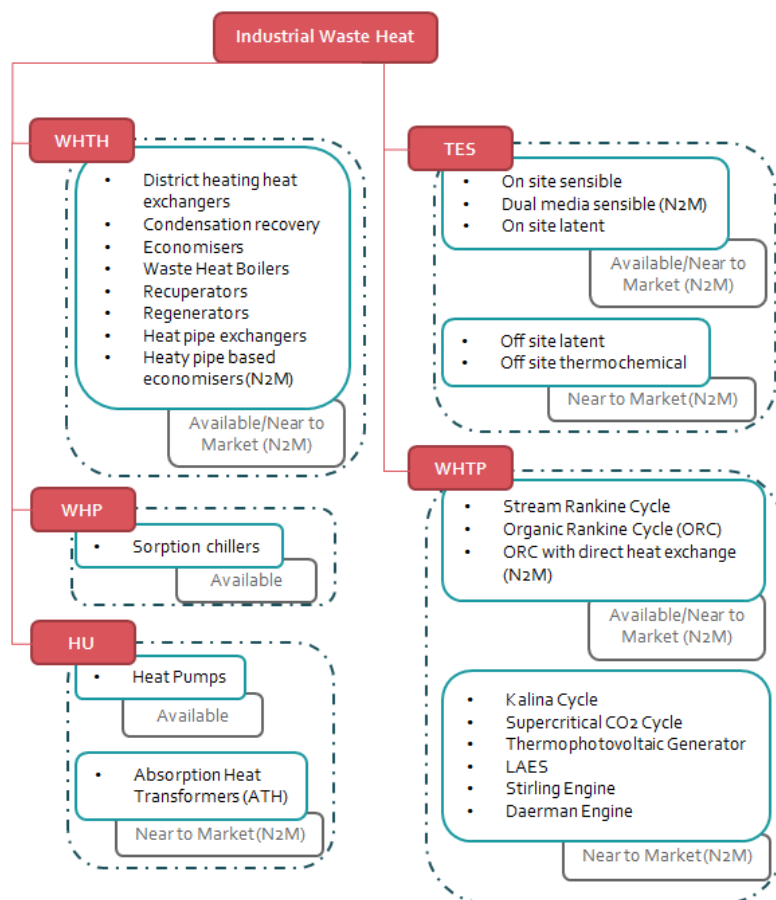
2.6   Recovery Technologies

The following five classes of WH/C recovery technologies have been identified in order to cover all the WH/C recovery options currently technically feasible:

1. Waste Heat-to-Heat (WHTH) technologies
2. Thermal Energy Storage (TES) technologies
3. Waste Heat-to-Cold (WHTC) technologies
4. Waste Heat-to-Power (WHTP) technologies
5. Heat Upgrade (HU) technologies

◯ **Waste Heat-to-Heat (WHTH):** Class of passive WH/C recovery technologies designated to transfer a waste heat or waste cold stream to a lower temperature sink so that it can be reutilized by heat. No conversion or upgrade of the WH/C stream takes place.

◯ **Thermal Energy Storage (TES):** Class of passive technologies designated to store thermal energy (heat and cold options available) for subsequent use in time, bridging mismatch between thermal energy availability and thermal energy demand. This is a class of enabling technologies. TES can capture waste heat or waste cold for its subsequent reutilization but more advanced uses are possible by integrating TES with other WH/C recovery technologies.

◯ **Waste Heat-to-Cold (WHTC):** Class of technologies designated to produce cooling from WH. This is a class of active technologies which transforms the original WH stream. The WH stream is used to provide the energy necessary to drive the cooling process. The latter typically takes advantage of sorption phenomena involving a sorbent-sorbate pair.

◯ **Waste Heat-to-Power (WHTP):** Class of technology designated to produce an electrical power output from WH. This is a class of active technologies which transform the nature of the original WH stream. More specifically, the WH stream is used to drive an energy conversion process. The latter can be of different nature; options include power cycles and thermos-electric materials, the suitability of which largely depends on the size of the WH sources as well as the WH temperature.

○ **Heat Upgrade (HU):** Class of technology designated to upgrade the original WH source. This means lifting the temperature at which WH is originally available. This is an active technology which alters the conditions at which WH is available but do not transform it into a different form of energy. In the most common instances HU requires an expenditure of electrical energy to uplift WH temperature, although HU technologies purely driven by heat are available. In such instance a cooling effect is also provided as by product.

The next diagram illustrates the classes of WH/C recovery technologies, as well as the specific technologies within each class.

Industrial Waste Heat

WHTH
- District heating heat exchangers
- Condensation recovery
- Economisers
- Waste Heat Boilers
- Recuperators
- Regenerators
- Heat pipe exchangers
- Heaty pipe based economisers (N2M)

Available/Near to Market (N2M)

TES
- On site sensible
- Dual media sensible (N2M)
- On site latent

Available/Near to Market (N2M)

- Off site latent
- Off site thermochemical

Near to Market (N2M)

WHTP
- Stream Rankine Cycle
- Organic Rankine Cycle (ORC)
- ORC with direct heat exchange (N2M)

Available/Near to Market (N2M)

- Kalina Cycle
- Supercritical CO2 Cycle
- Thermophotovoltaic Generator
- LAES
- Stirling Engine
- Daerman Engine

Near to Market (N2M)

WHP
- Sorption chillers

Available

HU
- Heat Pumps

Available

- Absorption Heat Transformers (ATH)

Near to Market (N2M)

This concept has been further described in *Deliverable 1.6: Report on H/C recovery/storage technologies and renewable technologies.*

2.7   End Use of Waste Heat

As described in the Deliverable 2.1: Report on end-users' current status, practices and needs in waste H/C recovery and RES integration, the final use of recovered industrial heat can be classified in two categories: **Internal use** and **external use**.
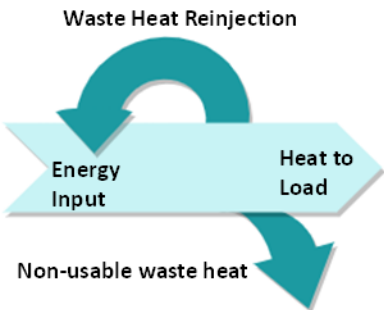
> **Internal use**
>
> The industrial facility where the waste heat is recovered will transform and consume it.

The internal use can also be split in two ways of WH recovery:

Direct Recovery to the original process

Waste Heat Reinjection

It would include the installation of economizers in steam boilers or heat recovery exchangers to preheat the intake air to the furnace burners.

Recovery with transfer to a second process
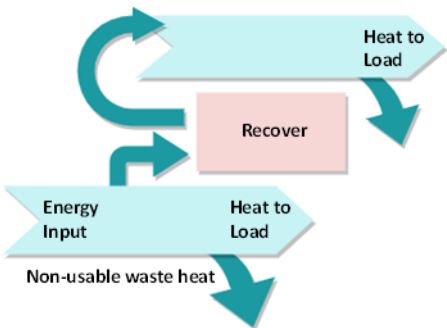
It would include heat recovery in the compressors as well as any other heat recovery to be transformed into another form of energy such as electricity or cooling.

17

The waste heat can be used by third parties such as administrative, commercial or residential buildings or even other industries. The main challenge is the adjustment or synchronization of the potential waste heat and the demand of third parties.
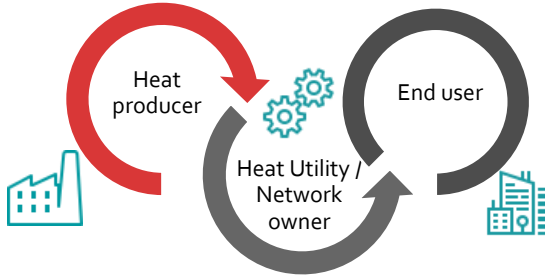
This scenario usually appears in those processes of Energy Intensive Industries where huge quantities of high-temperature thermal energy are required and therefore the amount of waste heat exceeds the needs of this type of heat of the factory itself.

In the external use case there is the possibility of introducing intermediate actors (ESCOs) between heat producers and end users of the recovered waste heat.
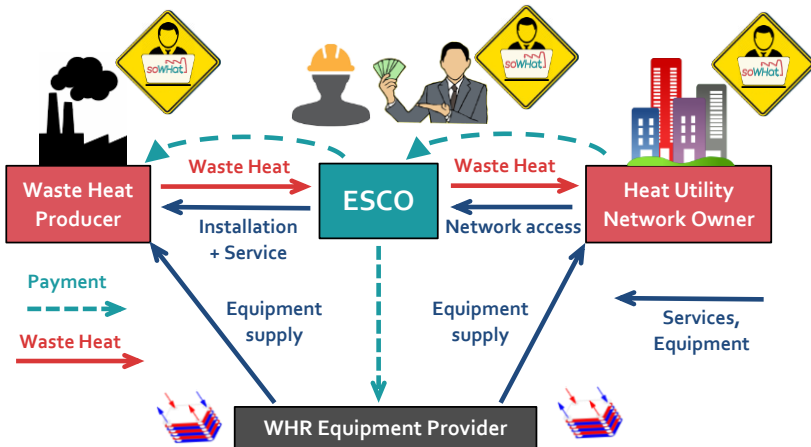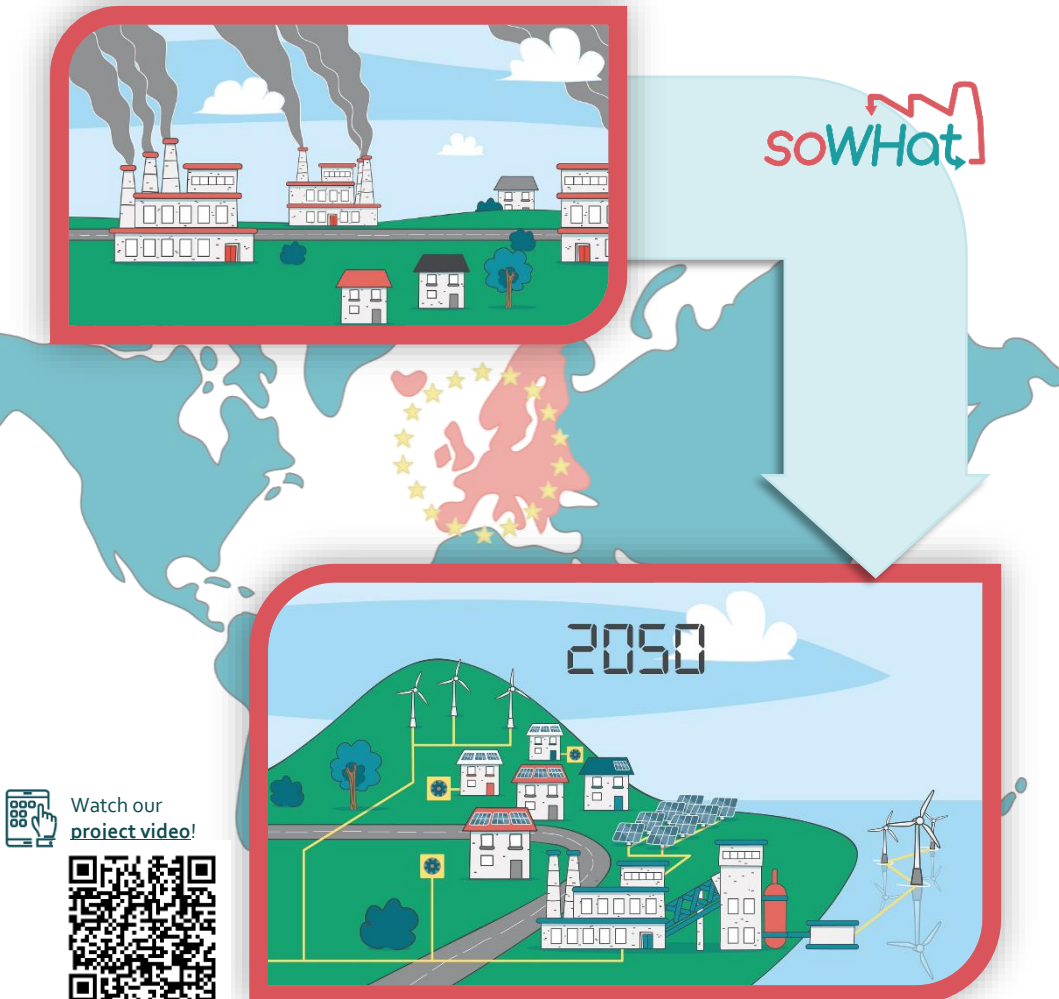
3 SO WHAT Project

3.1 Objectives and Missions

SO WHAT aims to develop and demonstrate an integrated software which will support industries and energy utilities in selecting, simulating and comparing alternative **Waste Heat** and **Waste Cold** (WH/C) exploitation technologies that could cost-effectively balance the local forecasted H&C demand also via renewable energy sources (**RES**) integration.
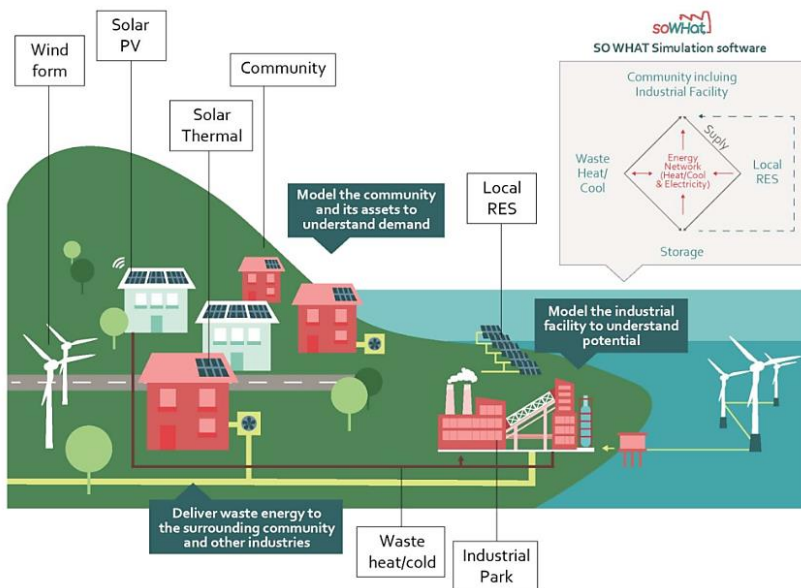
Watch our
project video!

The SO WHAT integrated tool will be developed to support *industries* and *energy utilities* in different **missions**:

 Auditing the industrial process to locate potential WH/C

 Mapping potential of locally available RES sources to be integrated with WH/C

 Mapping the local forecasted demand for heating and cooling

 Define and *simulate* alternative cost-effective scenarios based on WH/C technologies and RES introduction

 Evaluate the impacts (economic, energetic and environmental) against the current situation, both at industrial and local level

 Promoting innovative contractual arrangements and financing models to guarantee economically viable solutions and less risky investments

To do so *SO WHAT* will capitalize already existing tool and knowledge from previous research experiences.

3.3   Demosites

ENCE Pulp & Mill

Located in **Navia**, it is the most efficient pulp & Mill on the eucalyptus market in Europe, with a production **of 950,000 ton/y** of pulp obtained from their raw material. Additionally it has a power generation capacity of **220 MW** with biomass.

Göteborg Energi's multiple WH and DH&CN

In **Göteborg,** GOTE covers **90%** of city demand: 80% waste heat, incineration and electricity production, 15% biofuels and 5% fossil. Currently, with **130 MW** installed power, they reduce **25,000 tons** of CO_2 annually.

IMERYS carbon black and graphite manufacturing

Placed in **Willebroek**, during its process of Carbon Black, a mixture of H_2 and CO is formed, IMERYS generates a max total of **30MW** of waste heat. With the project this waste has stream will be valorised

ISVAG Waste to Energy Plant

ISVAG, in **Antwerp**, is a new waste-to-energy plant used to maximise energy efficiency by additionally recovering heat for a DHN. Incineration of the wastes takes place in a grate furnace.

LIPOR Waste-to-Energy Plant

Located in **Maia,** this WtE Plant treats **380,000 tons** of municipal waste per year.
It is composed by high temperature gases that go through an energy recovery boiler to produce steam for power production.

SO WHAT Project - Demosites

Martini & Rossi's Distillery

Located in **Pessione,** Martini, sparkling wines and liquors are produced. In the plant it is produced a large amount of low temperature waste heat (**15GWh/year**) which is cooled in evaporative condensers

MPI Steel Industry Research Pilot Plant

Materials Processing Institute in **Middlesbrough**, are specialized in challenging processes involving high T° (**~1600ºC**), hostile environments and high specification materials. They generate **large quantities** of heat at all stages in the process.

Termoficare Constanta SRL DHN

Termoficare is the District Heating Company of the municipality of **Constanta**, Romania, ensuring **70%** of the urban heating demand of **170,000 inhabitants**.

UMICORE Rare Material recycling and production centre

UMICORE, in **Olen**, is a global player in materials technology that develops technologies and produces/recycles materials. It is close to the current heat users, which are all supplied with two turbines (**12.8 MWe**) and multiple steam boilers

Varberg Energi Pulp and Mill WH and DH&CN

Located in **Varberg**, this DH&CN identified waste heat from a pulp mill situated about 20 km from the city.

Waste heat is used as the main source for the network **(85%)** apart from another sources like wood chips, biogas and bio oil.

4 SO WHAT Tool

4.1   Tool overview and functionalities

Why is the project called SO WHAT? The idea was creating an answer providing tool for those that could say *I have lots of waste heat and cooling*, SO WHAT can I do with it right now?

The SO WHAT tool is made up from a number of different software, some of which were wholly or partially born from previously funded EU funded projects, and some which were already existing commercially and need to be enhanced for the purposes of SO WHAT. The challenge for the development phase of the project is to ensure the integration of these software so that the end user experiences SO WHAT as a single platform with a smooth and efficient workflow.

The first step was the clear identification of the SO WHAT tool users. The final decision returned three different possible users with their different specific ways to use the tool

<u>INDUSTRY</u> – *Operation/Energy Manage of Industrial Facilities will use the tool to understand the potential to:*

- ✓ Recover waste Heat/Cooling and use within the factory
- ✓ How waste heat can be used to supplement Renewable Energy systems
- ✓ Recover waste Heat/Cooling and supply it local community
- ✓ Where waste Heat/Cooling could be purchased from in the local community

<u>Municipality / Regional Energy Agencies / Public Authorities</u> will use the tool to understand:

- ✓ Supply areas with waste Heat/Cooling
- ✓ Where there is demand for waste Heat/Cooling
- ✓ Areas for integrating waste Heat/Cooling with Renewable Energy technologies
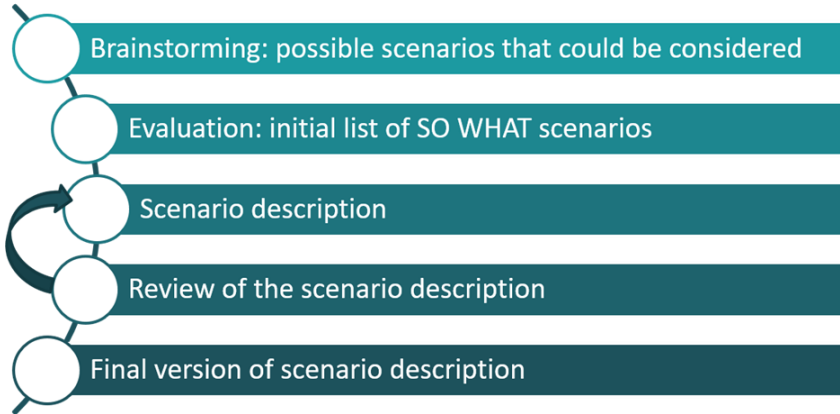
<u>ESCO's / DH Operators</u> will use the tool to:

- ✓ Recognize which solutions relating to waste Heat/Cooling in a community would best suit the business models they operate under
- ✓ Assess the costs/risks of any investments required

Scenario-Based Analysis of Software Architecture

A 'scenario' is defined as a potential future state that a user of the software may wish to simulate in order to understand how to recover waste heat/cooling and how best to use this either in their own facility or in the wider community. Next figure summarises the process used to identify the list of scenarios to be considered concerning the SO WHAT tool.

- Brainstorming: possible scenarios that could be considered
- Evaluation: initial list of SO WHAT scenarios
- Scenario description
- Review of the scenario description
- Final version of scenario description

The methodology for the hierarchy of scenarios was designed in order to guide the different users to view and choose the most appropriate technologies and combinations that suite their context and requirements. It has been used in the development of the SO WHAT tool whereby the scenarios available to choose from will be dependent on the type of user and the version (Free or Commercial) they are using. The methodology is numbered sequentially, however there are many different sub scenarios grouped under one main theme and a number of them will only apply to specific user types.

The methodology is based on the principles of reducing waste as much as possible, before recovering waste and reusing in the most efficient ways. It is summarized in 6 stages. And associated to them there were 34 Scenarios considered and developed.

1 **BASELINE WH/C POTENTIAL OF FACILITY COMMUNITY**

- WH/C potential of individual facility
- Identify potential WH/C community
- Identify potential WH/C sources in my community

2 **REDUCE ENERGY USE AND ELIMINATE WH/C**

- Improve the energy efficiency of my building
- Eliminate WH/C from my processes/ services where possible

3 **RECOVER AND REUSE WH/C AT A FACTORY LEVEL**

- Recover WH/C to be reused in the same process in my facility
- Identify how to recover WH/C to be re-used in a different process in my facility
  → 16 Sub Scenarios (additional)

4 **RECOVER AND REUSE WH/C TO PROVIDE POWER AT A FACTORY LEVEL**

- Recover WH/C to generate power for my facility
- Add solar panels/solar thermal collectors on my site
- Maximise the use of RES I have installed
- Optimal mix of RES installations at my site to reduce fossil fuel use

5 **RECOVER AND REUSE WH/C AT A COMMUNITY LEVEL**

- Match local potential supply of WH/C with local demand
- Recover WH/C from the site and supply into the DHN
- Recover WH/C from the site and transport it for use in other buildings without need of a DHN or pipes
- Recover WH/C from industry and store it to be used at a later date
- Conduct a cost benefit analysis of expanding a DH&CN to connect to newly identified WH/C sources
- Conduct a cost benefit analysis of a new DH&CN

6 **USE WH/C TO GENERATE POWER TO SUPPLY BUILDINGS OF THE GRID**

- Power generation through conversion of WH for other buildings
- Recovery of industrial WH for electricity production (to be mainly sold to the grid)

More detailed information about the complete list and detailed definition of the Scenarios considered can be found in the <u>Deliverable 2.6 Scenario Definition</u>.

It is important to remember that two clearly differentiated versions of the SO WHAT tool we considered from the very beginning of the project: one is a free tool that is available online through the SO WHAT project website. And the other tool is much more advanced that we intend to release commercially after the project.

Both tools have similar aim and main objective: to help and enable people to understand and assess the waste heat and waste cooling potential that they might have in their community or in their own industrial facility.

Although some of the functionalities will be obviously restricted to only the advanced (and commercial) version, both versions will have the same online workflow.

In both cases (free and advanced tool) the workflow and therefore the possible tool functionalities are organized somehow around these three steps:

1st) Waste heat baseline

The first step is always defining the baseline of the industry and/or the community. This baseline refers to energy supply, demand and possible waste heat. And the aim is enabling easy data collection to understand the current situation.

2nd) Simulation of Technologies and Scenarios

The second step is the related with the simulation of technologies and scenarios for waste heat recovery options and also for the possible integration of renewable sources.

3rd) Reporting & Decision Support

And the third and final step is about allowing decision support and analysis for a variety of different users. Including as well business models and financial aspects.

Integrated SO WHAT Tool – Supported By Online Workflow

Baseline Waste Heat/Cooling Industry/Community	Simulation of Technologies & Scenarios	Reporting & Decision Support
Minimal Data Collection via Energy Asset Audit Portal ★	Methodology for scenario & technology selection ★★	KPIs to suit user focus (financial, energy, ☆
Industrial energy flow and waste H/C baseline ★★	Modelling of technologies to recover and reuse waste H/C ☆★	Compare scenarios to optimise solutions ★
Community heat & power supply baseline ★	Modelling of ways to reuse waste H/C ★	Business Model & Energy Performance Contracting ☆
Community heat & power demand baseline ★★	Modelling of how to integrate waste H/C ★	KPI Panel & Dashboard for Results Visualisation to suit ★
3D View of Individual site or Community ★	Balance local forecasted H/C demand with supply ★	Automated M&V software to allow ongoing reporting ★

☆ Online free version (partially)   ★ Online free version (fully)   ★ Advanced commercial version

4.2 SO WHAT free tool

The online free version is intended to engage the users and present some initial results. It should be used as an initial guide only in order to help the user to understand the estimated potential waste heat/cooling that the considered site may be producing and how to recover and re-use this.

This is not supposed to be the final sort of piece of work that the user would do on it. It is just to allow to do a quick 30-minutes sort of overview to provide a possible answer for the some of the next questions:

- ☞ Is there something worth here?
- ☞ Should we go further with this?
- ☞ Can I take this to my boss and say give some resources to now do a much more detailed assessment?

The user interface consists of 6 consecutive steps where the user will be asked to introduce or select the minimum information. Each step will also provide intermediate results like estimated waste heat potential in terms of energy and temperature values.

The tool contains 35 different waste heat and cold recovery technologies that have been mapped to different temperatures and different industries. Also the market maturity of different technologies is considered. The project has modelled not only technologies that are easily available across different countries in the market, but also ones that are just coming to market or even in development phases

IMPORTANT: Every internal calculation is based on different academic references and sources. Clicking on the ⓘ icons will show the user the used references and in case these references are the own SO WHAT deliverables, it will allow the user to directly download them.
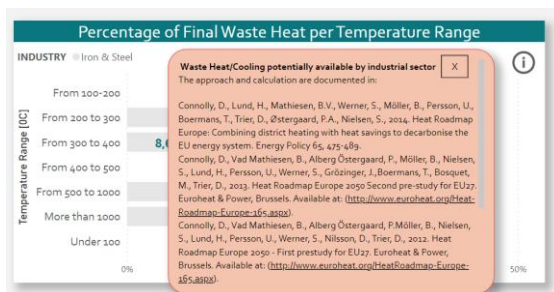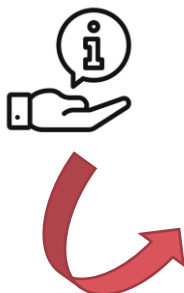
STEP 1   USER INPUTS

All the users need to initially introduce is their country, the main fossil fuel that it is used on their site, their industry type and the overall energy consumption of that particular site.

STEP 2   WASTE HEAT POTENTIAL (GLOBAL)
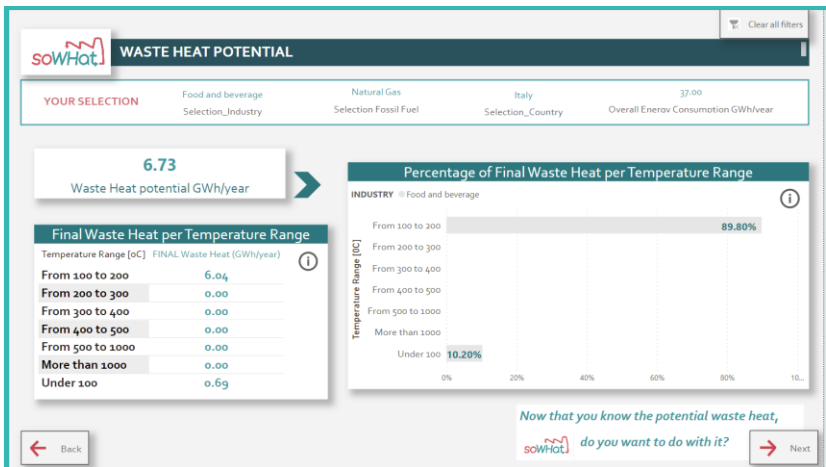
Based on previous value the tool indicates the waste heat potential. And it is also split by different temperatures grades in both total amount and percentage.

STEP 3 — TECHNOLOGIES TO RECOVER WASTE HEAT

In this step the user selects the temperature range of interest and once selected the tool indicates the possible waste heat recovery technologies suitable for this range. Maturity of possible technologies is also indicated.

STEP 4 — WASTE HEAT RECOVERY POTENTIAL (SPECIFIC)

According to the selected technologies of the previous step, the tool indicates the values of recovered heat in terms of energy and temperature.

TECHNLOGIES RISK ASSESMENT

Next a quick risk assessment for the particular industry is performed. The user has to indicate the possible likelihood of each risk while the impact is already pre-assigned. Final results are graphically presented.

STEP 6   ECONOMIC KEY PERFORMANCE INDICATORS

Finally, a simple financial analysis is presented for quick obtaining the payback, internal rate of return or net present value under different values of costs and investment scenarios, discount rates and over time values.

SO WHAT Tool – SO WHAT free tool

4.3 SO WHAT Advance Tool

Once the user has gone through this quick assessment for free at the SO WHAT project website. Then the user would ideally come the SO WHAT consultants and say: OK, I think there is something to out here and I would like to look at this further. And that is where the trained user would start using the more advanced tool.

As explained in the introduction the Advanced SO WHAT Tool is made from different pieces of software and it is though as a consultancy tool for expert users previously trained in the use of the advanced tool. Depending on the specific use case considered the workflow will change. Obviously is not the same an internal waste heat recovery than an external one. And the different steps for data input, model simulations and results analysis will be different. But in any case, we can consider the next steps:

- ✓ Use case identification in terms of data availability
- ✓ Data collection and processing, mapping and rough-cut profiling
- ✓ Manufacturing process component modelling
- ✓ Waste heat resources time aspects assessment
- ✓ Overall heat resources (sources and sinks) assessment
- ✓ Energy and heat demand 3D modelling
- ✓ Energy Supply Networks
- ✓ Online dashboards for analysis and results
    - o 3D model visualisation
    - o KPI visualisation
    - o Different Scenarios Energy comparisons
    - o CO_2 comparisons
    - o Financial Results Analysis
    - o Risk analysis
    - o Business Model Guidance

Use case identification in terms of data availability

In the advanced tool data requirements are larger in terms of quantity, quality and diversity. Some industries are highly monitored including sub-metering of all their processes or components, but other companies only have partial sub-metering or in the worst scenario they might only have the monthly utility bills.

Data collection is actually a key issue and a key barrier to the understanding of what can be done with the waste heat and cold. The first step for the user is determining the data available and decide to which of the considered 5 data use cases the situation corresponds

Five standard data use cases (1 to 5, being 1 the less complete and 5 the most complete in terms of available data) have been considered.		Data use case number				
		1	2	3	4	5
Data type available	Utility bill data	✓		✓		✓
	Partial sub-metering time series		✓	✓		
	Detailed sub-metering time series				✓	✓
Minimum additional information required	Description of processes and services (e.g. diagrams)	✓	✓	✓	✓	✓
	Description of process/service inputs and outputs (e.g. PFDs)	✓	✓	✓	✓	✓
	High-level information on production calendar, operation schedules	✓	✓	✓		
	Information on what inputs/outputs the sub-metering relates to		✓	✓	✓	✓
Tool solution	Disaggregated rough-cut profiles (from utility bills or sub-metering)	✓	✓	✓		
	Expressions required to derive energy flow profiles	✓	✓	✓	✓	✓
	VE/iCD (detailed) model may be required to simulate flow profiles	✓	✓	✓		
	Metered data uploaded to data processing platform		✓	✓	✓	✓

Data collection and processing, mapping and rough-cut profiling

In this step data from utility bills is mapped to meter energy sources, end-use, process and product, which is essential for future data processing and syncing stages

Rough-cut profiling allows for increasing the time resolution of monthly utility bill or sub-metered data up to hourly energy consumption or production profiles, as required by the manufacturing module. The user will be requested to introduce the scheduled description of the main processes
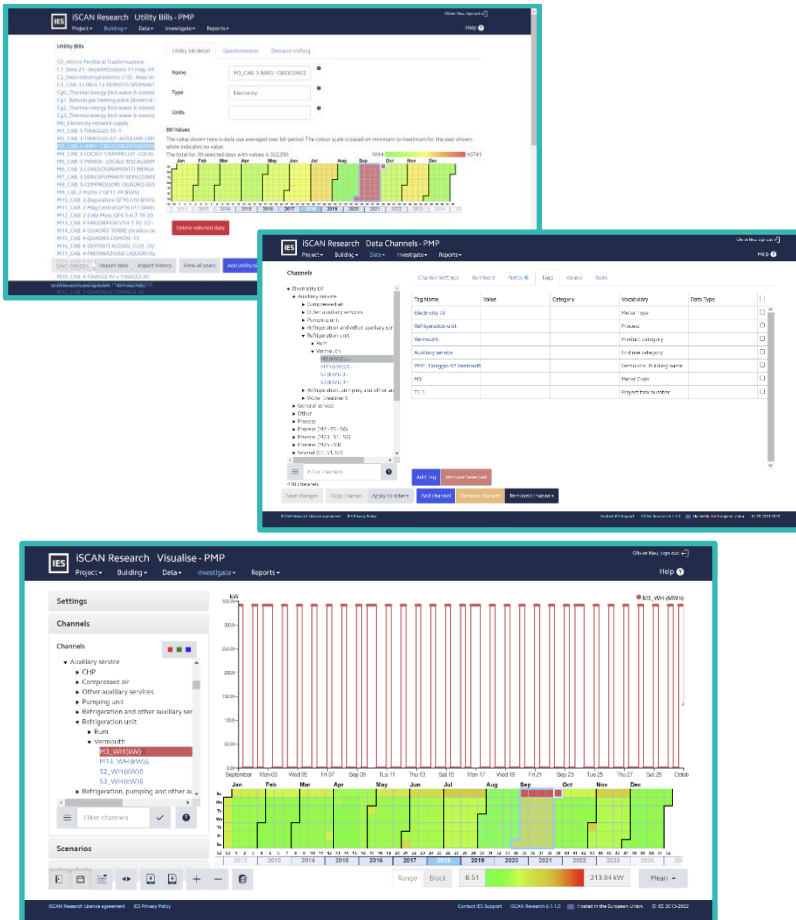
Manufacturing process component modelling

The tool allows to create a factory model including the factory building and also the different components and systems involved in the manufacturing processes. These models can be detailed 3D models of the physical systems or can be reduced to single cubes. In any case, to these components is possible to associate specific time series data of energy and heat demand as well as waste heat generation.
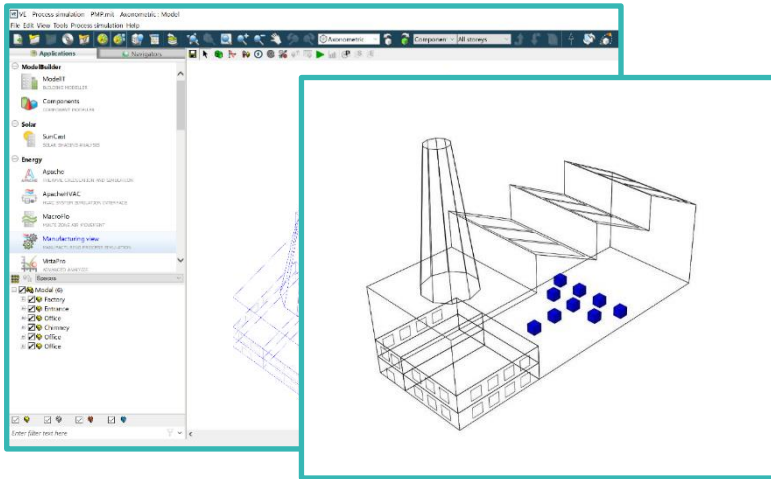
The models can be adjusted for weather conditions and for the HVAC systems which can be relevant in terms of thermal energy flows. Additionally, CHP systems or renewable energy systems (PV, solar-thermal, wind turbines) can also be included in the model
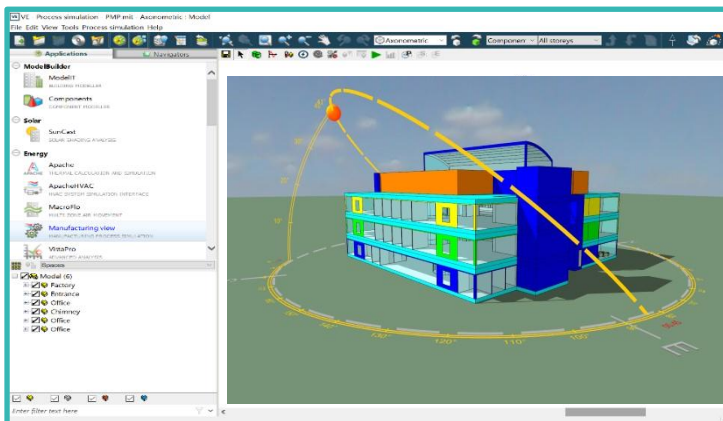
Waste heat resources time aspects assessment

At the end of the data collection exercise the tool is capable to provide several visualisations of the assessed waste heat and cooling resources.

☞ **The tool can reach up to hourly time resolution !!**

Overall heat resources (sources and sinks) assessment

It is also possible the visualisation of assessed waste heat/cooling resources through the generation of an energy Sankey diagram that shows how the energy is used in the different processes of the facility. What could be called the sources of the sinks of energy and waste heat.
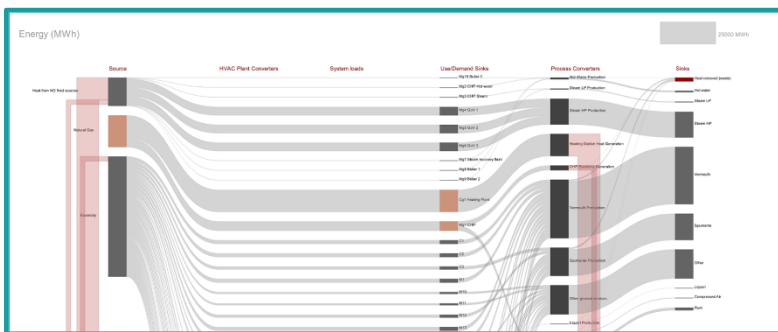
Energy and heat demand 3D modelling

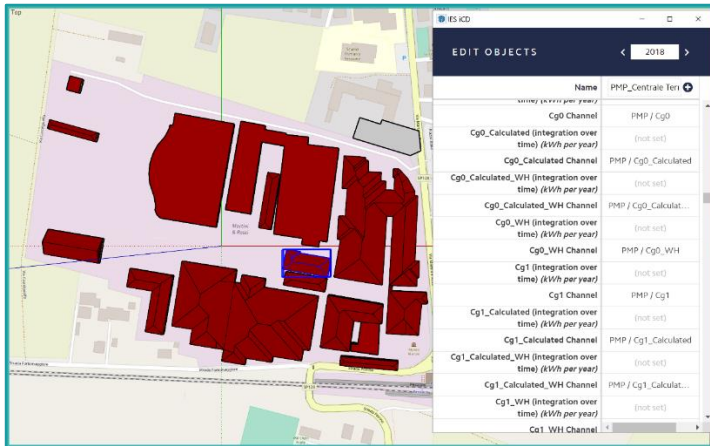The tool gives the user the ability to model buildings in 3D through importing files from other 3D software (sketchup or cad files). And them associate to these building heat demand profiles. This way the simulation results include both the supply and demand energy values.

Energy Supply Networks

The advanced tool allows the option to create thermal and electricity energy networks that include the supply, the distribution and the final demand. New RES (like PV) or WHR (heat exchangers) systems can be added and connected to the baseline networks.
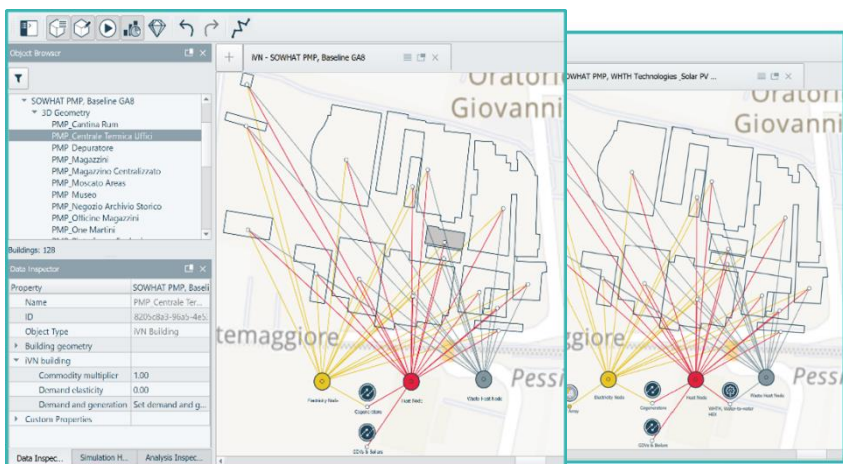
Online dashboards for analysis and results

IMPORTANT: All the previous modelling steps were implemented in different desktop software components. These specific pieces of software provide their corresponding technical results.

In order to group and show the final results of the modelling and simulation tool components, it has been developed an online dashboard that allow the next advantages:

- ☞ Combine the results provided by different software components that in some cases required previous training
- ☞ Give access to the results to as many people as desired. Especially in big companies where financial departments require quick access to the economic figures.
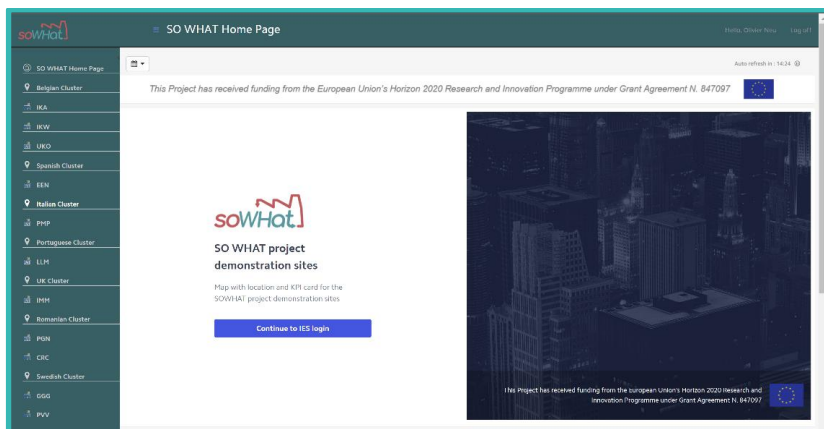
Since this is a research project, all the names of all the demos are visible from the online dashboard main screen. Although different users and passwords are required to access the results of each use case.

The user interface is generic for all the possible use cases without considering the possible specificities of each demo. Obviously when the advance tool becomes a commercial product, this interface will be customized to each specific client.

Dashboard: 3D model visualization

Through the online dashboard is possible to view (but not modify) the 3D model of the different buildings including in simulation modelling.
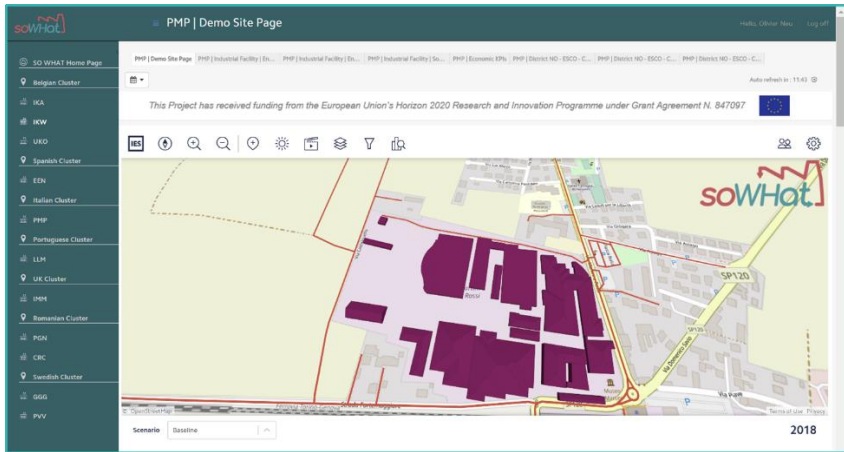
Dashboard: KPI visualization

The tool indicates the initial baseline of the facility in terms of energy use and consumption through the Sankey diagrams. Also the annual values of available waste heat are shown split by temperature.
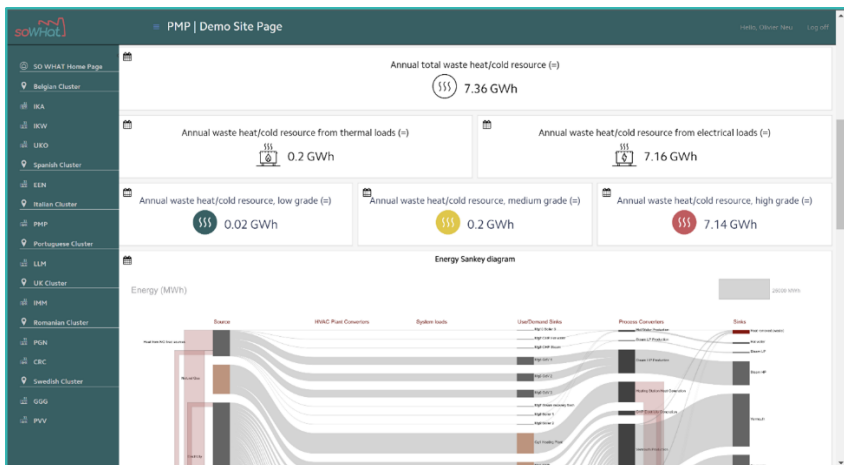
Dashboard: Different Scenarios Energy comparisons

The final energy consumption is graphically compared for the industrial facility baseline versus a possible Scenario where waste heat recovery and or RES have been included and simulated.
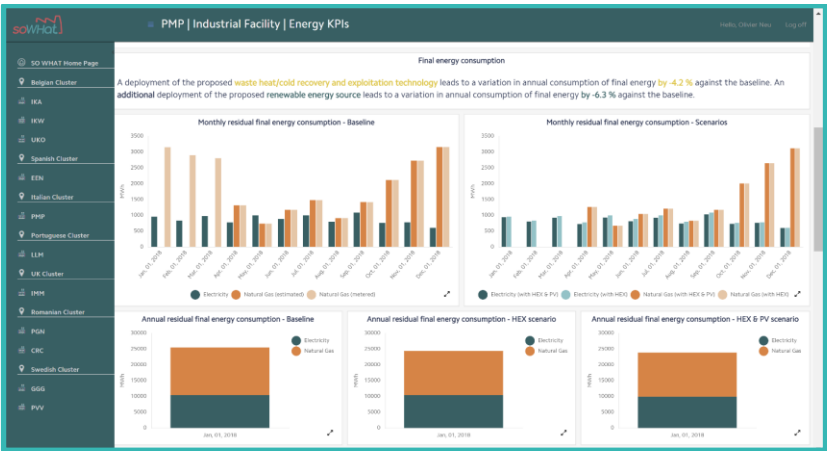
In the case where renewable energy sources are added to the simulation scenario, the tool also provides the expected electricity generation values as well as the useful energy balances.
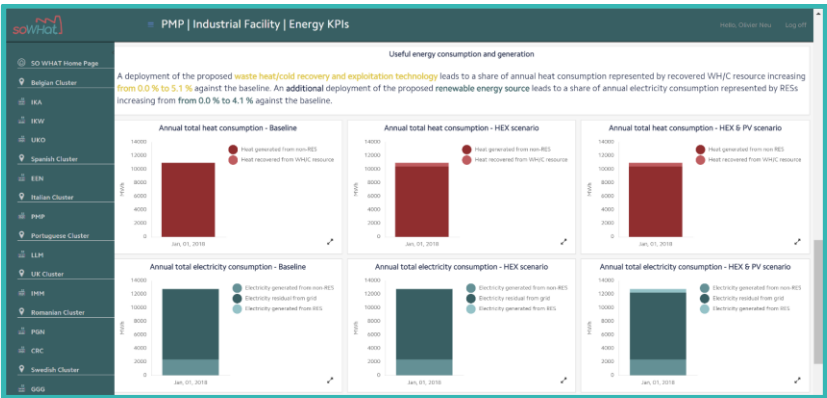
Dashboard: CO2 comparisons

The dashboard also provides the comparison results in terms of primary energy consumption and carbon emissions.
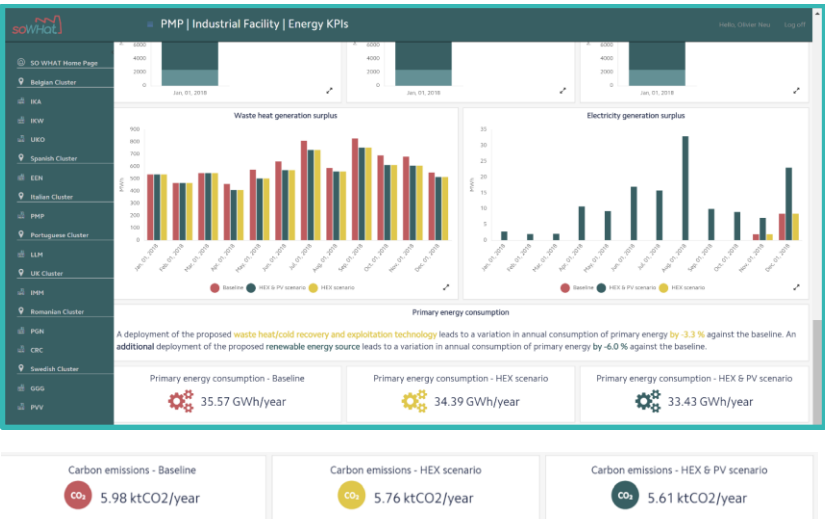
Dashboard: Financial Results Analysis

Similar to the online tool, the dashboard includes a quick economic calculator where Internal rate of return, discount payback periods and net present values are shown.
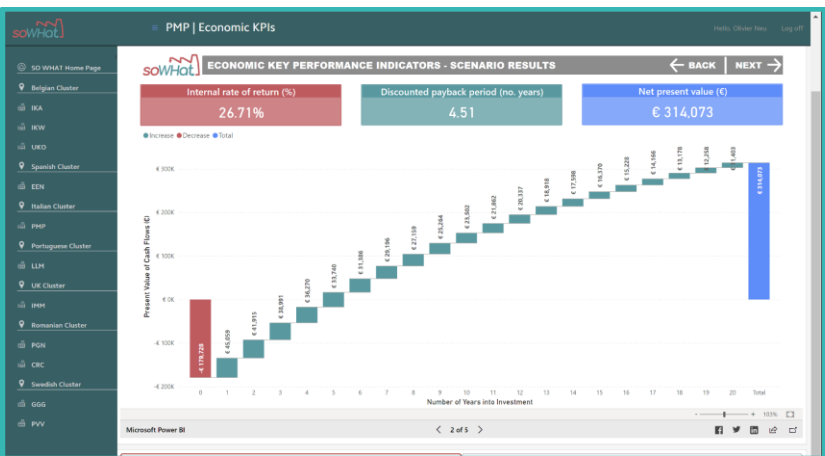
Dashboard: Risk analysis

Again, the dashboard allows to evaluate the risks for the considered scenario. The user has to indicate the possible likelihood of each risk while the impact is already pre-assigned.

Dashboard: Business Model Guidance

Finally, based on the risk assessment the dashboard provides some kind of preliminary business model guidance.

☞ Clicking on the ⓘ icons will show the used references

5   Demonstration Results

5.1   LIPOR Maia Use Case

LIPOR is a waste-to-energy (WtE) plant where municipal waste is burned every year in a continuous and automated manner. Through the plant, high temperature gases go through an energy recovery boiler in order to produce steam for electrical power generation. The *Use Case* studied in this demo is the excess heat recovery from LIPOR WtE plant.

BASELINE

- o   **380,000 tons** of waste treat in LIPOR per year
- o   Natural gas boilers and electric chillers

USE CASE

- o   **40,8 GWh** of waste heat will be recovered
- o   **26,8 GWh** of thermal energy shared with **Porto Airport**
- o   Heat pumps, absorption chillers and DHN (2 km)

Identification of *new* potential users: Super Bock brewer factory and Lionesa Business Hub

The results obtained comparing to the baseline were:

✓ Energy savings

✓ Emissions savings

✓ Economic key performance indicators (KPIs)

Economic KPIs

Internal rate of return (%)
19,53

Discounted packback period (nº years)
5,66

Net present value (€)
12.040.240

Waste Heat Recovery (GWh)
40,8

Airport thermal energy needs (GWh)
26,8

5.2 ENCE Use Case

ENCE, with an installed capacity of 1.2 million tons distributed in its two bio-factories, 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. The *Use Case* study the heat recovered from the dilution fluid of the bleaching stage and send to a water 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.

BASELINE	USE CASE
o Production of **685,000 tons** of high-quality ECF (Elementary Chlorine Free) eucalyptus cellulose o Expansion of **80,000 tons** (2019)	o Potential Waste heat recovery to feed a Biomass dryer installation o Aim maximize biomass savings

✓ Biomass and, indeed, environmental savings

✓ Economic key performance indicators (KPIs)

Regarding the CO_2 and GHG (Greenhouse Emissions) savings, the biomass is considered neutral in CO_2.

[TECHNOLOGY CENTRE] **CARTIF**

⊙ eleukon

FAEN Fundación Asturiana de la Energía

Sustainable **INNOVATIONS**

Biomass Savings (tons)
50.000
Biomass savings (%)
~6,5

Economic KPIs

Internal rate of return (%)
27,54
Discounted packback period (nº years)
3,89
Net present value (€)
6.147.838

SOWHat TOOL
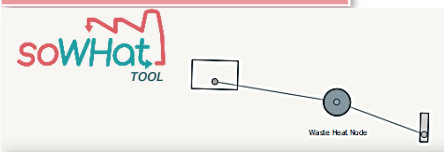
Waste Heat Node

Demand and generation editor				✕
Name	Type	Commodity type	Profile	Multipli
BD_CF_HEX_Q (m3/h)	Demand	Waste heat	SOWHAT EEN: EEN_Biomass Dryer: ...	1
BD_BIOMASSout (t/h)	Generation	Biomass	SOWHAT EEN: EEN_Biomass Dryer: ...	1
BD_CF_HEX_Tin (Â‚Â°C)	Demand	Waste heat	SOWHAT EEN: EEN_Biomass Dryer: ...	1
BD_HF_HEX_VV (%)	Generation	Waste heat	SOWHAT EEN: EEN_Biomass Dryer: ...	1

Add   Insert   Delete

Synchronise energy simulation results   OK   Cancel

5.3   Martini & Rossi Use Case

In Martini & Rossi's (M&R) Pessione industrial site all the products of company are produced: Martini, sparkling wines and liquors, following their recipes. The *Use Case* is the heat recovery from rooftop condenser of cooling plants for process with heat exchangers for the sparkling wine process.

BASELINE

- Overall cooling production is of **10 GWh/year**
- Production of low temperature waste heat accounts for **15GWh/year**

USE CASE

- Heat exchangers for waste heat recovery
- Saving of Natural gas and CHP plant.
- Recovery for winter season
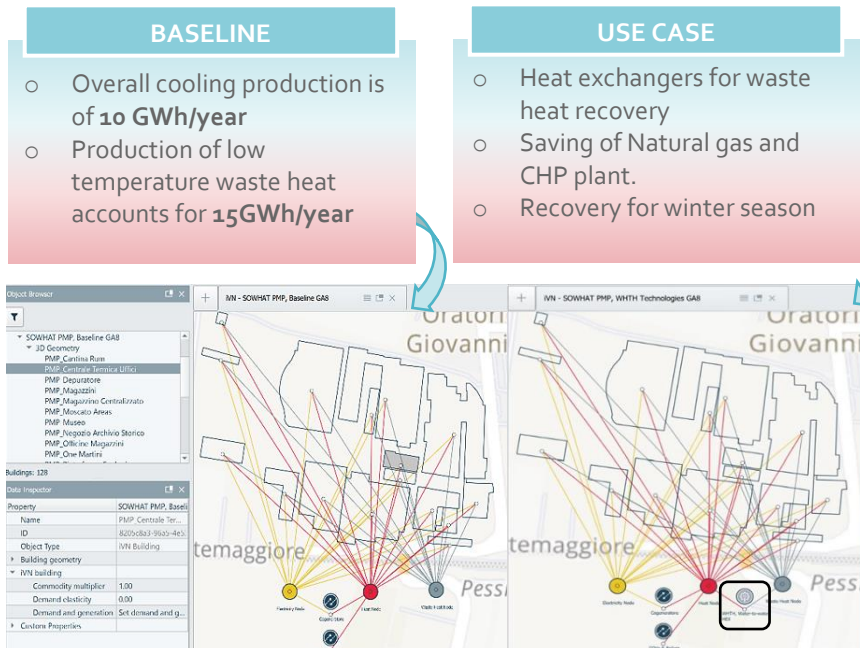
The main *results* obtained show that this use case has potential energy saving rate:

✓ Energy savings

✓ Emissions savings

✓ Economic key performance indicators (KPIs)

Gross Avoided CO_2 emissions (ton/y)
71
Potential heat production (kWh$_t$)
478

Economic KPIs

Internal rate of return (%)
26,71
Discounted packback period (n° years)
4,51
Net present value (€)
314.073

5.4 Termoficare Constanta Use Case

Termoficare Constanta DH aims to become less fossil fuel dependent and to promote new business models with SO WHAT Project. With the injection of heat from neighbouring industries the valorization of waste heat will be possible.

BASELINE	USE CASE
o Heating demand supply with Natural Gas boilers o Consumption of natural gas of ~600 MWh per year o No Waste heat or cogeneration used in the DH	o Restructuring process of the Constanta DH system. o Investment of 50 mil for the upgrading of the distribution network o Investment 120 mil for cogeneration power plant

The results obtained comparing to the baseline were:

In terms of energy efficiency, the overall efficiency of the pilot plant after the conversion to renewable energy sources is 92%, due to the high performance solar thermal panels and pellet boilers

In emission savings, the emission savings are about ~120 tons/year of CO_2

5.5   MPI Steel and Research Pilot Plant Use Case

The Materials Processing Institute is a not for profit research & technology organisation located in the North East of England, UK. The *use case* involves 3 buildings with offices, laboratories and pilot processes. Cooling water from all processes is pumped from and returned to a large water tank containing over 80 m3 of water, when the arc furnace is used the temperature of this water increases. The tank was identified as a potential source of waste heat.

BASELINE

- o   Key energy Users
  - •   5 tonne electric arc furnace
  - •   Ladle arc furnace
  - •   Continuous casting machine
  - •   Office and laboratory heating

USE CASE

- o   Water tank with 80 m3 of water used as a potential source of WH
- o   21.6 MWh waste heat per year
- o   May double in the next 2 years to 43.2 MWh

SO WHAT Tool enabled rapid modelling of building heat demand and the model showed potential to recover waste heat from cooling water.

In terms of energy, *21 MWh* of heat could be recover per year.

In emission savings, the emission savings are about *~4 tons/year* of *CO2.*

In economy results, financial model shows payback time of *25 years*

Building 1	
Internal rate of return (%)	
8,56	
Discounted packback period (nº years)	
12,06	
Net present value (€)	
13.284	

Building 2	
Internal rate of return (%)	
2,54	
Discounted packback period (nº years)	
24,74	
Net present value (€)	
3.738	

Gross Avoided CO2 emissions (ton/y)
4
Potential heat production (MWh/y)
21.6

5.6   Göteborg Energi's multiple WH and DH&CN Use Case

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%). 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.

BASELINE	USE CASE
o 1000 Km district heating established in 1953 o District cooling since 1990 bases on absorption chillers, river free cooling and compressors	o Expansion of the cooling production by 20MW o Use of new types of sorption chillers o Search of non-conventional sources of waste heat

Göteborg Energi activities:

Installation and connection of sensors in our network to server/database for:

- Improved Data collection Pressure cone

- Production optimization

Distributed district heating in Gothenburg

G Göteborg Energi

ivl
SVENSKA
MILJÖINSTITUTET
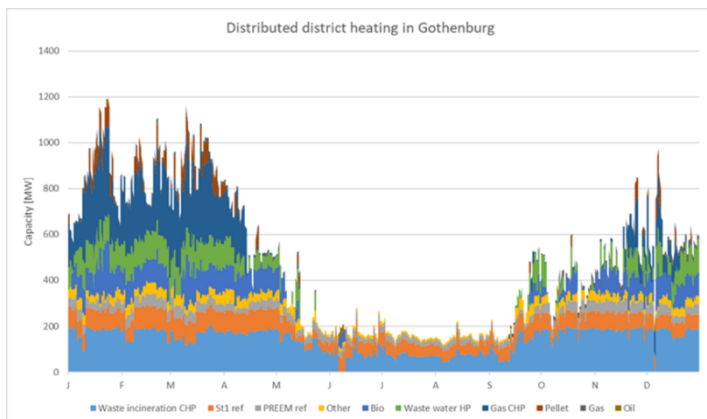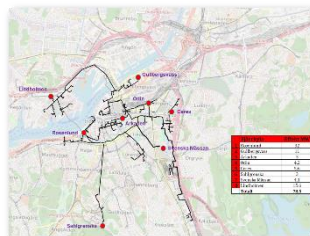
VARBERG ENERGI

5.7   Varberg Energi Pulp and Mill WH and DC&CN Use Case

Valberg Energi (VAEB) is the municipality district heating. Their main thermal supply (85%) for the DH comes from a pulp mill, but to diversify and secure the system, additional conventional systems based on wood chips, biogas and bio-oils are also used. Two scenarios are being considered: increase the amount of waste heat injected in the network and provide district cooling during summer through absorption chillers exploiting the unused summer waste heat.
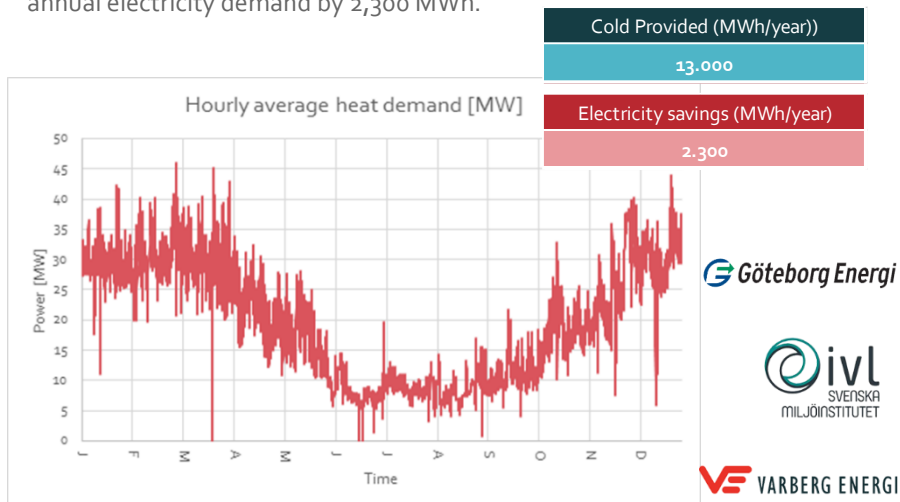
BASELINE	USE CASE
o Existing DHN (140 Km total length) mostly based on waste heat from pulp mill o No District Cooling network (pipes) is deployed	o Increase the waste heat injection (larger HEs and also reducing the temperature level) o Provide district cooling during summer using absorption chillers

The results obtained comparing to the baseline were:

✔ The tool was used to test how hourly district heat demand could be matched by the excess heat from the pulp mill

✔ Total capacity of 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.

Cold Provided (MWh/year))
13.000

Electricity savings (MWh/year)
2.300

Hourly average heat demand [MW]

Göteborg Energi

ivl SVENSKA MILJÖINSTITUTET

VARBERG ENERGI

5.8   UMICORE rare material recycling and production Use Case

UMICORE rare materials recycling plant located in Olen covers its thermal needs through steam output of co-generation turbines. The considered use case aims to recover the residual waste heat still present in the CHPs exhaust flue gases to produce hot water. At the same time, some specific manufacturing processes whose heat requirements are now provided with steam-water heat exchangers must be modified to be able to operate with the recovered hot water.

BASELINE	USE CASE
o Complete gas-fuelled steam production by 2 CHP and 2 back-up steam boilers. o Heat demand mostly devoted to process heat and not buildings	o Installation of waste heat recovery mechanism at the exhaust of the CHP o Transformation of internal process from steam to hot water

The results obtained comparing to the baseline

✓ natural gas savings and, indeed, environmental savings

✓ Economic key performance indicators (KPIs)

The biggest deterrent for this study case is that new hot water distribution pipes (~2600 meters) will be required.

Kelvin Solutions

ECONOMIC KEY PERFORMANCE INDICATORS - USER INPUTS

Natural Gas Savings (MWh/year))
38.044
Emissions savings (tn CO2/year)
6.938

BASELINE INPUTS	
Internal rate of return (%)	
19,83	
Discounted packback period (nº years)	
5,57	
Net present value (€)	
10.670.886	

Initial investment cost	Annual O&M costs	Annual energy supply cost
€ 0	€ 0	€ 0

Initial investment cost	Delta annual cash flow
−€ 6.031.000	€ 1.228.954

5.9   ISVAG Waste to Energy Plant Use Case

ISVAG WtE plant generates electricity through the incineration of the residual household waste. Currently, a limited part of the available residual heat is already being recovered and sent to the near "Terbekehof" district heating. The use case considers the valorisation of additional residual heat by constructing a new district heating network to connect with big industrial users nearby. Specially the near Atlas Copco factory has a total heat demand of up to 8.52 GWh/year.

BASELINE	USE CASE
o WtE incineration plant that currently is providing heat to a near DHN o Excess heat for DHN is extracted before the turbine	o Installation of additional heat exchangers for increasing recovered heat for new DH o Stop extracting steam upstream the turbine and do it downstream.

The results obtained comparing to the baseline

✓ natural gas savings and environmental savings

✓ Economic key performance indicators (KPIs)

85% of the estimated investment is required for the distribution pipes.

Kelvin Solutions

Natural Gas Savings (MWh/year))
10.023

Emissions savings (tn CO2/year)
2.024
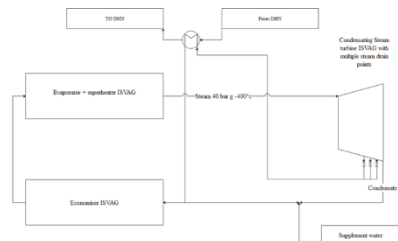
6   SO WHAT Lessons

6.1   European Policies Overview

Project partners have made several recommendations aimed at improving the policies developed by their countries for the promotion of the WH/C recovery. The next ones are common to all country partners.

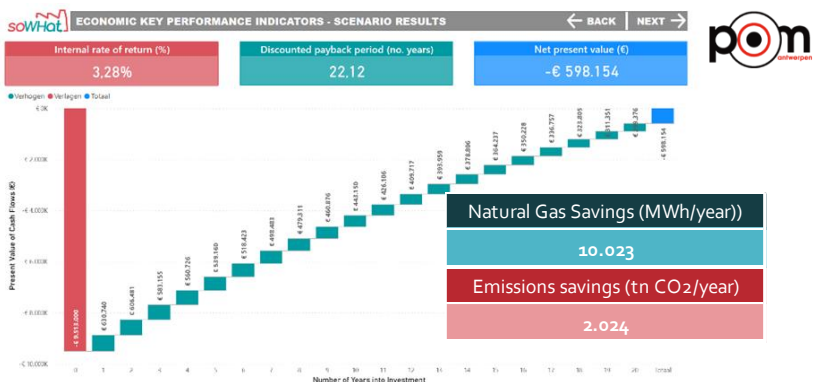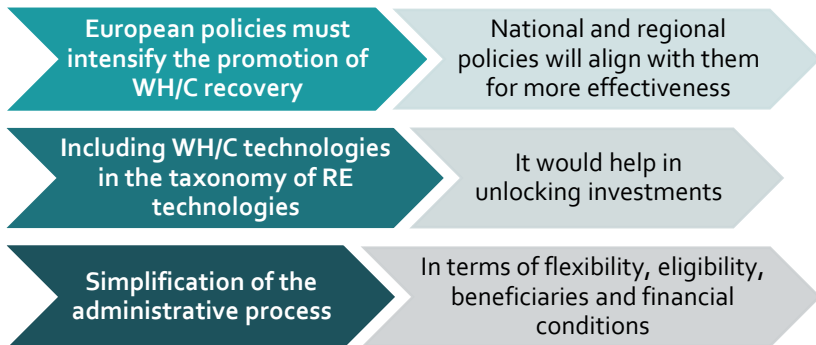|	
European policies must intensify the promotion of WH/C recovery	National and regional policies will align with them for more effectiveness
Including WH/C technologies in the taxonomy of RE technologies	It would help in unlocking investments
Simplification of the administrative process	In terms of flexibility, eligibility, beneficiaries and financial conditions

Focusing on the countries, the specific following **recommendations** where obtained:

Sweden

○   Defining a more attractive scenario for WH/C recovery: introducing a cost for polluting or inefficient use of energy.
○   Facilitating the collaboration with (public) energy companies for finding benefitting business models for both parts.

○ Creation of a portfolio of funding programs aimed at the promotion of WH/C recovery.
○ Designing mechanisms focused on companies subjected to trading emission rights to encourage them to implement WH/C recovery systems.

Portugal

Spain

❍   Promotion of district heating networks, with special effort in locations where production and potential consumption of H/C are close.

❍   Considering the specific industrial processes of the most representative industrial actors. This will facilitate their participation in the funding programmes.

❍ Designing specific policy measures in the industrial sector by considering specific conditions of industrial activity and sectorial characteristics.

❍ Creation of facilitating funding mechanisms for transfer/sale of H/C among companies.

Italy

Belgium

❍   Creation of social tariffs for heat supplied by District Heating networks.

❍   Creation of CO₂ taxes on fossil fuels and electricity and give priority to decentralized cogeneration units in the compensation for flexible

More information can be found in the *Deliverable 6.3 Policy instruments to promote industrial WH/C recovery*.

6.2   SO WHAT Training

SO WHAT main objective is to develop and demonstrate an integrated software which will support **Industries**, **Energy Utilities**, **Municipalities** and also **Academic Sector** in selecting, simulating and comparing alternative Waste Heat and **Waste Cold** (WH/C) exploitation technologies that could cost-effectively balance the local forecasted H&C demand also via **RES** integration.

Thanks to SO WHAT training, you will be able to:

- Understand how enhance WH/C
- Identify the best technology to implement
- Identify the most suitable business model for your company
- Analyse the legal framework and regulatory issues related to the different options.

Industrial sector

You will learn how to sell waste heat and cold energy, how to reuse internally waste heat energy and renewable energy, how to purchase external waste heat and/or cold energy and renewable energy.

Municipality / Energy agency

You will learn how reuse waste heat energy and renewable energy, how map the condition given and simulate additional configurations. You will be able to compare the results via a KPI panel and choose a wise option for the reuse heat and cold, both in the industrial perimeter but also outside it.

Academic sector

You will learn new technics to be updated with the technologies available; you can deepen your knowledge on cutting edge technologies for WH/C recovery as well as specific schemes for the integration of the recovered energy.

SO WHAT training proposes **3 training modules**:

| Module 1 | How to investigate your energy consumption, the potential of WH/C technologies and how to exploit it externally to the industrial plant. |

Main objectives

To achieve both high-level information about industrial energy consumption, following standard auditing techniques and insights about the WH/C technologies that could be implemented.

To learn about general SO WHAT project concepts, analysis and methodologies that will be implemented in the tool.

| Suitable business and financing schemes for WH/C installation. | Module 2 |

Main objectives

To understand the limitations and how they can take advantage of WH/C for industries and learn about socio-economics by the implementation of new technology or local RES benefitting the EU.

| Module 3 | Using SO WHAT Tool |

Main objectives

To understand the SO WHAT tool, its advantages, how the tool can simulate both the industrial environment and the surrounding community on a single platform. You will learn how to map, accommodate, simulate and post-process the data collected and prove the solutions for further query and cross-check the steps you have followed correctly for the understanding of user knowledge.

You will also know the chronology of the creation: inputs, technologies, outcomes.

6.3 SO WHAT Recommendations for Policy Makers

The **policy recommendations** developed in the SO WHAT project are presented in detail in the *Deliverable 6.7 SO WHAT Positioning paper*, and include:

To define and standardize "waste heat/cold", to support energy planning activities at urban and industrial site level and to align WH/C with renewable energy sources, in order to increase its inclusion in energy plans.

To integrate recovered heat/cold in building energy performance calculation, in order to increase the exploitation of this sustainable source of energy for H&C of buildings.

To simplify procedures for permitting and connection to electricity and DHC networks, with the aim of making clearer and shorter the authorization procedures that obstacle the realization of this kind of projects.

To make waste heat/cold recovery attractive for investors, by increasing its profitability through investments but also reducing the risk perceived for these projects.

To abate residual technological gaps to waste heat/cold recovery by continuing demonstrating their technical feasibility and their profitability.

7   References

1. Mapping and discussing industrial waste heat (IWH) potentials for different countries (https://repositori.udl.cat/bitstream/handle/10459.1/58575/022995.pdf?sequence=1)
2. Waste heat recovery: Technology and Opportunities in U.S. Industry (https://www1.eere.energy.gov/manufacturing/intensiveprocesses/pdfs/waste_heat_recovery.pdf)

References

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