H2020 Work Programme

D7.6 – TRAINING RESOURCES FOR RELEVANT STAKEHOLDERS

Lead Contractor: ENVI

Date: 30/11/2022

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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 – RINA-C		
Website	www.sowhatproject.eu		

Deliverable details			
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Deliverable responsible	Environment Park – ENVI		

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

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28/11/2022	V04	Sabina Fiorot	Final integrations

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Executive summary

This document is developed under indications of [deliverable 7.3 SO WHAT Training plan and guidelines for training materials][2]. The deliverable showcases the structure of the training developed during the period starting from the guideline for training material. The material is also linked to the outlines of the project and giving a detail explanation of each topic.

Task 7.3 aims at proactively educating various audiences to the SO WHAT project and its results by providing targeted information. The promotion activities are also part of the dissemination and communication plan, and this document presents also the brochure developed and charged on the website useful to achieve the students.

An active training module has been structure and design which is accessible by any device. The content and description of the training modules are explained in this document, incorporated in the SO WHAT website https://training.sowhatproject.eu/ defining the purpose of the SO WHAT project and describing the targeted groups which can be classified in different stages, including general public, scientific audience, industry and government, with an objective for decarbonization.

The structure of these modules has been defined by ENVI with the support of all the partners involved in SO WHAT project. The training is structured in 3 modules, consisting in particular of text documents, explanatory and descriptive videos, summarized in the form of slides. All materials are accessible upon registration and can be downloaded by the student.

The document below reports the main structure of the training developed; all the material is collected in the Annex below.

[2] https://sowhatproject.eu/wp-content/uploads/2018/05/D7.3-SO-WHAT-Training-plan-and-guidelines-for-training-material_compressed.pdf

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1 Abbreviations

CBA: Cost-Benefit Analysis

DH: District Heating

DHN: District Heating network

ESCO: Energy Service Company

GDPR: General Data Protection Regulation

H/C: heat and cold

KPI: Key Performance Indicator

RES: Renewable Energy Sources

WH/C: Waste Heat/Cold

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1 Introduction

It is necessary to underline the deliverable delayed of 6-months due to the delay in the development of the tool. In particular, module 1 was prepared and developed already in June 2022, but in particular module 3 was totally dependent on the tool manual (D4.3) which was submitted in September, furthermore some materials of module 2 were dependent on the development of the tool.

The training module is now fully produced and accessible via online registration, but so far there have been no training trials to collect feedback from external users/stakeholders. An internal trial was performed by 10 trainees from the Clusters in order to collect training feedbacks.

The training resources that can be found below, were developed under Task 7.3 with the aim of enabling the "student" to:

- Analyse the legal framework and regulatory issues related to the different options
- Access a detailed energy analysis with the integration of the more suitable WH/C recovery technology based on a techno-economic evaluation
- Access technological solutions to optimally exploit the identified available sources
- Evaluate the actual local H/C demand
- Individuate WH/C streams in an industrial site
- Provide to industrial stakeholders as well other potentially interested actors (DH providers, public authorities, energy agencies, etc.) financing schemes and business and risk models as
- well as deployment plans to effectively implement the identified technologies
- Know different schemes to finance recovery according to its needs and the technical solution is chosen

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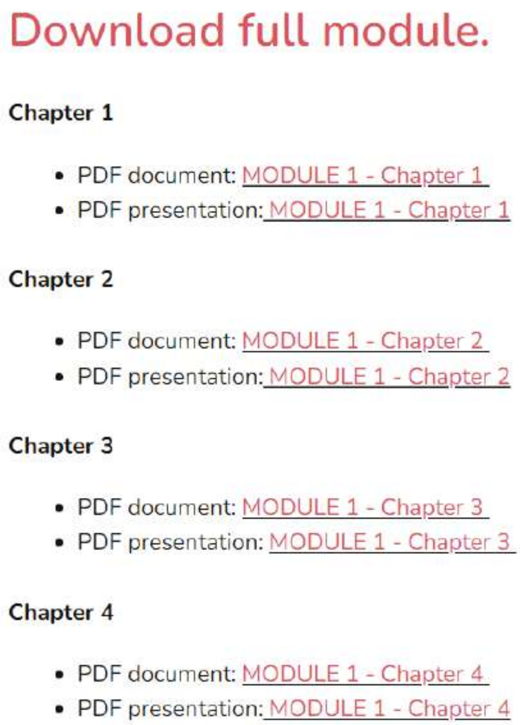
2 Training resources

SO WHAT project provides not only a simulation tool to evaluate the techno-economic viability of WH/C potential valorisation but also with a specific training strategy (based on both traditional and e-Learning tools) to guarantee their autonomy in the use of the tool.

The online training is structured to be easy to understand and follow, flexible (online training courses can be taken anytime and anywhere), allows exchanges of ideas (trainees with same interests or with the same learning goals may join a community that interacts effectively by exchanging questions, doubts, and ideas).

Training materials (presentations, papers, etc...) have been made publicly available on the project website and uploaded to the e-learning section as well.

All the material is charged on the eLearning and it is also available for downloading.



2.1 WEB MODELLING

The e-Learning sections are settled on the project website https://training.sowhatproject.eu/ (Figure 1) and maintained using the latest technology to develop a user-friendly platform. The e-learning section have been designed with an easy-to-follow structure with clear, modern graphics design focused on presenting the value of the content. From these aspects, SO WHAT has successfully launched the website. A process of registrations and the log-in access towards the training material and session is needed.

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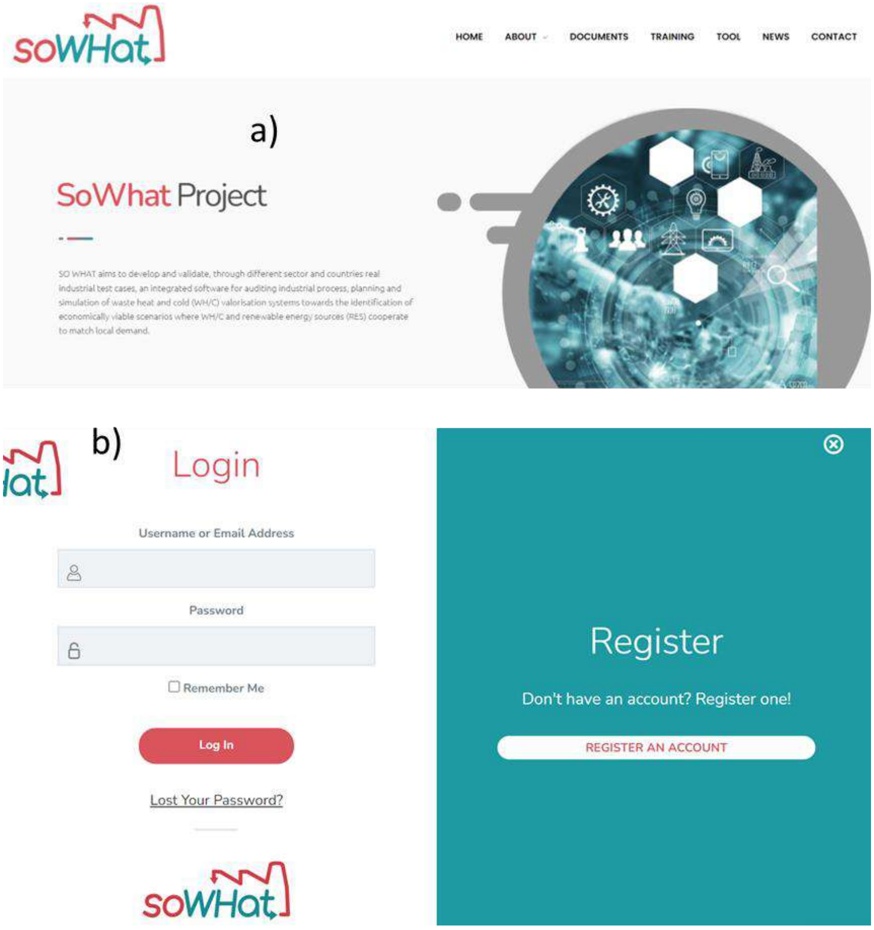

Figure 1 SOWHAT project website and e-learning first registration

Access/login. For the complete access of the training modules, it is requested that every individual has to sign-up and compile a set of questions as following in order to complete the registration, this requirement is envisaged to track the trainees.

The access is guaranteed from the SO WHAT website from a dedicated Training page. The "student" can start the first step of registration by inserting mail and password. After that, additional information is requested:

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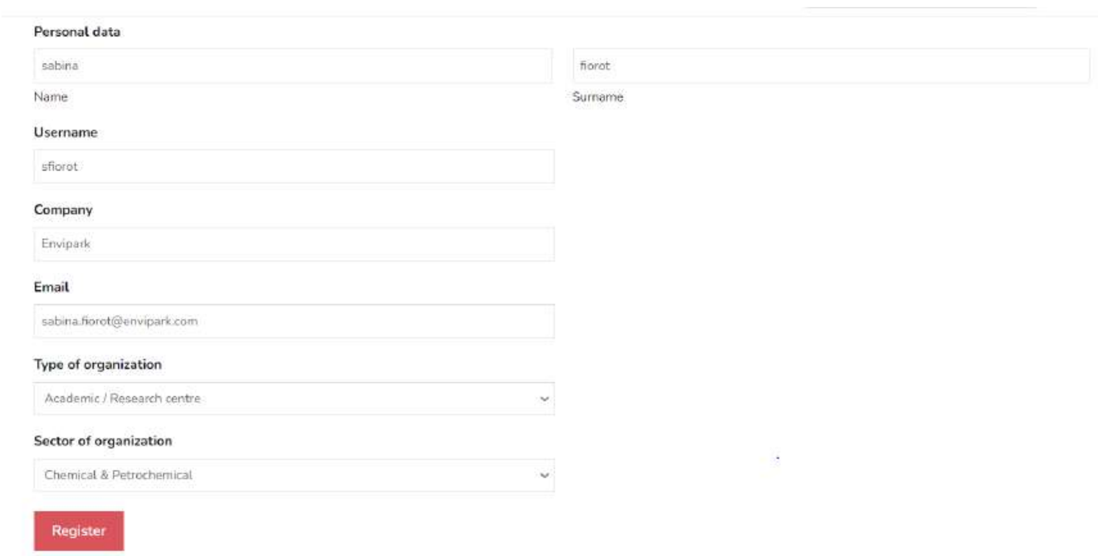
Personal data
sabina
Name
fiorot
Surname
Username
sfiorot
Company
Envipark
Email
sabina.fiorot@envipark.com
Type of organization
Academic / Research centre
Sector of organization
Chemical & Petrochemical
Register

Figure 2 SOWHAT e-learning first registration: information requested

- General student information: first name, last name
- Company name
- email
- Type of Organization:
    - Academic/ Research centre
    - Energy Agency
    - Utility/ESCO
    - Regional Authority
    - Municipality
    - Industry
    - Other
- Industry sector activity
    - Chemical & Petrochemical
    - Food & Beverage
    - Paper, Pulp & Printing
    - Iron & Steel
    - Power & Energy
    - Other

As mentioned, the first registration of the students is useful to track them and identify from which target group they derive. The data collected can be useful for tracing the type of target groups and follows the GDPR policy.

Satisfaction final section. Satisfaction section, with some oriented questions:

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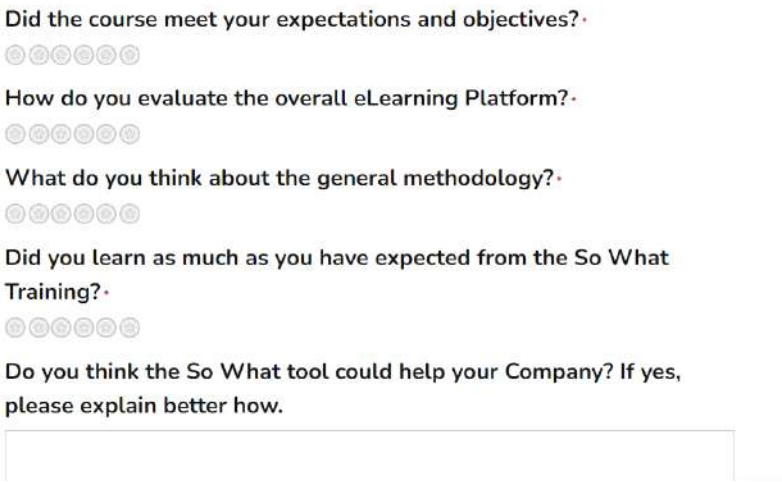

Did the course meet your expectations and objectives?

How do you evaluate the overall eLearning Platform?

What do you think about the general methodology?

Did you learn as much as you have expected from the So What Training?

Do you think the So What tool could help your Company? If yes, please explain better how.

Figure 3 Final satisfactory survey

First training webpage. The page reports a short summary of the main objectives of SO WHAT tool and the objective of the SO WHAT training. SOWHAT is mainly focused on 3 TARGET GROUPS:

1. Industrial sector. The target group of this training strategy is formed of industrial energy managers and industrial owners as well as energy companies who are willing to develop WH/C recovery solutions that are environmentally and economically sustainable and based on the local peculiarities of the territory they work in. The industrial sector is interested in selling waste heat and cold energy, internally reusing waste heat energy and renewable energy, or in purchasing external waste heat and/or cold energy and renewable energy.
2. Municipality/Energy Agency. The SO WHAT tool allows municipalities and / or/energy agencies to learn about the reuse of hot and cold waste which is very helpful in the decarbonization of the H/C system. The SO WHAT tool will help to map the condition given and simulate additional configurations: the user will be able then 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.
3. Academic sector. In comparing with the corporate sector, learning in the education sector focuses primarily on knowledge transfer and not on training i.e., in education, they are mainly striving to learn things with global scope (e.g., a subject such as mathematics) whilst corporate e-learning is more focused on business needs (e.g., new recruit induction). The academic sector will be the intermediary for the uptake of WH/C in industrial sites/DHN, especially with regards to more advances technologies.

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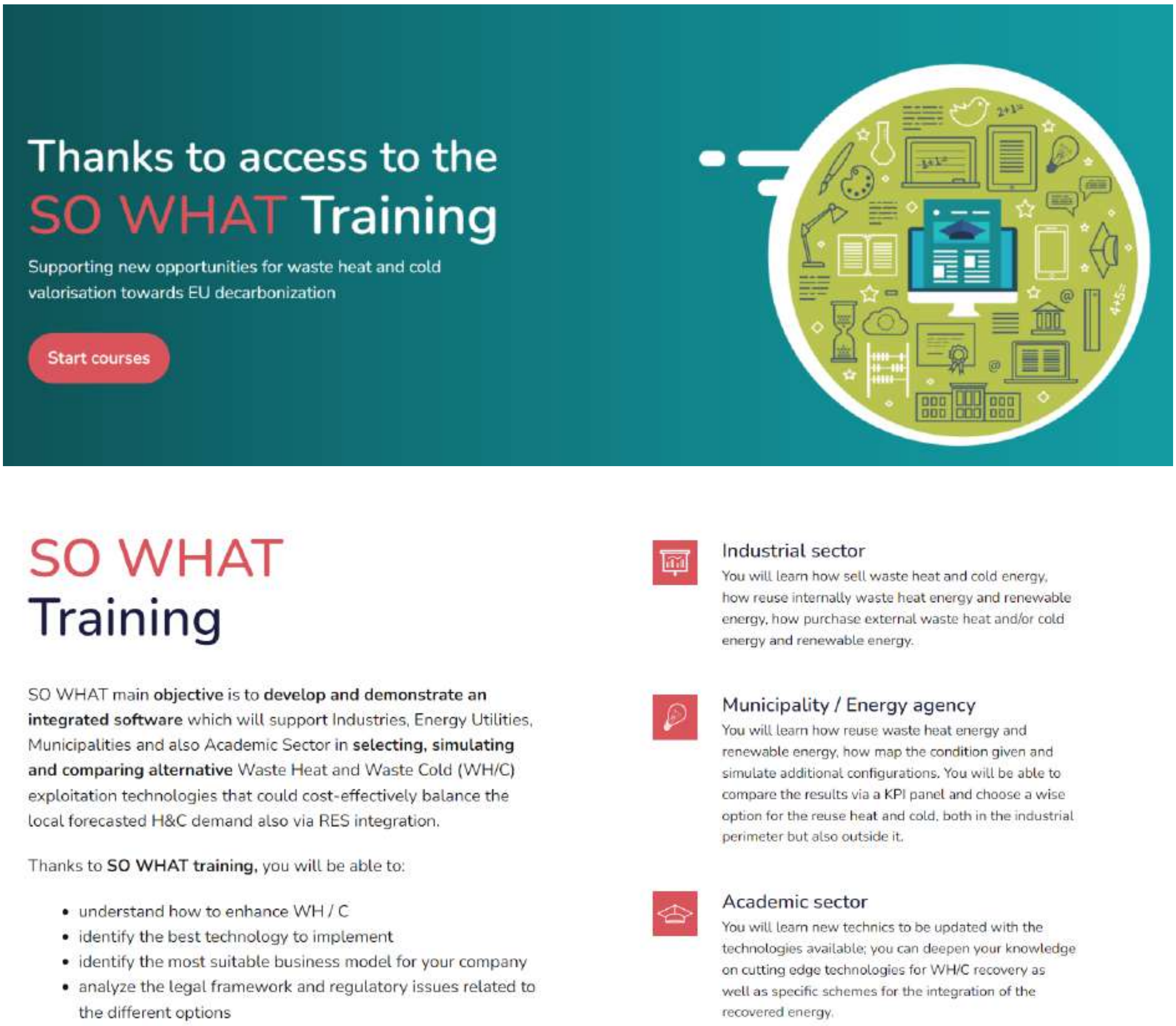

Figure 4 Outlook of first training webpage (1)

First page also reports the three Training Modules that the "student" will meet along the eLearning and the general objectives:

- **Training module 1: How to investigate our own energy consumption, the potential of WH/C Technologies and how to exploit it externally to the industrial plant**
- **Training module 2: Suitable business and financing schemes for WH/C installation**
- **Training module 3: Using SO WHAT Tool**

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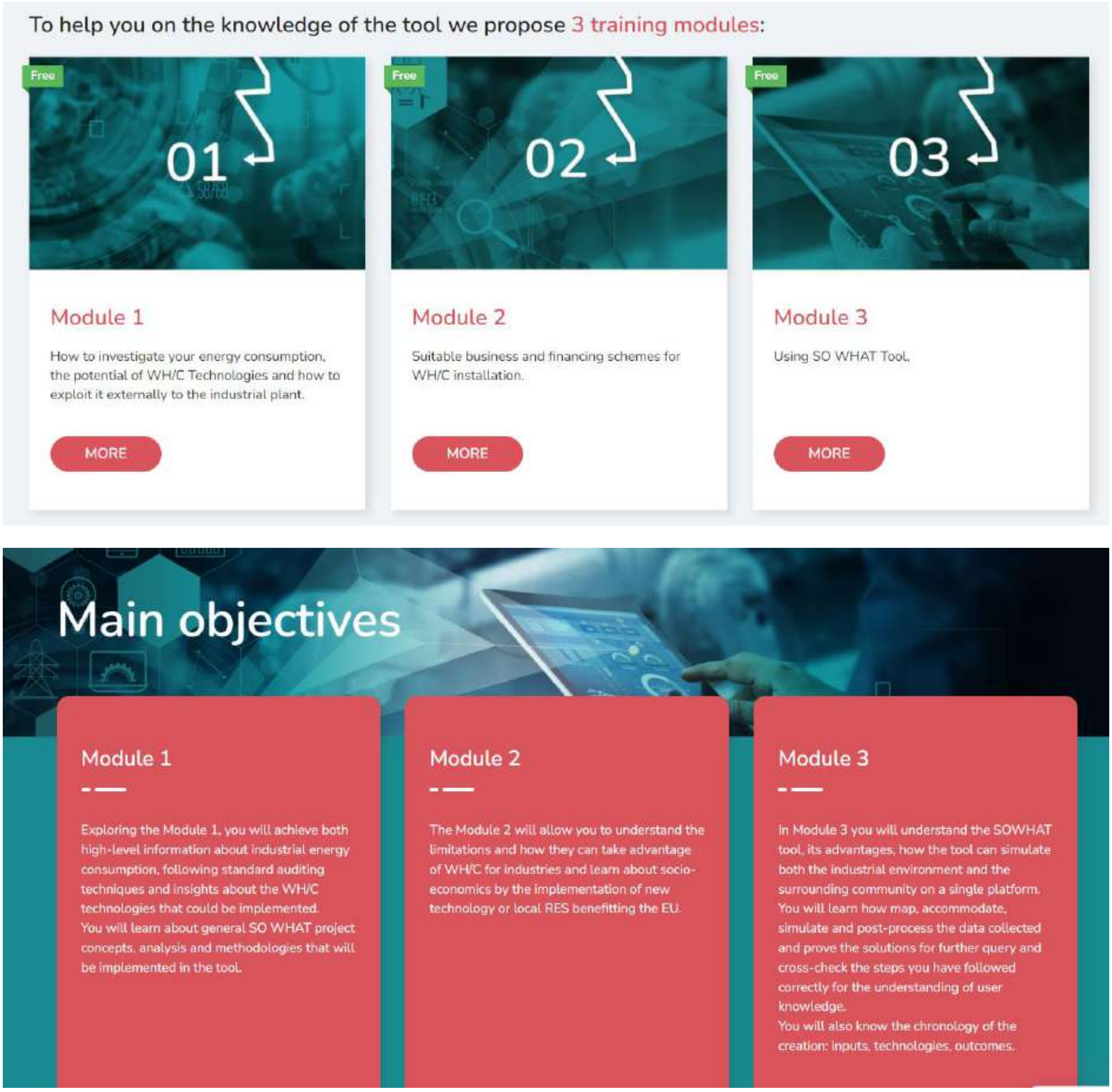

Figure 5 Outlook of first training webpage (2)

Once the student accesses the module, the trainee has the opportunity to view and download videos material, handbooks and slides.

2.2 TRAINING MODULES RESOURCES

2.2.1 Module 1 – How to investigate our own energy consumption, the potential of WH/C technologies and how to exploit it externally to the industrial plant

The training module 1 material was development under the responsibility of RINA-C and CAR and supervised by ENVI as training plan responsible. It consists of one intro video and a handbook.

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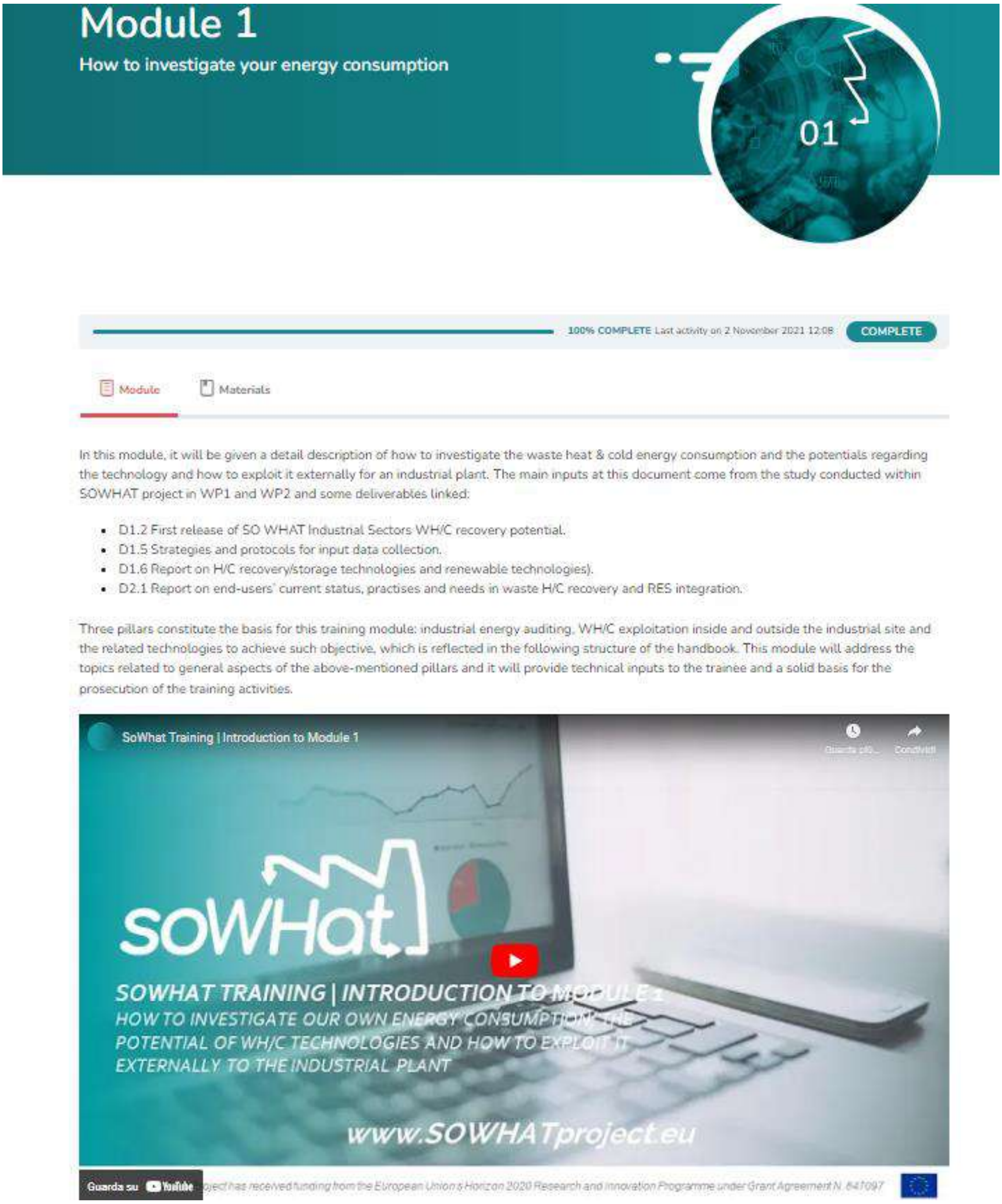

Figure 6 Module 1 home page & intro videos

Module1_Intro video

The section of the training starts with an intro video of 2.20 minutes (showing a *pptx file with the voice of the "teacher"). Link: https://www.youtube.com/watch?v=Eddbw1JEmc8&t=3s

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Module1_handbook

The training module 1 follows a user manual/handbook of the SO WHAT tool in which all the details consisting of the How? Where? What? are described.

The handbook is structured in 5 Chapters:

- Chapter 1: Description of the waste H/C: how it is generated and where it can be seen most in industrial plants.
- Chapter 2: Analysis of WH/C technologies
- Chapter 3: Data collection and formatting
- Chapter 4: Mapping H/C demand and RES potential
- Chapter 5: Analysis of data consistency

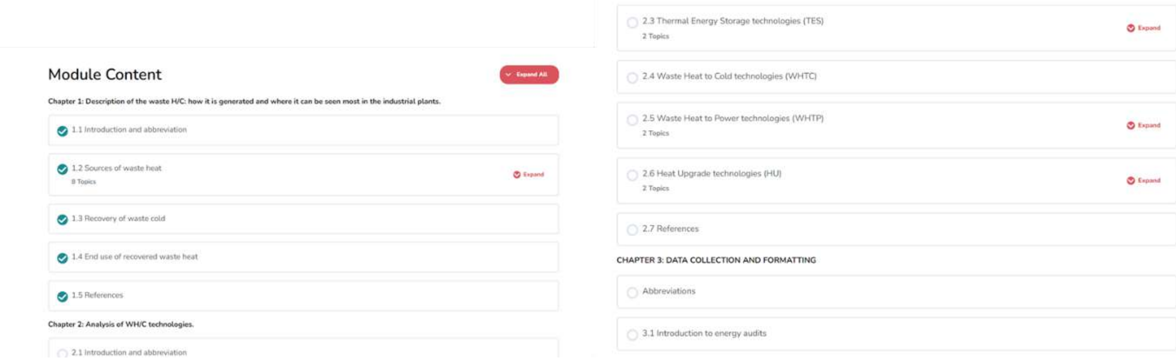

Figure 7 Module 1 Handbook chapters

Module1_videos

4 intro videos for each chapter are developed and charged:

- Intro video chapter 1: 11 minutes
- Intro video chapter 2: 13 minutes
- Intro video chapter 3: 12.22 minutes https://www.youtube.com/watch?v=2qqgBwkoOeo
- Intro video chapter 4: 11.32 minutes https://www.youtube.com/watch?v=H3O-XIKCYug

Module1_ppt

The handbook is translated in an easy to follow way, summarising slides presented in a live event that include the key information above mentioned, as well as the references to both the handbook and public deliverable, where extensive explanation can be found to deepen the subject.

Such presentation is prepared in a widespread format (i.e., pdf or PowerPoint) and it constitutes the main tool to be exploited during the training sessions.

2.2.2 Module 2 - Suitable business and financing schemes for WH/C installation

The training module 2 material is developed under the responsibility of IVL and ENVI and it is supervised by ENVI as training plan responsible.

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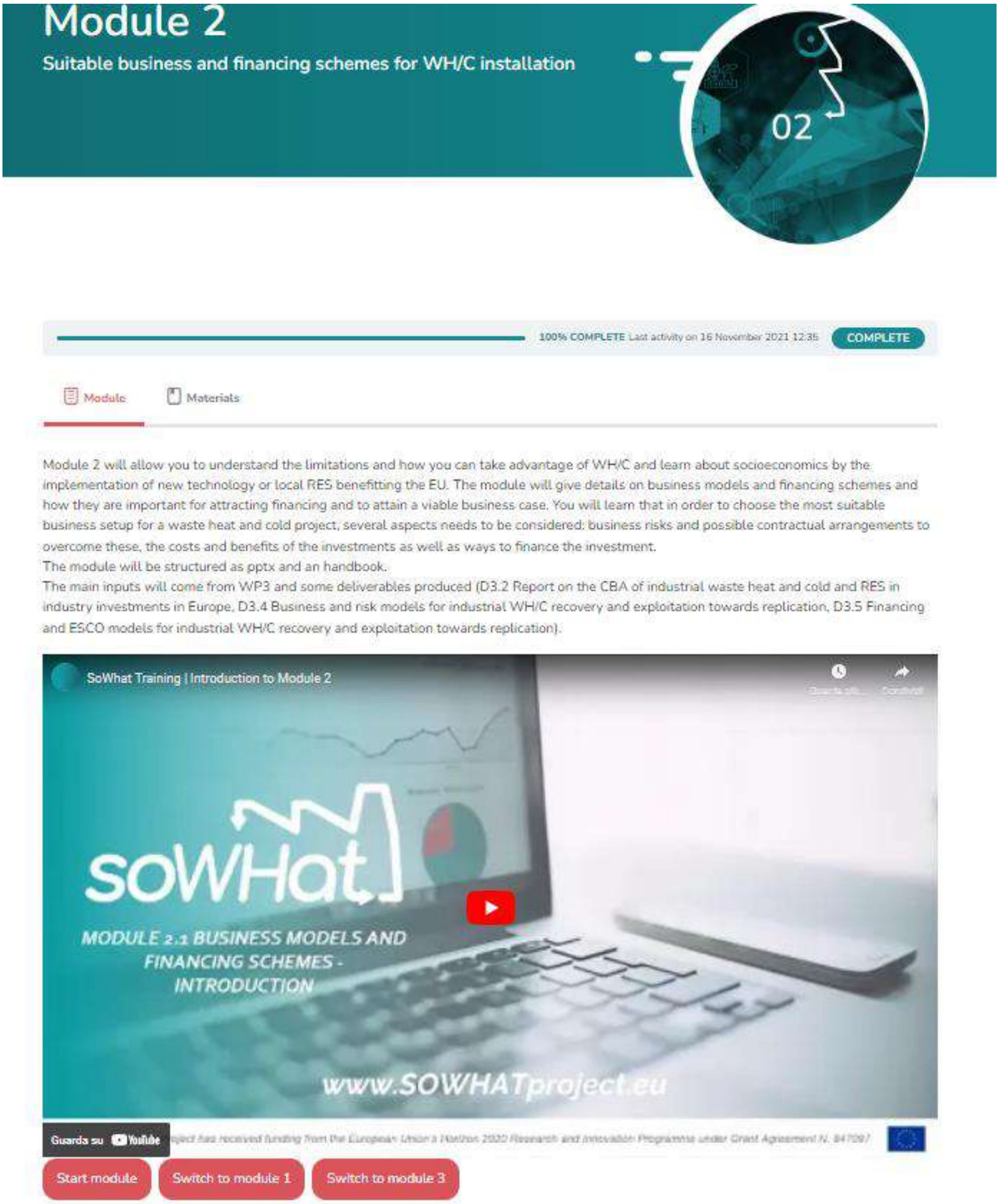

Figure 8 Module 2 home page & intro videos

Module2_Intro video

The section of the training starts with an intro video of 3.24 minutes (showing a pptx with the voice of the "teacher"). Link: https://www.youtube.com/watch?v=eEHhJ7OlxhE

Module2_video

4 intro videos for each chapter have been developed and charged:

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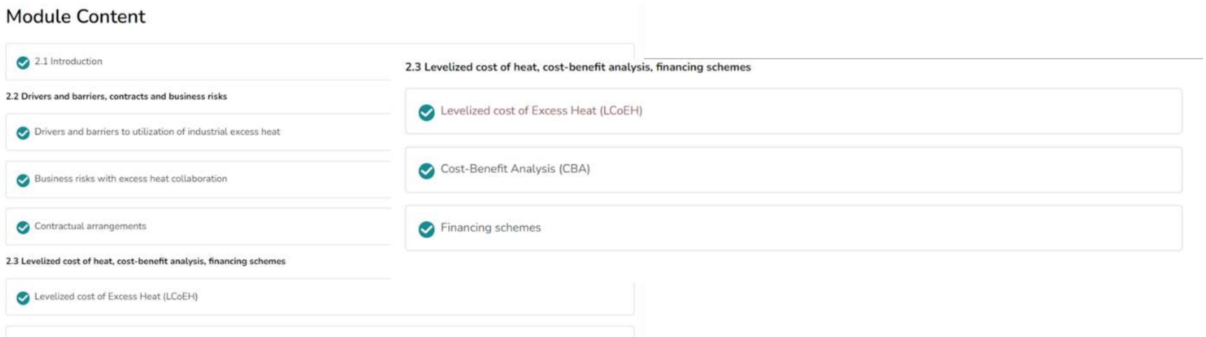
- Intro video chapter 2: 6.50 minutes https://www.youtube.com/watch?v=ovDZMXi4bJ4
- Intro video chapter 3: 5.29 minutes https://www.youtube.com/watch?v=Py8FBIt8y4A

Module2_ppts

As in module 2, the main focus is based on educating fellow individuals to understand the limitations and how they can take advantage of WH/C for industries and learn about socioeconomics by the implementation of new technology or local RES benefitting the EU. The module is structured as pptx and the main inputs come from WP3 and some deliverables produced (D3.2 Report on the CBA of industrial waste heat and cold and RES in industry investments in Europe, D3.4 Business and risk models for industrial WH/C recovery and exploitation towards replication, D3.5 Financing and ESCO models for industrial WH/C recovery and exploitation towards replication).

The arguments are spread in 3 ppts with these titles:



- ➢ First pptx: Introduction
- ➢ Second pptx: Drivers and barriers, contracts and business risks

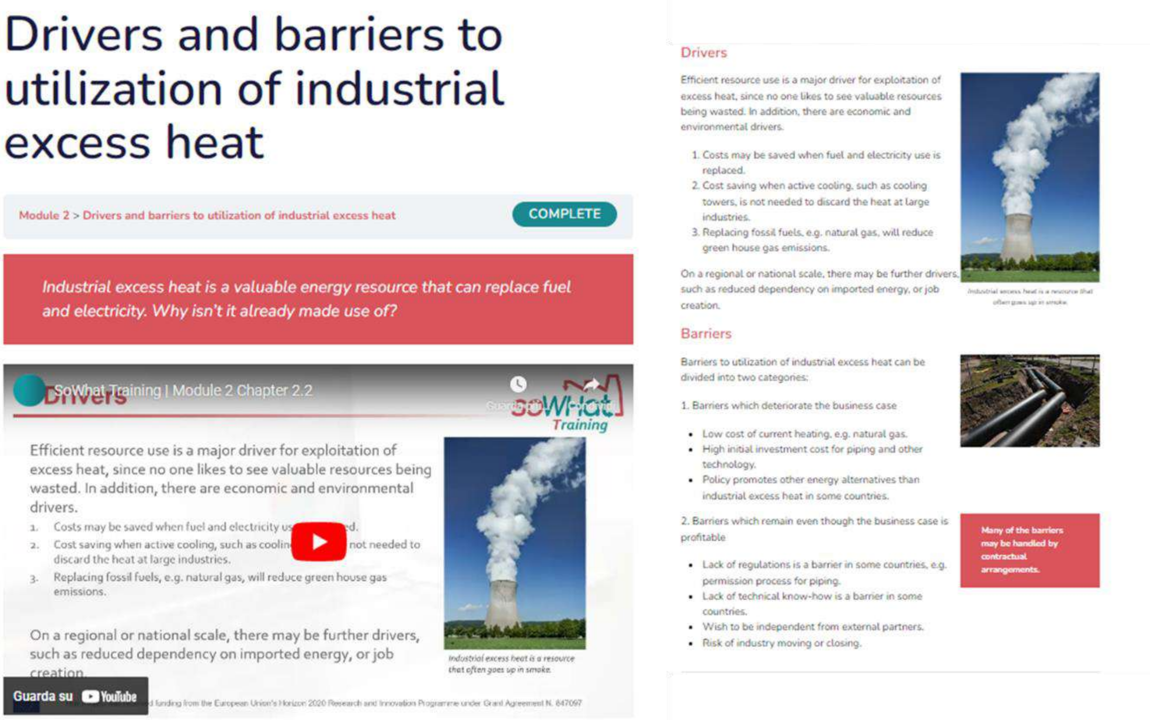


Figure 9 Module 2: second ppt on eLearning

- ➢ Third pptx: Levelized cost of heat, cost-benefit analysis, financing schemes

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2.2.3 Module 3 – Using SO WHAT tool

The training module 3 is developed under the responsibility of IESRD and it is supervised by ENVI as the main responsible for planning the training modules.

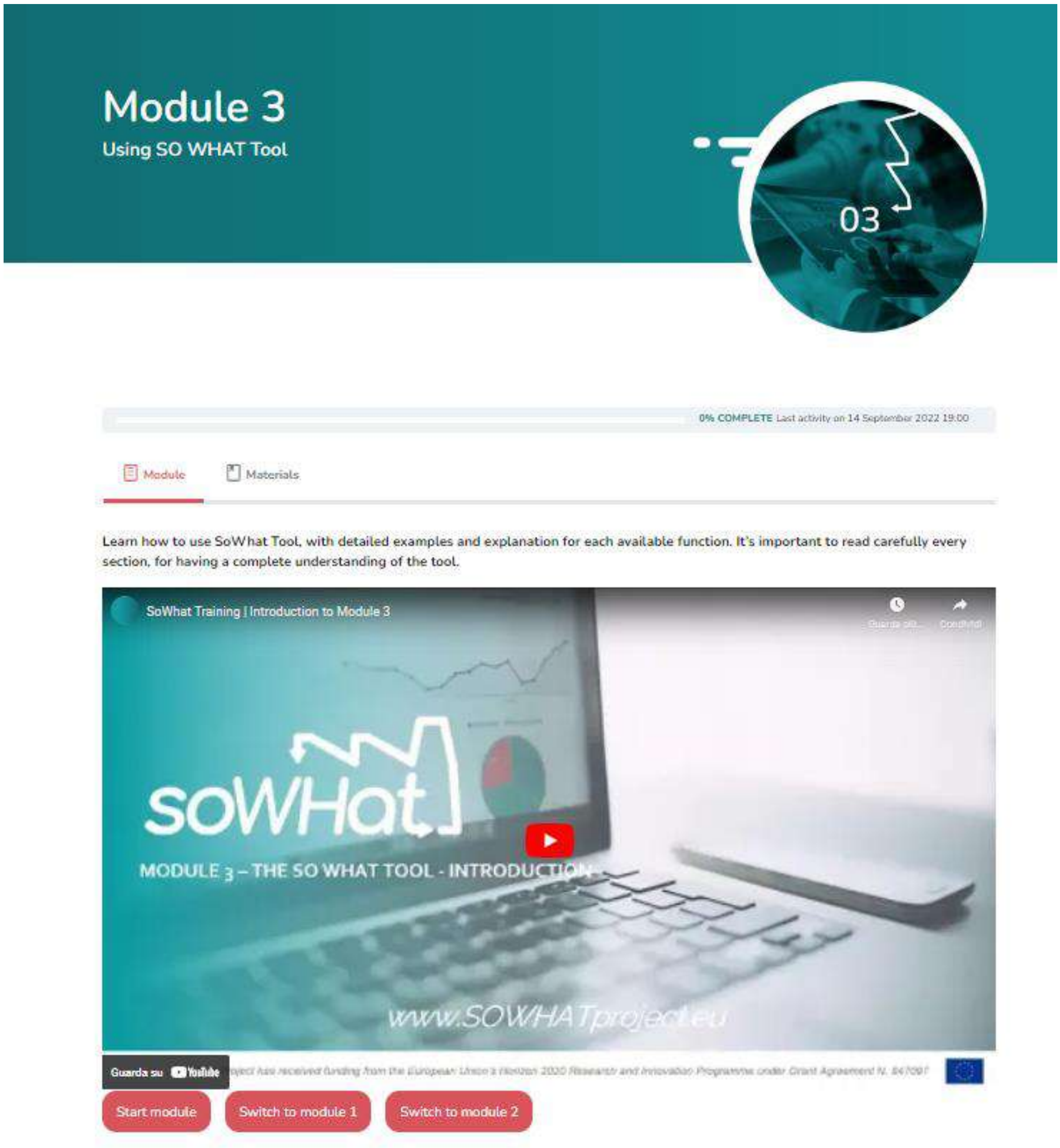

Figure 10 Module 3 home page & intro videos

It consists of:

Module 3_Intro video

The section of the training starts with an intro video of 1.58 minutes (showing a pptx with the voice of the "teacher"). Link: https://www.youtube.com/watch?v=S4j7BpEvfk4

Module 3_ SO WHAT manual

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The deliverable 4.8 developed by IESRD at M40 is inserted as training material. The material is divided in 3 Chapters:

- SECTION A: Install the SO WHAT software
- SECTION B: Waste heat/cooling potential for a single industrial/manufacturing site
- SECTION C: Waste heat/cooling potential for the community

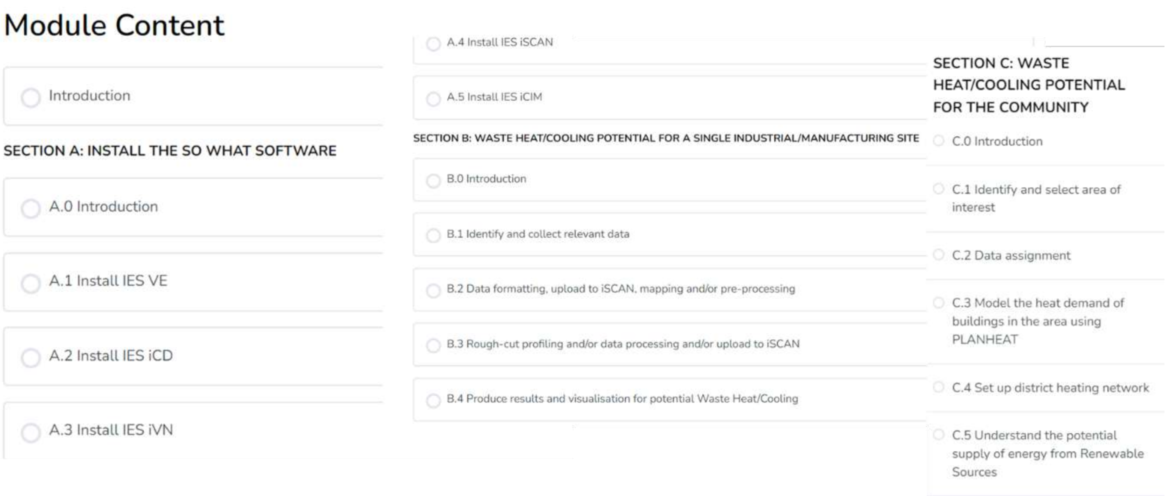

Figure 11 Module 3 SO WHAT manual contents

3 Training dissemination

A dedicated brochure was created and charged on the website.

4 Results from internal training trial

An internal trial was performed by 10 "trainees" from the Clusters in order to collect training feedbacks. The final satisfaction survey results are below reported, with the main number of students satisfied on the training material developed:

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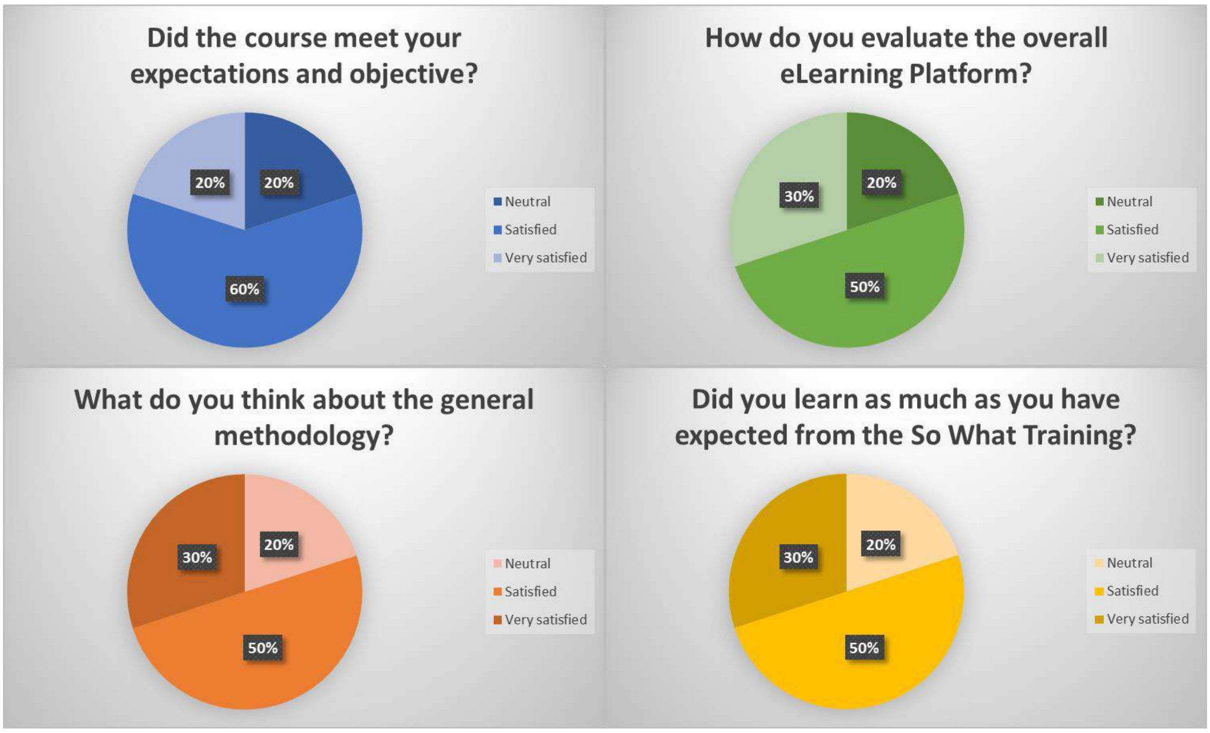

Figure 12 Internal trial training results

The last question is focused on analysing the tool expectations, below some results:

- the So What tool has the potential to help model waste heat use both on our Company's site and others but there are limitations with regards to the python scripts use of variable inputs that need to be overcome and the communications between the different parts of the software are overly complicated which can lead to problems when transferring data between the different software.
- the main expectations were for a tool that, by receiving as input real plant data, potential wasted energy and real energy price data, would be able to assess the amount of recoverable energy and economically evaluate its areas of use and economic aspects. Expectations regarding the economic evaluation of the investment, according to the main financial parameters has been met. However, it is still in charge of the user to carry out the energy evaluation of the scenario
- the main expectations were to simulate the cases and have a full feasibility result at the end Expectations have been satisfied, in fact we were able for both cases to reach the status of a full feasibility result.

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5 Annex

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MODULE 1

CHAPTER 1: DESCRIPTION OF WASTE HEAT AND COOLING

www.SOWHATproject.eu

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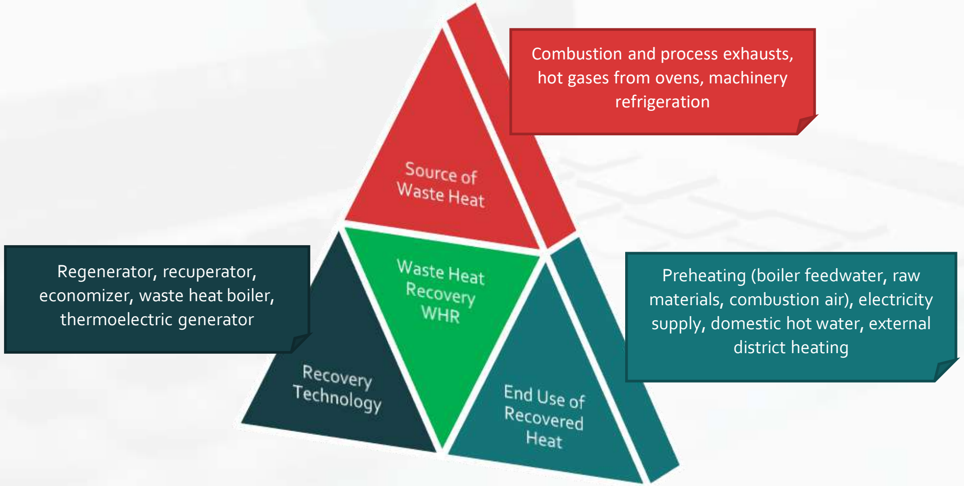
Preface

20-50% of the industry energy consumption ends as WH and 18-30% could be recovered

3 main components are required to accomplish it:



S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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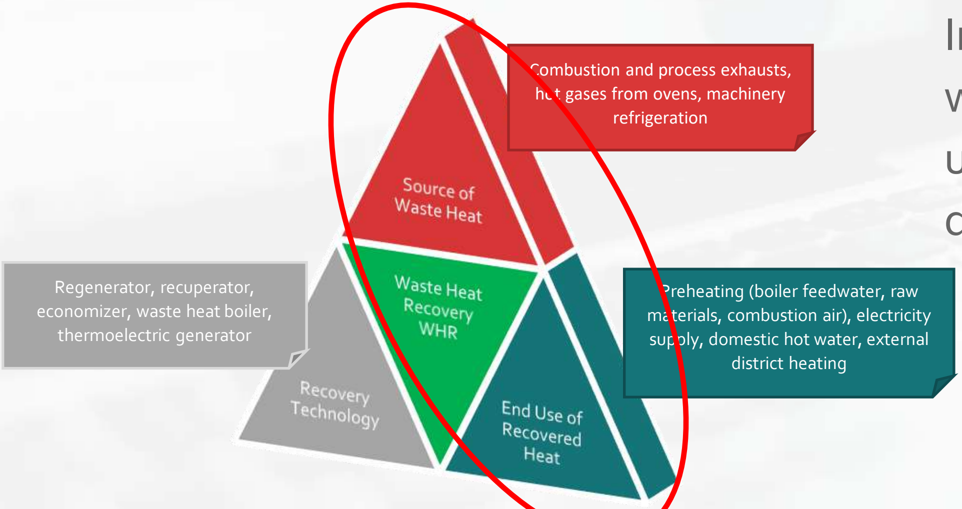
Preface

Waste heat is generated along the industrial processes as a by-product in different forms, but the key factor is a suitable "end use" for the recovered heat



In Chapter 1, the main sources of waste heat and the possible end use of the recovered heat will be described

S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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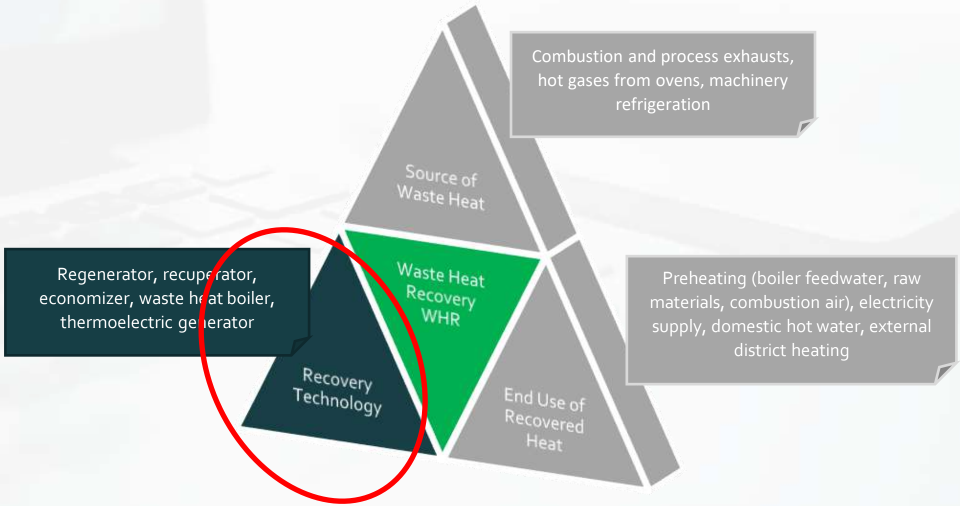
Preface

There are different technologies available depending on the type and power of the waste heat source, the temperature ranges and the final use of the energy

In Chapter 2, individual technologies will be reviewed with a focus on operating principle, performance and typical applications



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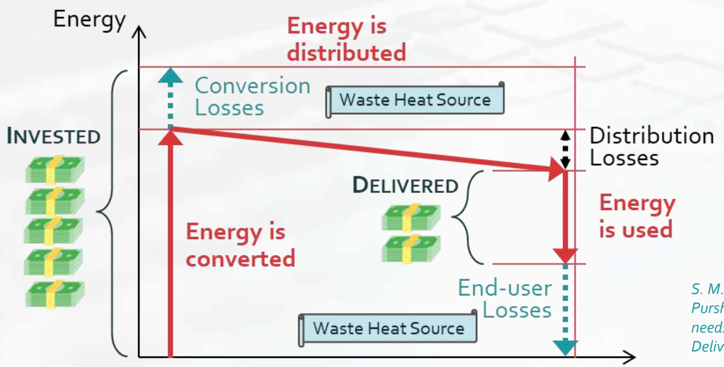
Introduction

WH is generated along the industrial processes as a by-product in different forms such as combustion gases, heated water or heated products.

Conversion losses and end-user losses represent possible sources of waste heat, while distribution losses are non-usable system inefficiencies.

Energy cycle and waste heat sources



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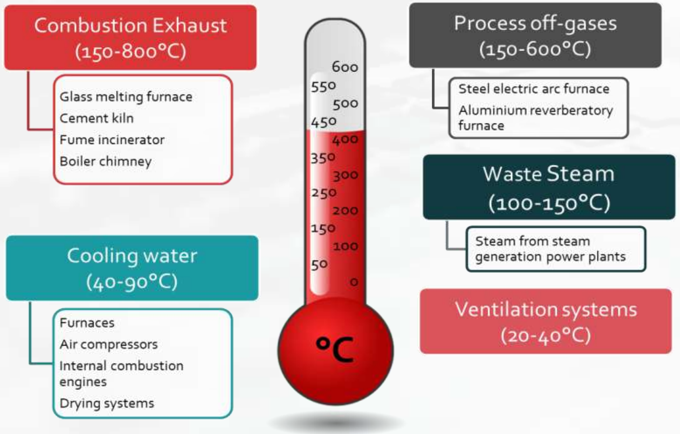
Introduction

Most waste heat recovery devices transfer heat from a higher temperature effluent stream to another lower temperature inlet stream

WH "usefulness" will be determined by its temperature, so that the higher its temperature, the higher its quality



S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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Sources of Waste Heat

Non-Ferrous Metals

In this sector most WH comes from low temperature sources (<200°C)

Used for space heating or power generation through ORCs

Aluminum

- Hall-Héroult process
- Most sources are at low temperature of 300°C or lower
- The amount of waste heat is limited
- Used for space heating and preheating of raw materials

Source: Shutterstock

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Sources of Waste Heat

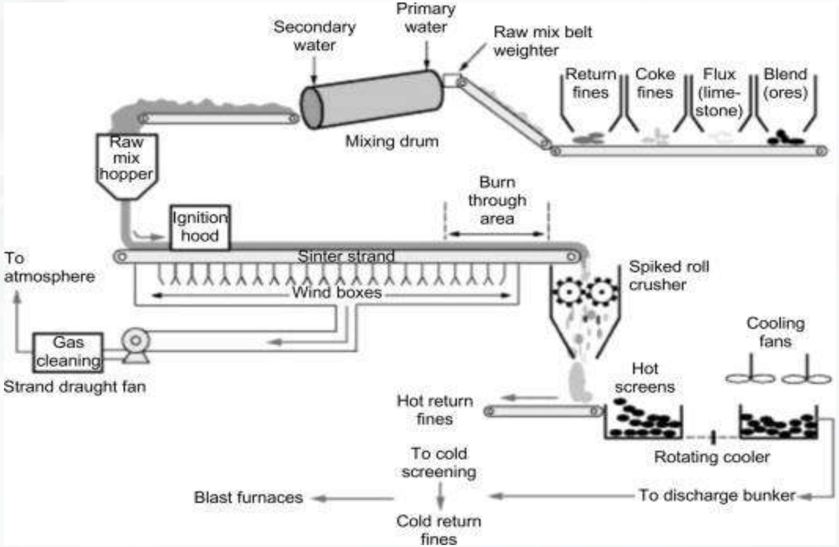
Non-Ferrous Metals

Zinc and Cadmium Roasting

- Exothermic process carried out at 900°C approximately
- Recovery through cooling systems
- Used to produce steam for power generation

Sintering and roasting processes of other ores

- Process at high temperature
- Recovery from flue gases
- Used to preheat air or produce steam



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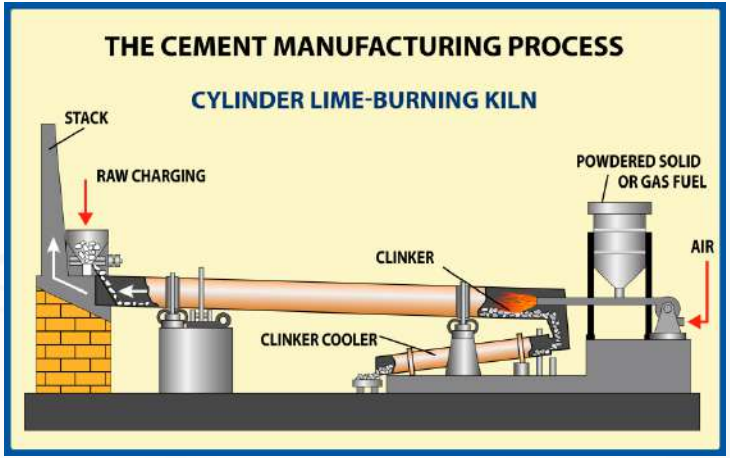
Sources of Waste Heat

Non-metallic minerals

Cement

- Process: calcination and sintering a mix of components in a rotary kiln at high temperature
- A kiln uses approximately 3.300 MJ per tonne of product using 55% of the energy to drive the process
- The gases coming from coolers or preheaters have a typical temperature between 250-380°C
- 0.3 GJ of energy per tonne of clinker is calculated to be available in the exhaust streams



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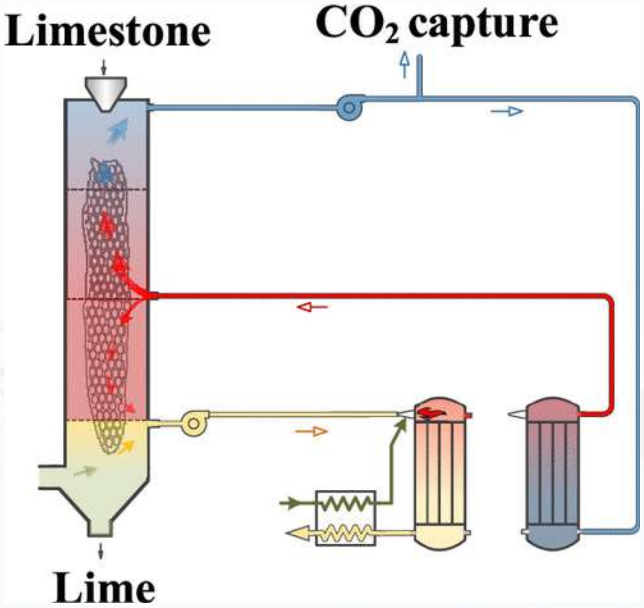
Sources of Waste Heat

Non-metallic minerals

Lime

- Process: calcination of crushed limestone at approximately 900°C
- Used for pre-heating the limestone being fed into the process
- Cooling air from cooling the lime may be used as warmed combustion air



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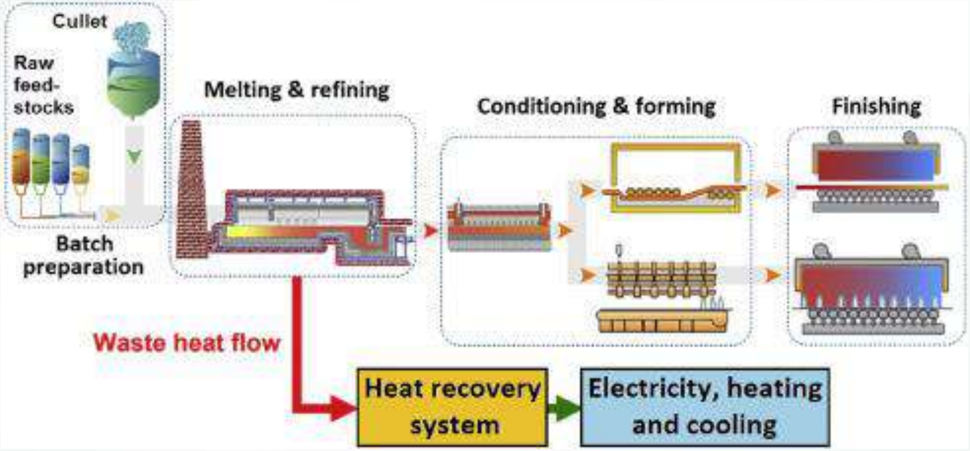
Sources of Waste Heat

Non-metallic minerals

Glass

- Process: melting a mixture of sand, minerals and recycle glass in a furnace at a temperature of over 1500°C
- There exist examples of using ORC machines to electricity generation
- WH used for reheating combustion air



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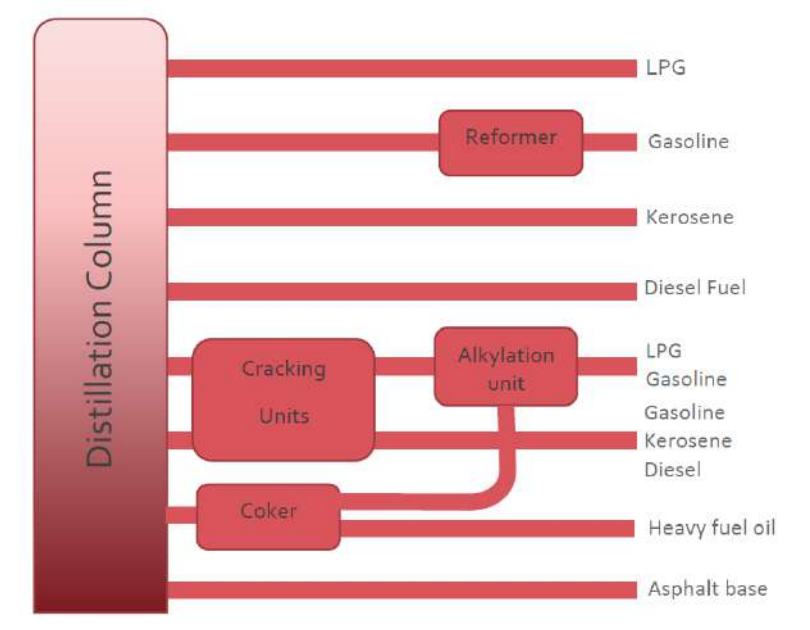
Sources of Waste Heat

Chemical and petrochemical

- Crude oil is heated to 400°C before be fed into a distillation column
- After distillation, the lighter fractions are reformed and hydrotreated to produce gasoline and diesel, while heavy fractions are cracked
- WH produced at medium and low temperature
- Used to preheat incoming feedstocks using heat exchangers



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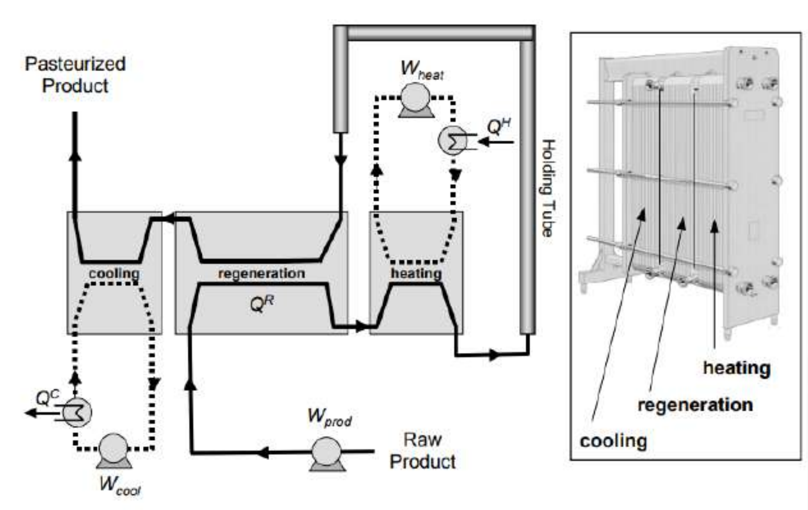
Sources of Waste Heat

Food and Beverage

- Processed: Baking, boiling, frying, drying, distilling, pasteurising and refrigerating
- Most processes are at low temperature (<260°C)
- WH from Pasteurisation can be used to warm the incoming product
- Using heat exchangers to warm the incoming product is very common



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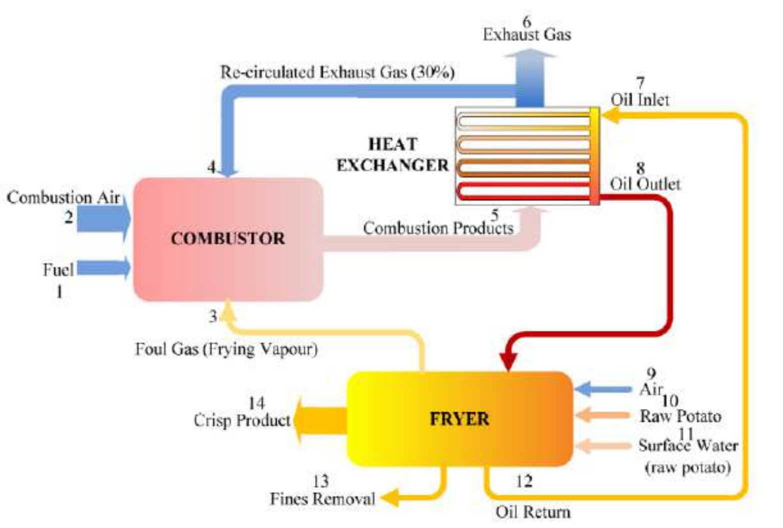
Sources of Waste Heat

Food and Beverage

- Baking ovens produce flue hot gases at >200°C. WH can be used to preheat combustion air
- Possible problems with dirty streams
- A solution to recycle frying vapours could be directly mix them with the combustion air pre-heating the entering stream and reducing the energy needed



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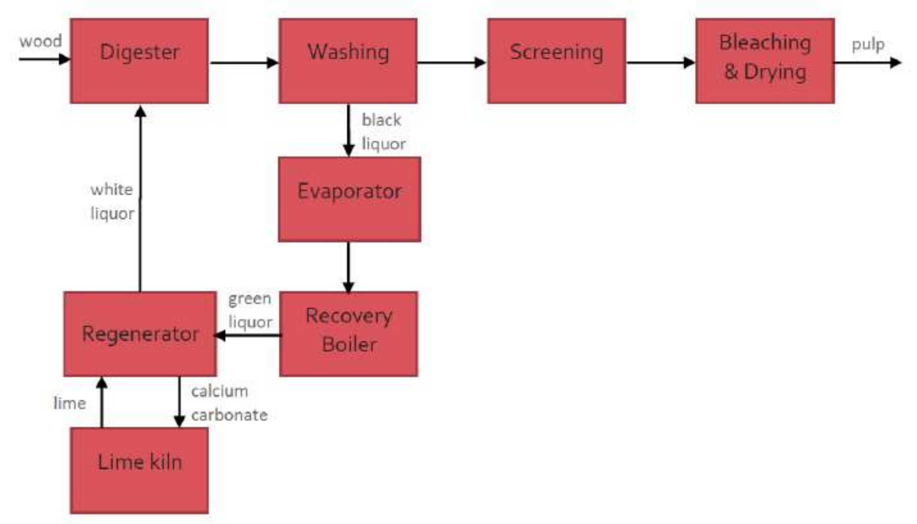
Sources of Waste Heat

Paper, pulp and printing

- Process: Kraft process. Wood is cooked at 170°C
- Tree bark and rejected pulp are often burned at paper mills to produce power and steam used in the processes
- Opportunities to recover energy from exhaust steam from the cooking and evaporating processes



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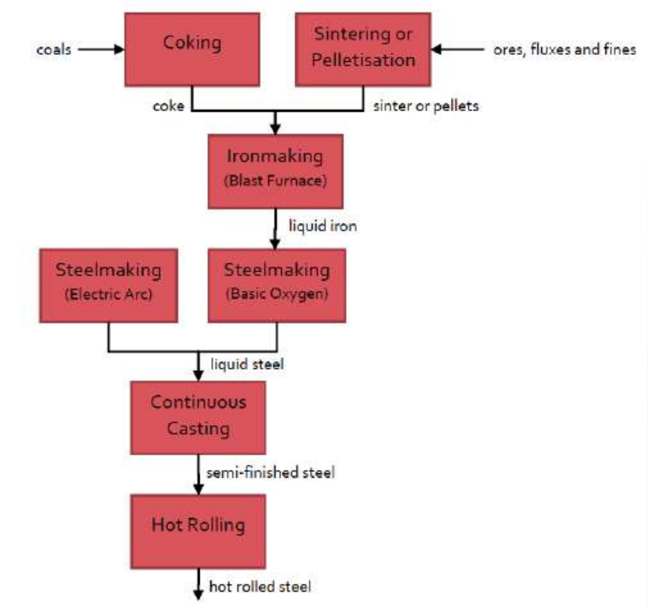
Sources of Waste Heat

Iron and steel

- Processes: Blast furnace and basic oxygen furnace (BF-BOF) process uses virgin ores. Electric arc furnace (EAF) process re-melt scrap and alloys
- 25% of the EAF input energy may be recovered to produce steam for power generation but this is rarely practised due to practical issues
- This industry produces hot steel products at high temperatures, over 700°C
- Economic payback and capital availability rather than technical feasibility typically limit the adoption of heat recovery solutions



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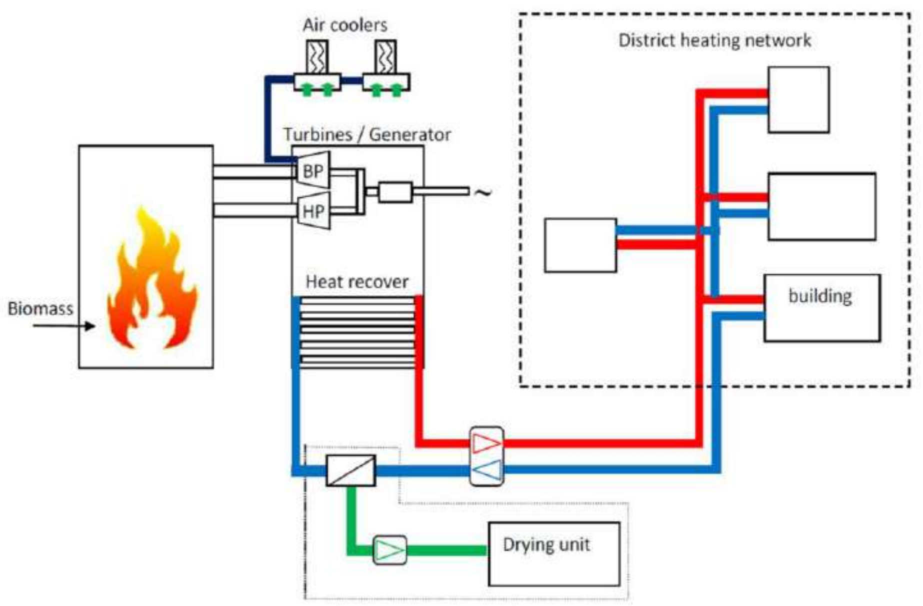
Sources of Waste Heat

Power and energy

- Combined heat and power stations are often used on to provide process heating and steam for industrial processes or heat for space heating
- WH mainly at temperatures less than 100°C and the rest at intermediate temperatures between 100 and 300°C
- Traditional incinerators handle temperatures between 1,000 and 1,300°C
- Hot exhaust gases can be used to produce steam for electricity generation



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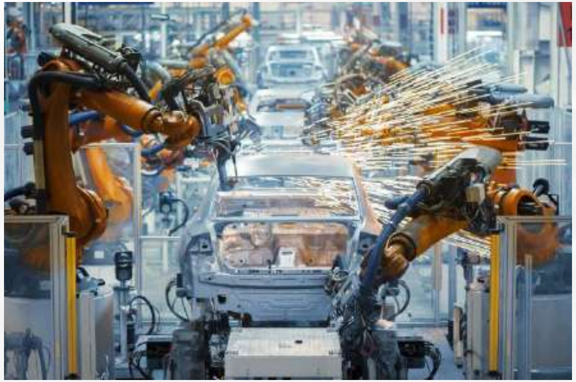
Sources of Waste Heat

Other industries

- Transport and machinery manufacture, textiles, mining, construction and wood processing, are assumed to be at temperatures less than 200°C which tend to be used in space or district heating applications



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Recovery of Waste Cold

- Main source of waste cold energy found in the literature is that released during the regasification of liquefied natural gas (LNG)
- This gas in liquid state is transported to consumer countries at a temperature of -160°C
- Regasification energy may be harnessed to produce electricity either by driving generators by the direct energy of gas expansion or by using ORC machines
- In 5th Gen District Heating networks cold water is pumped to customers for equipment of air conditioning. Absorption chillers and conventional Heat Pumps can be used to achieve the correct temperature with very high efficiency

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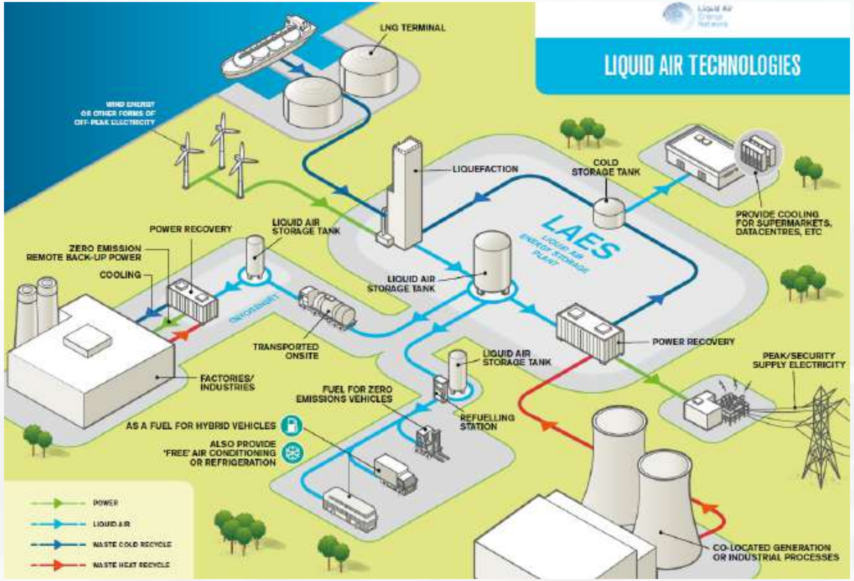
Recovery of Waste Cold



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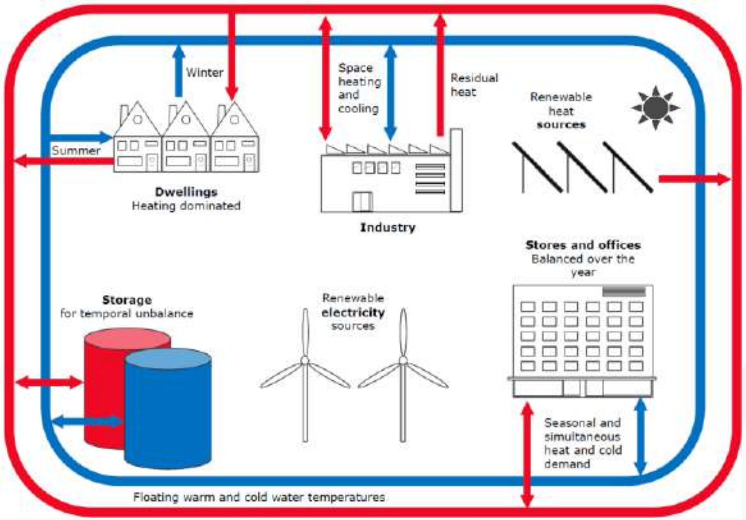

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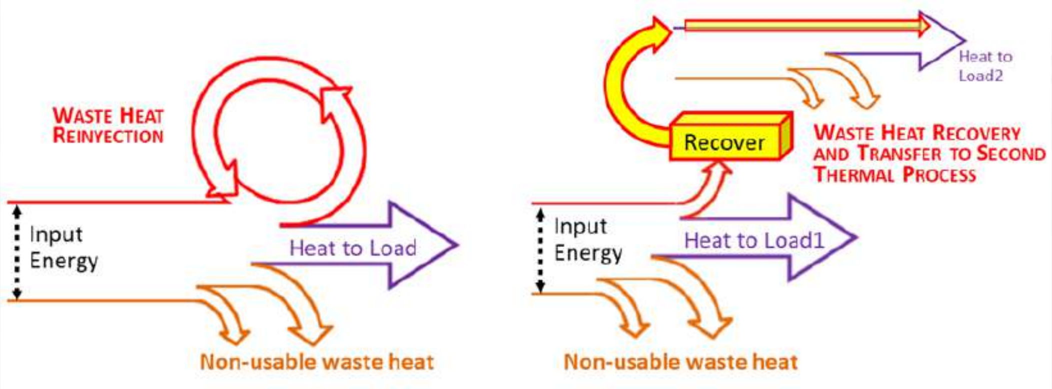
End use of recovered waste heat

Two possible ways to use WH: internal use or external use

- **Internal**: the industrial facility itself transforms and consumes the recovered energy. Whether it is in the form of heat or it is transformed into other forms such as refrigeration or electrical energy.
- Direct recovery to the original process or recovery with transfer to a second process is considered
- Direct recovery facilitates temporal synchronization production of waste heat and its reuse



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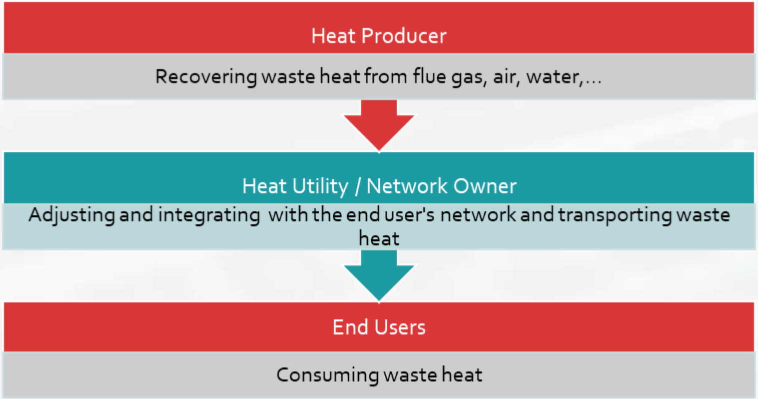
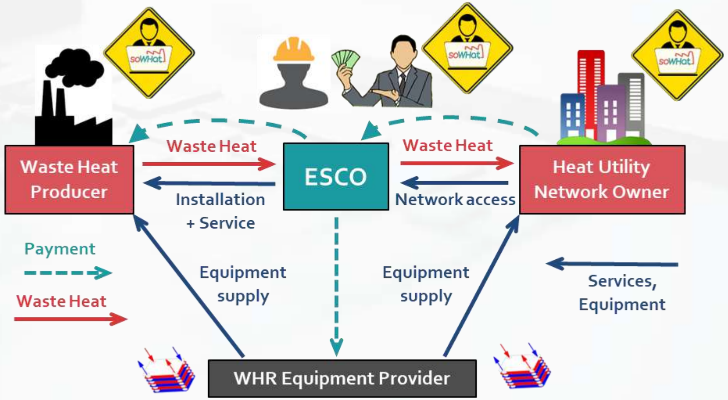
End use of recovered waste heat

Two possible ways to use WH: internal use or external use

- **External:** possibility of introducing intermediate actors (ESCOs) between heat producers and end users
- ESCO finances the installation of heat recovery systems in the factory and remunerates the heat producer for the recovered heat which is supplied to the heat utility or the owner of the heat network, which pays to the ESCO





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End use of recovered waste heat

The greatest challenge to implement a WHR scheme is finding the “end use” for the recovered heat. Some of the questions that must always be asked before considering the design of a WHR project could be the following:

- Where will you use the recovered heat?
- Is the heat sink close or far from the waste heat source?
- Is the heat sink appropriate for the heat source temperature?
- Will heat sink and heat source operate at the same time, all the time?
- Will its volume vary considerably, and often?

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MODULE 1

CHAPTER 1 DESCRIPTION OF WASTE HEAT AND COOLING

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ABBREVIATIONS

BF-BOF: Blast Furnace and Basic Oxygen Furnace

EAF: Electric Arc Furnace

ESCO: Energy Service Company

EU: European Union

LNG: Liquefied Natural Gas

ORC: Organic Rankine Cycle

RES: Renewable Energy Sources

WH/C, WH/WC: Waste Heat/Cold

WHR: Waste Heat Recovery

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SHORT SUMMARY

In this module, it will be given a detail description of how to investigate the waste heat & cold energy consumption and the potentials regarding the technology and how to exploit it externally for an industrial plant. The main inputs at this document come from the study conducted within SOWHAT project in WP1 and WP2 and some deliverables linked:

- D1.2 First release of SO WHAT Industrial Sectors WH/C recovery potential.
- D1.5 Strategies and protocols for input data collection.
- D1.6 Report on H/C recovery/storage technologies and renewable technologies).
- D2.1 Report on end-users' current status, practises and needs in waste H/C recovery and RES integration.

Three pillars constitute the basis for this training module: industrial energy auditing, WH/C exploitation inside and outside the industrial site and the related technologies to achieve such objective, which is reflected in the following structure of the handbook. This module will address the topics related to general aspects of the above-mentioned pillars and it will provide technical inputs to the trainee and a solid basis for the prosecution of the training activities.

The handbook structure is here reported:

- Chapter 1: Description of the waste H/C: how it is generated and where it can be seen most in the industrial plants.
- Chapter 2: Analysis of WH/C technologies.
- Chapter 3: Insights into the data needed to be collected to run the simulations and the related formats.
- Chapter 4: Inputs related to the mapping, the tool's needs to map local RES and municipality or an industrial plant feature.
- Chapter 5: High-level information and details linked to the simulation environment, including possible checks and evaluation of the consistency of data.
- Chapter 6: The cause-effect relation between input data and outputs will be introduced in terms of qualitative and quantitative information.

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1 Introduction

Thermal and mechanical processes always produce waste heat (WH) to the point that between 20 and 50% of the industry energy consumption finally ends as WH, of which a significant part between 18 and 30% could be used, according to estimations.

In the European Union, domestic hot water, space heating and other ways of process heating account for more than 50% of the energy use. But centring our scope in industry and according to the European Commission data [1], the 70% of the energy used in the European industry is used for space and industrial process heating (193.6 Mtoe). Taking into account this figures, the waste heat may represent an important source of energy as long as its recovery and use become technically and economically feasible, which may suppose between 7 and 30 Mtoe saved annually with its respective money and emission savings.

Starting to talk about the technical point of view of waste heat recovery (WHR), three main components are required to accomplish it: 1) a source of waste heat, 2) a recovery technology, and 3) an end use for the recovered energy. This concept, represented in Figure 1, is a key point to understand the conditions needed for a good implementation of a WHR strategy so that it will be totally unfeasible in case one of the three parts is not assured.

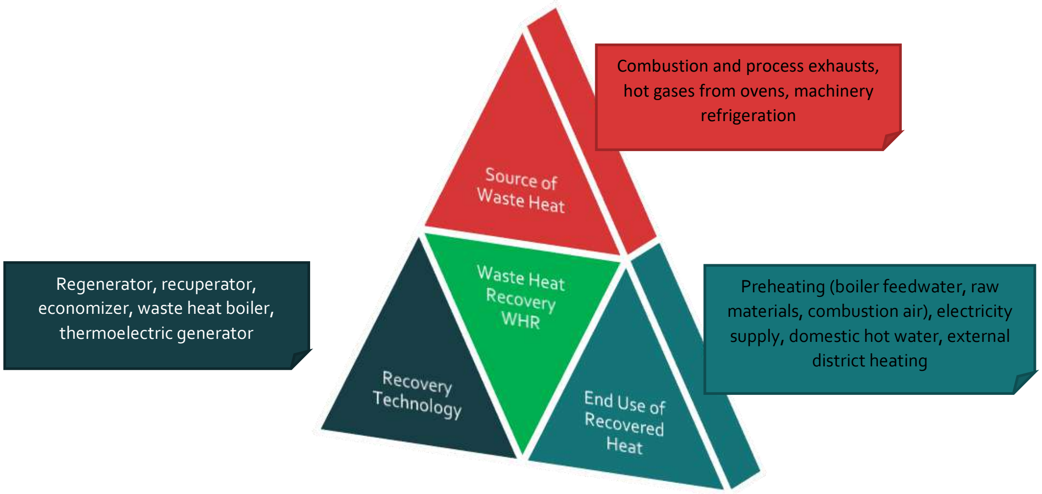

Figure 1 Essential components for Waste Heat Recovery (WHR) [2]

The sources of WH differ among themselves in the physical state, the temperature ranges, their type of occurrence and of course the power thermal available. WH is generated along the industrial processes as a by-product in different forms such as combustion gases, heated water or heated products. As depicted in Figure 2, conversion losses and end-user losses represent possible sources of waste heat, while distribution losses are not usually considered as sources of WH but non-usable system inefficiencies.

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Energy cycle and waste heat sources

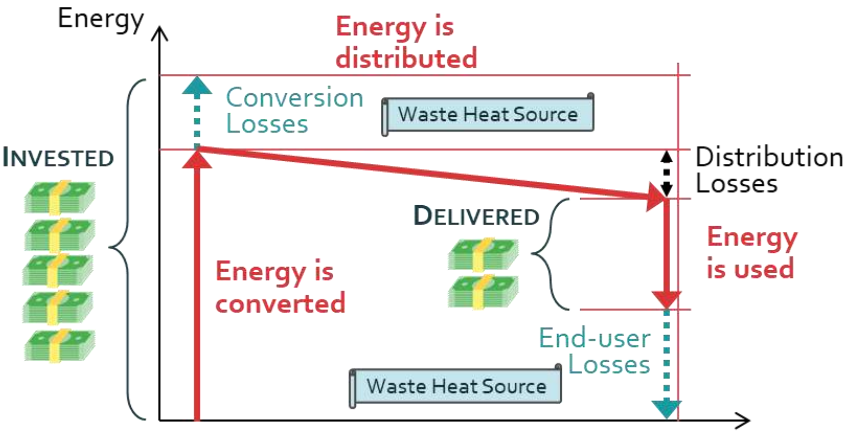

Figure 2 Industrial processes energy cycle [2]

Most waste heat recovery devices transfer heat from a higher temperature effluent stream to another lower temperature inlet stream. WH can also be used by passing hot gases or steam through a turbine to generate electricity. Therefore, as a general rule, it can be considered that the "usefulness" of a WH will be determined by its temperature, so that the higher its temperature, the higher its quality. The typical temperature ranges of processes commonly present in industry are described in Figure 3.

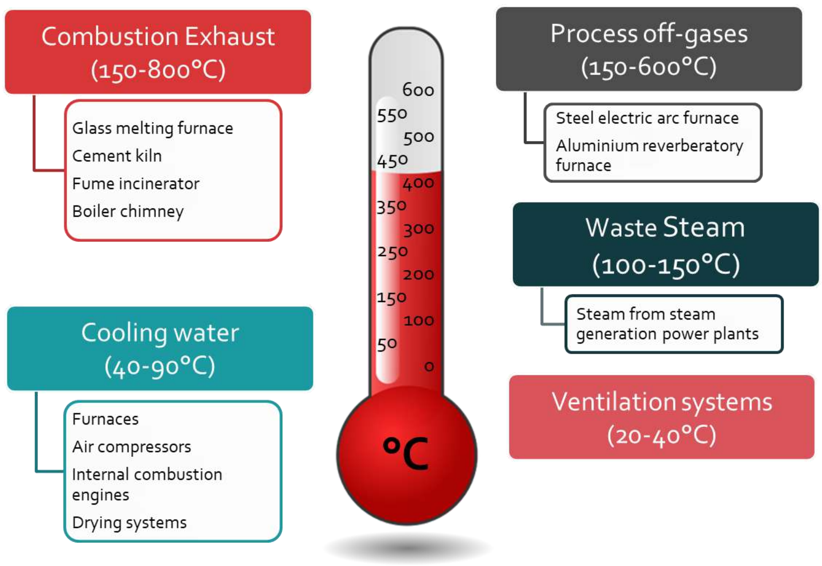

Figure 3 Industrial waste heat sources [2]

In sections below, the main sources of waste heat and the possible end use of the recovered heat will be described.

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2 Sources of waste heat

This section is focused in the description of the main energy consuming industrial processes with the highest heat recovery potential.

Non-ferrous metals

In this sector, some of the available waste heat is in the form of high temperature fumes but the most part comes from lower temperature heat sources (less than 200°C). These heat sources can most typically used for space heating or ORC machines to generate power.

Aluminium

The most common process to produce aluminium is the known as Hall-Héroult process (Figure 4). This process is performed at high temperature; however the amount of waste heat is limited due to the relatively large distances between sources and sinks. The fact that most sources are at low temperature of 300°C or lower joined to the presence of high dust loading of the streams so that the use of heat exchangers is difficult, make heat recovery to be focused in space heating and preheating of raw materials both in primary operations and in auxiliary processes.

Figure 4: Electrolytic Hall-Héroult smelting process. Source: Shutterstock

Zinc and Cadmium ore roasting

Zinc and Cadmium ores participate in an exothermic process carried out at 900°C approximately using a fluidised bed in oxygen enriched air. Waste heat is recovered through cooling systems of the machines, and it can be used to produce steam for power generation.

Sintering and roasting processes of other ores

The processes of sintering and roasting are usually high temperature and there exist opportunities for recovering waste from flue gases for pre-heating air of produce steam.

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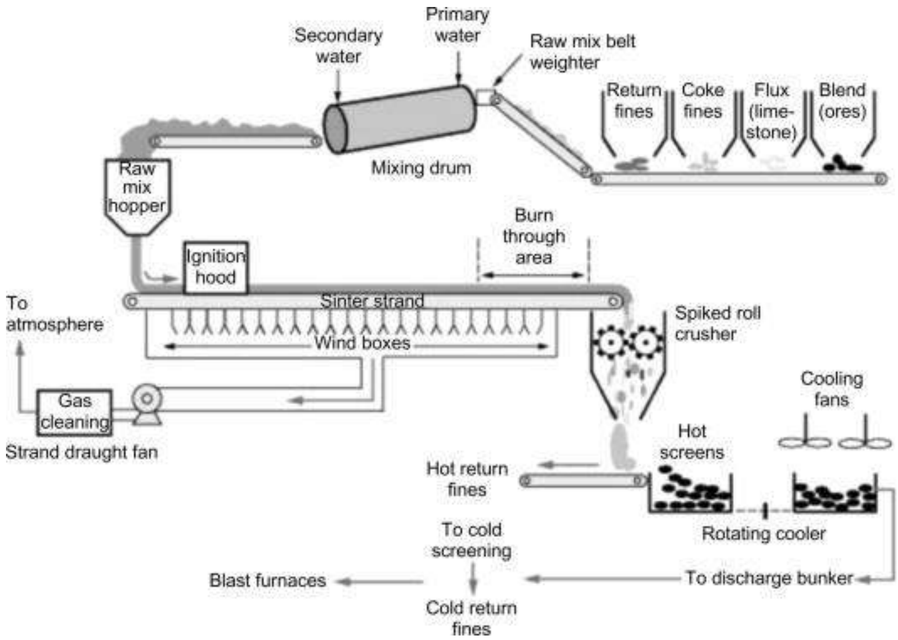

Figure 5: Schematic of a sintering plant [4]

Non-metallic minerals

The production of non-metallic minerals such as cement, lime, gypsum and ceramics is energy intensive and processes require high temperatures.

Cement

Cement is produced by a process of calcining and sintering a mix of different metallic and mineral components in a rotary kiln at temperatures of around 1.450°C to form clinker. Clinker usually constitutes at least 90% of ordinary Portland cement. The exhaust gas from the kiln is usually used to pre-heat the cement raw materials before entering the kiln.

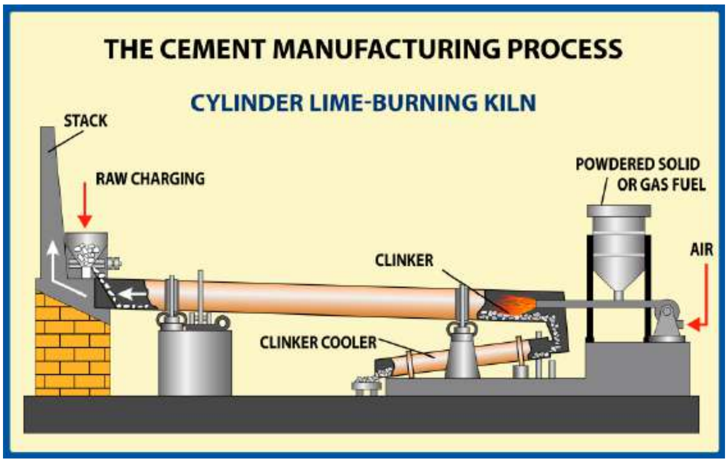

Figure 6 Energy output flows of a modern dry type clinker kiln. Source: Shutterstock

A modern kiln will use approximately 3.300 MJ per tonne of product using 55% of the energy to drive the process of clinker formation. A typical modern dry clinker cement kiln are shown in Figure 6.

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The gases coming from coolers or preheaters have a typical temperature between 250-380°C, representing 11% of the energy involved in the process. These hot gases can be used to generate electricity producing steam or using a Rankine Cycle. Even in a modern plant, 0.3 GJ of energy per tonne of clinker is calculated to be available in the exhaust streams.

Lime

Lime is produced by heating crushed limestone to approximately 900°C in vertical or rotary kilns in a process known as calcination (Figure 7).

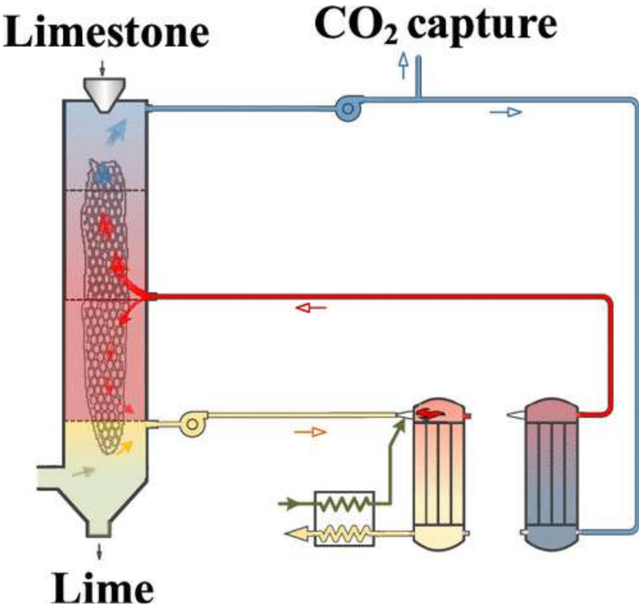

Figure 7: Vertical kiln for calcination process [6]

Waste gases from the calcination can be used for pre-heating the limestone being fed into the process. Cooling air from cooling the lime may be used as warmed combustion air in the kiln recuperating heat coming directly from the product.

Glass

Glass is produced by melting a mixture of sand, minerals and recycle glass in a furnace at a temperature of over 1500°C (Figure 8). Using economizers to preheat combustion air is a common practice due to the fact that over half the energy from glass furnace exhaust gases can be recovered. There are also examples of energy recovery from glass manufacturers using ORC machines.

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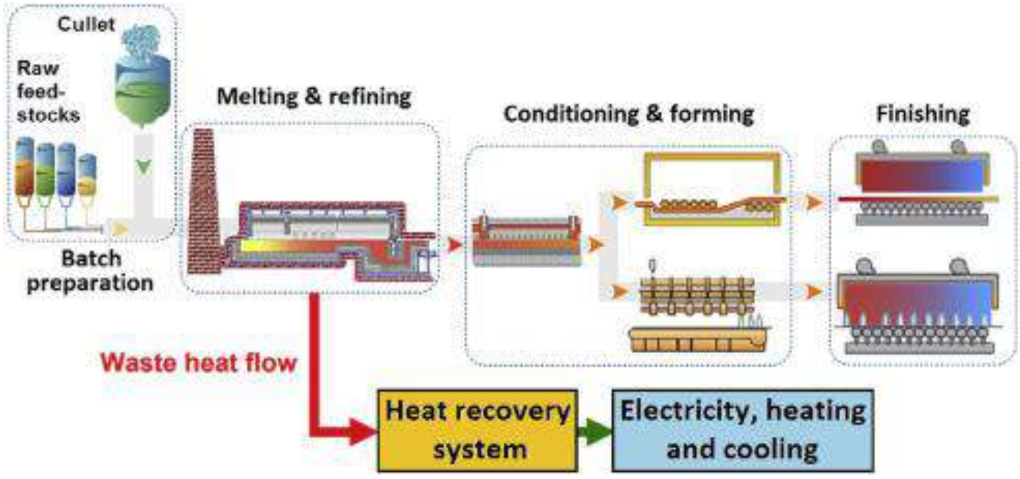

Figure 8: Glass production processes [7]

Chemical and petrochemical

Crude oil is processed by first desalting before being distilled into the fractions required. Typically the oil is heated using heat exchanged from hot distilled fractions before being heated to 400°C by a furnace and fed into a distillation column. After distillation, the lighter fractions are reformed and hydrotreated to produce gasoline and diesel, while heavy fractions are cracked. A diagram of the process is shown in Figure 9.

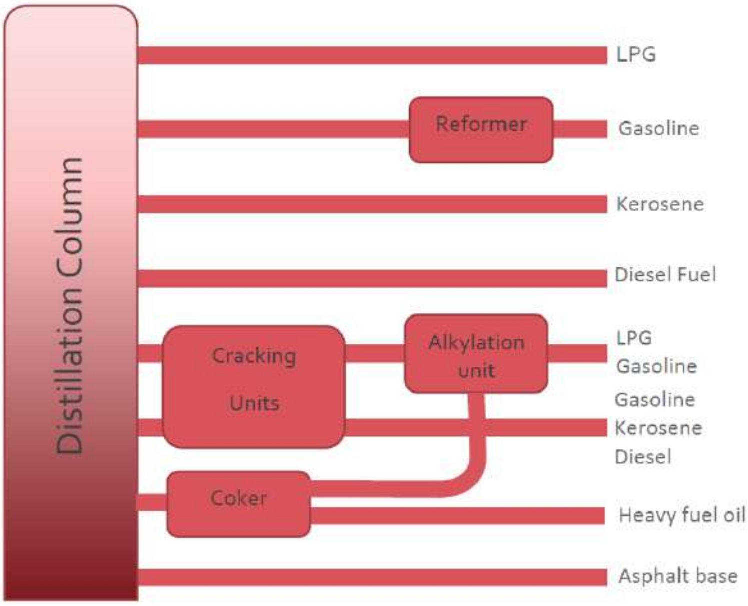

Figure 9: Diagram of oil refinery distillation process [8]

Waste energy streams from petrochemical refining are hot products and waste steam at low or medium pressures at medium (300-500°C) or low temperatures (<200°C). The hot streams are frequently used to heat incoming feedstocks using heat exchangers.

Other chemical manufactures includes the production of ammonia, sulphuric acid, cyanides, chlor-alkali and polymers. These processes require significant amounts of energy and produce waste heat streams in the medium to low temperature.

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Food and Beverage

The food and beverage industry uses a numerous heat processes including baking, boiling, frying, drying, distilling, pasteurising and refrigerating. Despite the fact that most processes are at low temperature (<260°C), heat recovery can still be usefully applied to reduce energy use.

Pasteurisation is commonly used to reduce the number of pathogens in foods. The process consists on heating food or liquids to a temperature usually less than 100°C (Figure 10). Using heat exchangers to warm the incoming product is very common and increases very much the efficiency of the process.

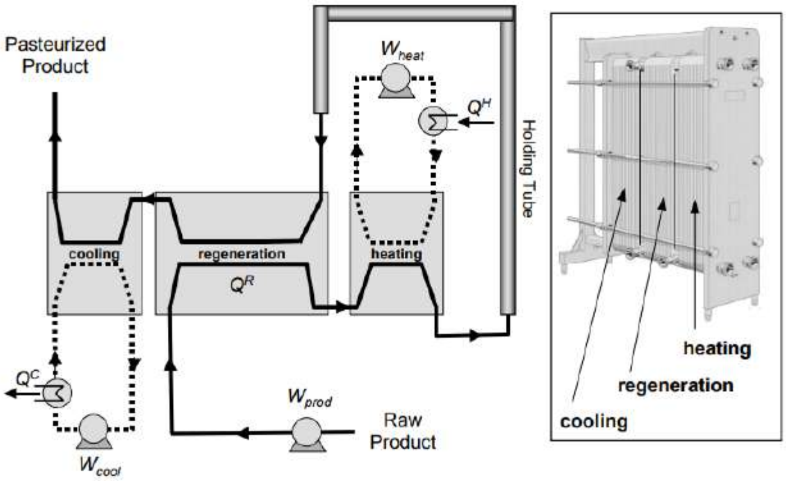

Figure 10: Schematic of pasteurization process [9]

Baking oven flues contain hot gases at temperatures over 200° which may be used easily to heat the combustion air entering the oven, reducing the amount of energy required. On the contrary, gases from frying processes contain vapours that make the use of heat exchangers quite difficult, so a solution may be recycling frying vapours directly mixed with the combustion air pre-heating the entering stream and reducing the energy needed (Figure 11).

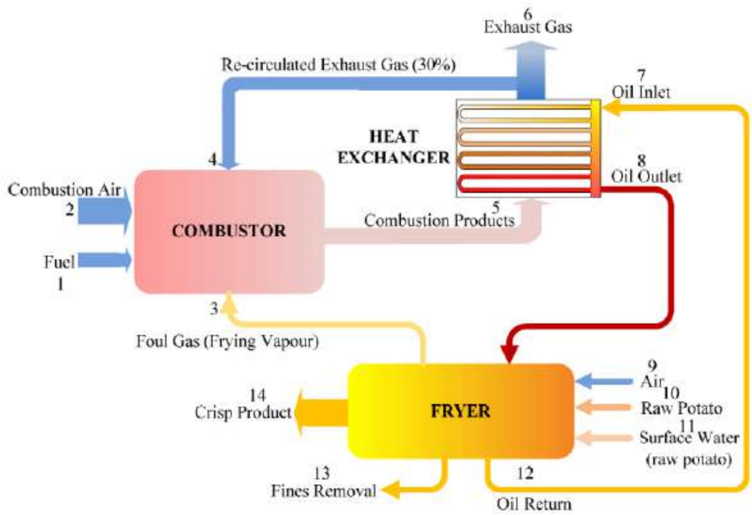

Figure 11: Schematic diagram of frying system [10]

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There are also numerous opportunities to use waste heat for space and water heating or use it combined with heat pumps increasing its performance and obtaining heat at higher temperature.

Paper, pulp and printing

The main chemical pulping process in use is the Kraft process, whose diagram is shown in Figure 12. Chipped wood is cooked in a digester, mixed with several chemicals, at 170°C to degrade the wood fibres. The pulp fibres are then removed, washed, screened, bleached and dried for paper making.

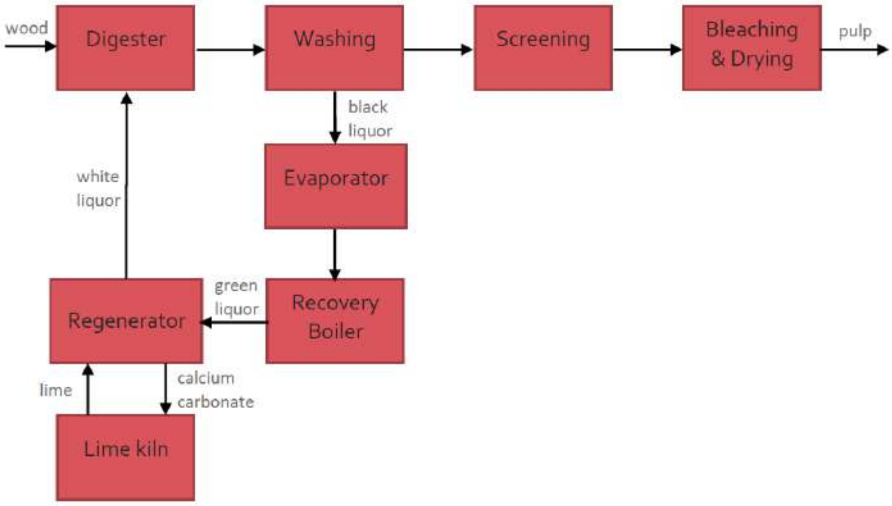

Figure 12: Diagram of the Kraft pulp making process [8]

Tree bark and rejected pulp from the screening progress are often burned at paper mills to produce power and steam used in the processes. Coupled with energy from the energy recovery boiler this can allow the process to be self-sufficient or even a net generator of energy.

There are opportunities to recover energy from exhaust steam from the cooking and evaporating processes as mentioned above for different sectors, but also to use heat exchangers to heat air entering the drying process with outgoing air or with low grade steam.

Iron and steel

Iron and steel making processes are usually divided in two types depending on the origin of the feedstock material used. Blast furnace and basic oxygen furnace (BF-BOF) route uses mainly virgin ores, while electric arc furnace (EAF) route re-melt scrap and alloys. Figure 13 describes these two major process routes.

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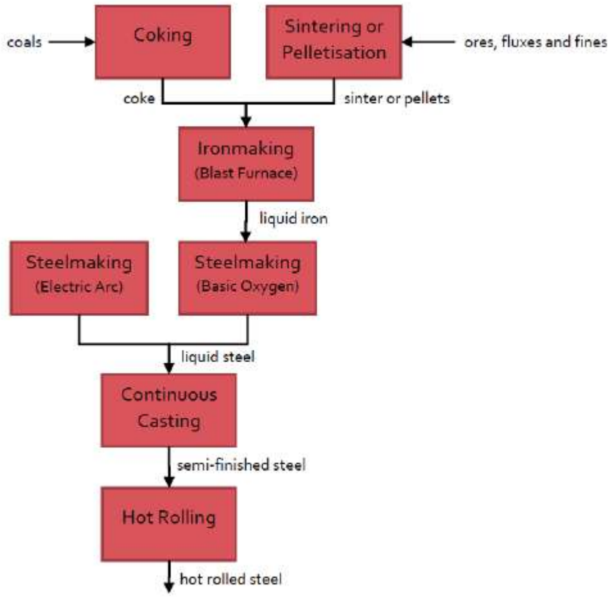

Figure 13: Diagram of iron and steel process route [8]

Some studies notes that up to 25% of the EAF input energy may be recovered to produce steam for power generation but this is rarely practised due to the harsh environment of the fume system and intermittent nature of the process.

Steelmaking processes are by nature high temperature and produce a number of hot gases streams which are particularly suited to heat recovery. Heat energy is commonly recovered to either preheat combustion fuel and air or to produce steam. Kinetic energy is also commonly recovered from blast furnace exhaust gas flows using a low pressure turbine. This industry produces hot steel products at high temperatures, over 700°C, from which very little energy is recovered due to the lack of cost effective practical technologies although projects to address this have been carried out or are ongoing.

Figure 14: Steelmaking plant. Source: Shutterstock

Most steelmakers use heat recovery in parts of their process routes; however, heat recovery solutions implemented across all steps of the route are not common. In this industry, economic payback and capital availability rather than technical feasibility typically limit the adoption of heat recovery solutions.

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Power and energy

Combined heat and power stations are often used on oil refinery and paper pulp production plants to provide process heating and steam for industrial processes or heat for space heating through district heating schemes (Figure 15).

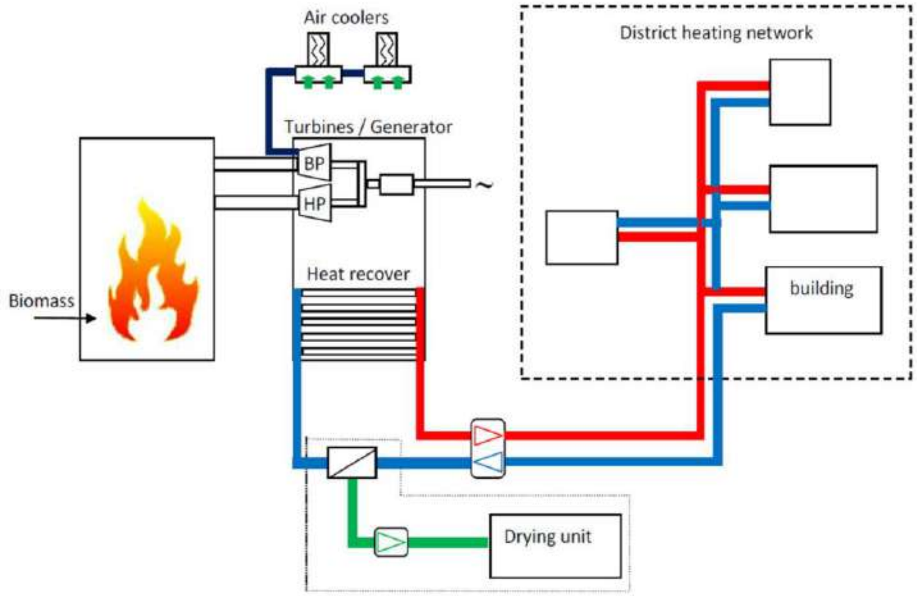

Figure 15: Schematic diagram of a cogeneration facility linked to a district heating network [12]

Waste heat energy from electricity production is mainly at temperatures less than 100°C and the rest at intermediate temperatures between 100 and 300°C. This low-grade energy is useful for space heating or recovery using ORC machines.

Europe has a long history using energy from waste both for district heating and combined heat and power plants. Traditional technologies make the incinerator to handle temperatures between 1,000 and 1,300°C, so that the hot exhaust gases can be used to produce steam for electricity generation and then heat may be used for heating water or space heating.

Modern plants using waste to generate electricity may adopt pyrolysis or gasification technologies producing carbon monoxide and hydrogen gases that may either be burned or used as inputs for other industrial processes.

Other industries

Most of the waste heat streams from other industries not described above, such as transport and machinery manufacture, textiles, mining, construction and wood processing, are assumed to be at temperatures less than 200°C which tend to be used in space or district heating applications.

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3 Recovery of waste cold

The main source of waste cold energy found in the literature is that released during the regasification of liquefied natural gas (LNG). This gas in liquid state is transported to consumer countries at a temperature of -160°C. Regasification energy may be harnessed to produce electricity either by driving generators by the direct energy of gas expansion or by using ORC machines. There exist some projects that study building a complete cold economy where waste cold recovery is a key technology (Figure 16). The cold from LNG regasification can also be used to improve the efficiency of some distillation facilities or cool the input of compressors systems in order to increase their efficiency.

Another interesting system with which waste cold recovery can be implemented is fifth generation district heating and cooling networks. In these networks cold water is pumped to customers who require coolant for equipment of air conditioning. Absorption chillers using waste heat are commonly used to generate cold during warmer seasons which is transported through the network to the users. Conventional heat pumps can also be used in these networks as boosting devices to achieve the correct temperature of use with very high efficiency and reduced energy consumption.

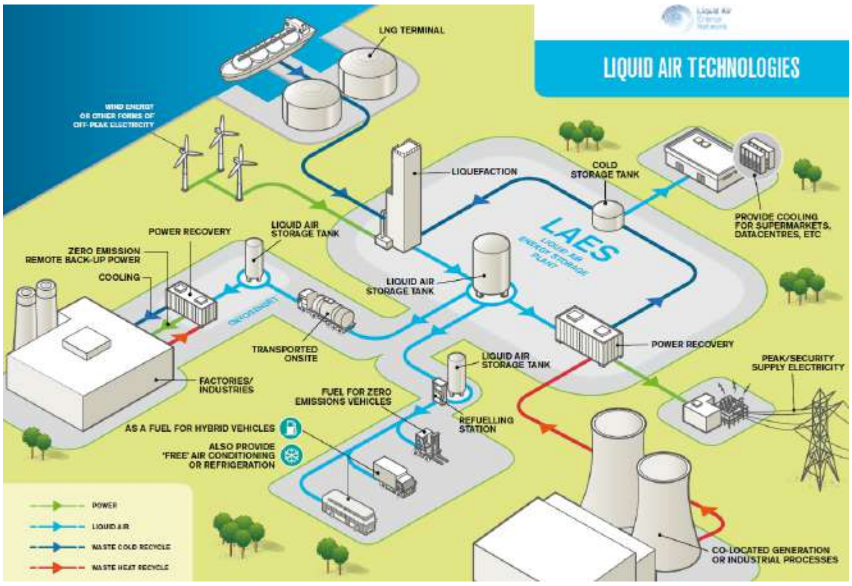

Figure 16: Diagram of potential of cold economy [13]

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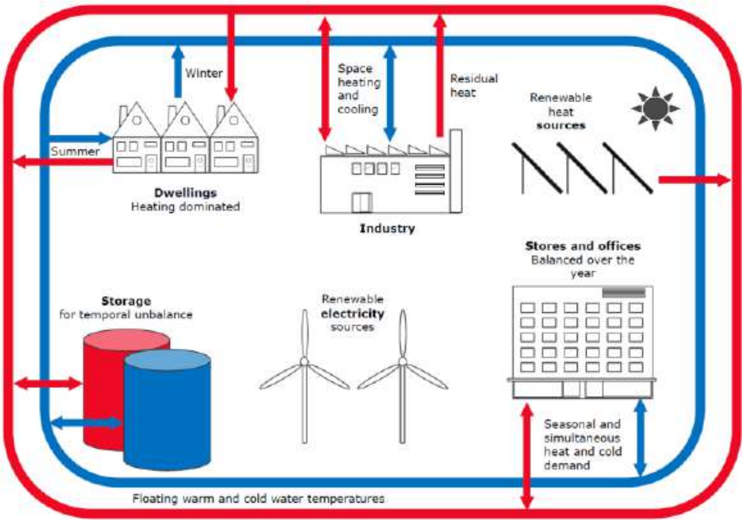

Figure 17: Fifth generation district heating network. [14]

4 End use of recovered waste heat

Regarding the final use of recovered industrial heat, its use can be classified in two possible ways: internal use or external use. When the internal use is considered, the industrial facility itself where the waste heat is recovered will transforms and consumes the recovered energy, whether it is in the form of heat or it is transformed into other forms such as refrigeration or even electrical energy. Direct recovery to the original process or recovery with transfer to a second process within the original production facility can be considered in this category. In Figure 18, energy balances of both types of internal recovery are represented.

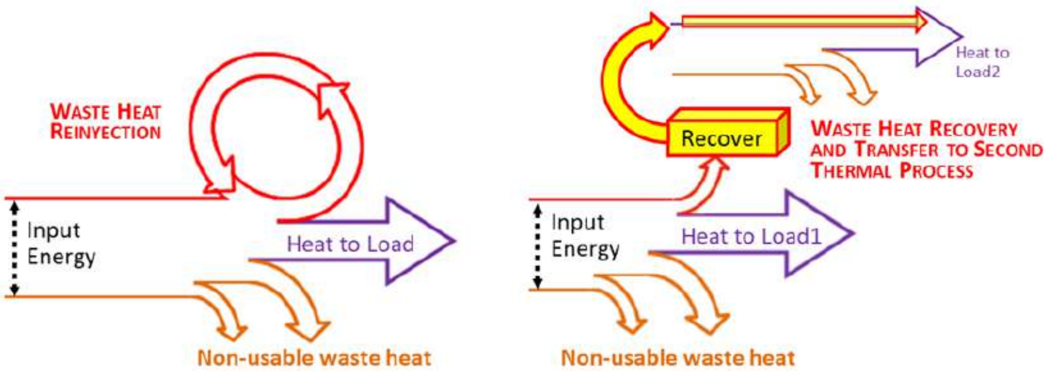

Figure 18 Schematic representation of direct WHR (left) and inter-process WHR (right) [2]

The main advantage of the direct WHR is that the temporal synchronization (matching) between the production of waste heat and its reuse is naturally guaranteed, whereas in the reuse in another process of the factory certain simultaneity of both processes must be ensured.

In the external use – represented in Figure 19 –, which is often explored when the waste heat cannot be used internally in the origin facilities, the waste heat can be used by third parties such as administrative, commercial or residential buildings or even other industries. In this case, the first challenge is the adjustment or synchronization of the potential waste heat and the demand.

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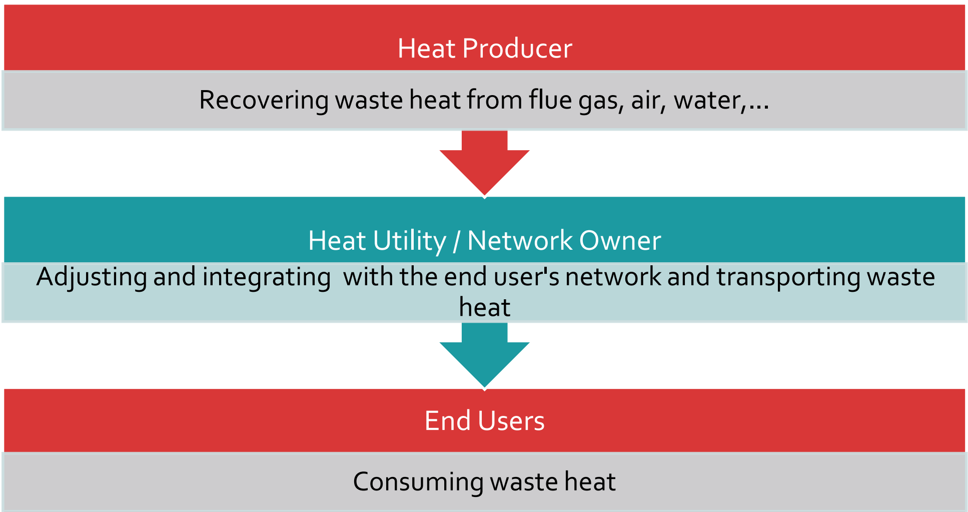

Figure 19 Schematic representation of an external use of WH recovery case. [2]

In this external use case there is the possibility of introducing intermediate actors (ESCOs) between heat producers and end users of the recovered waste heat. An intermediate ESCO finances the installation of heat recovery systems in the factory and remunerates the heat producer for the recovered heat which is supplied to the heat utility or the owner of the heat network, which pays to the ESCO for the corresponding energy supply (Figure 20).

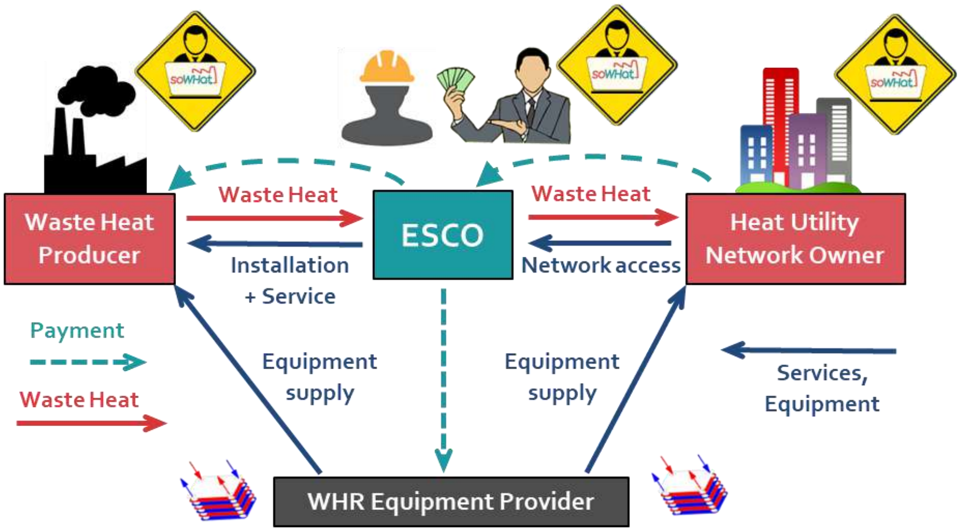

Figure 20: Schematic representation of a business model of a case of ESCO as an intermediary in an external use of WH recovery [2]

The greatest challenge to implement a WHR scheme is finding the "end use" for the recovered heat. Some of the questions that must always be asked before considering the design of a WHR project could be the following: Where will you use the recovered heat?, Is the heat sink close or far from the waste heat source?, Is the heat sink appropriate for the heat source temperature?, Will heat sink and heat source operate at the same time, all the time?, Will its volume vary considerably, and often?

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MODULE 1

CHAPTER 2: ANALYSIS OF WASTE HEAT AND COLD TECHNOLOGIES

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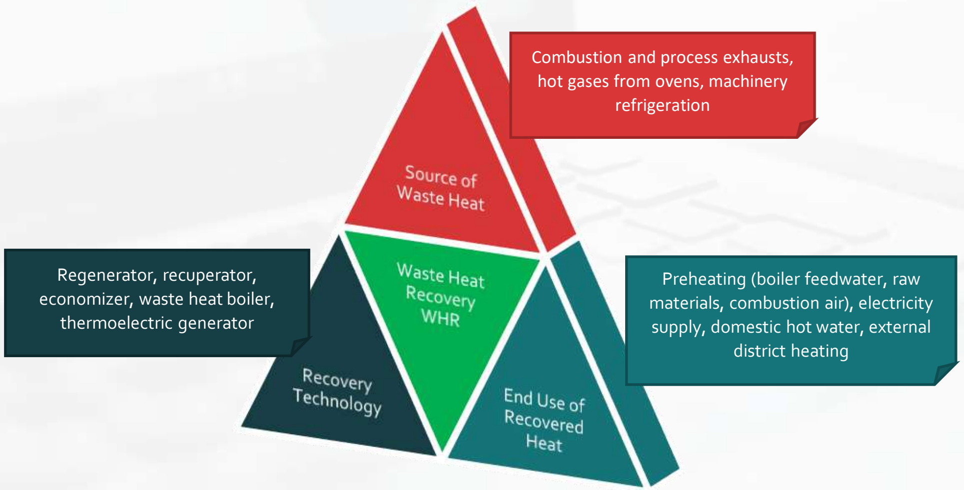
Preface

20-50% of the industry energy consumption ends as WH and 18-30% could be recovered

3 main components are required to accomplish it:



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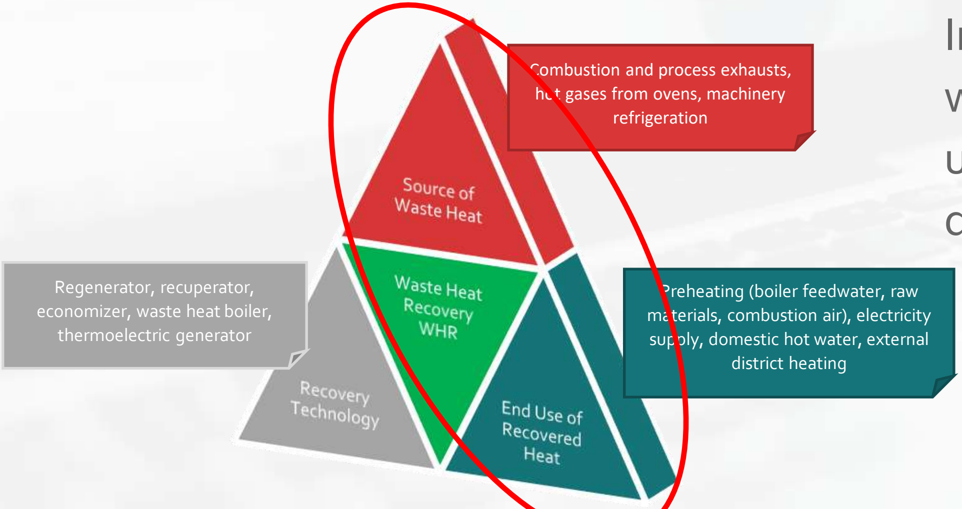
Preface

Waste heat is generated along the industrial processes as a by-product in different forms, but the key factor is a suitable "end use" for the recovered heat



In Chapter 1, the main sources of waste heat and the possible end use of the recovered heat were described

S. M. Gutiérrez Caballero, F. Morentin, L. Á. Bujedo Nieto, F. Peccianti, N. Purshouse, and C. Ferrando, 'Report on end-users' current status, practices and needs in waste H/C recovery and RES integration', SO WHAT H2020 Project, Deliverable 2.1, Jan. 2020. [Online]. Available: www.sowhatproject.eu.

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Preface

There are different technologies available depending on the type and power of the waste heat source, the temperature ranges and the final use of the energy

In Chapter 2, individual technologies will be reviewed with a focus on operating principle, performance and typical applications

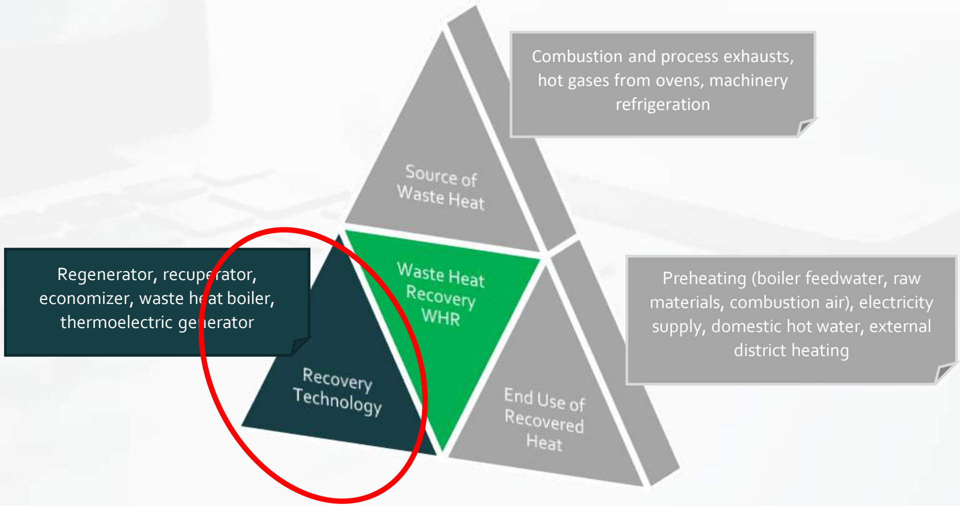

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Table of Contents

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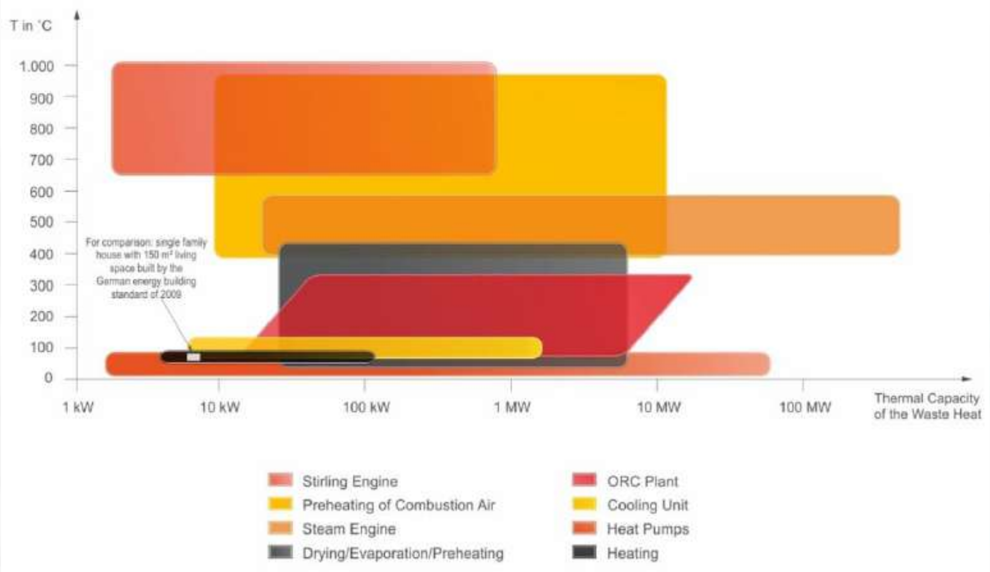
Introduction

The equipment used for waste heat recovery must take into account parameters such as pressure and temperature operation ranges, waste heat source size, carrier, purity and corrosiveness of the streams



Source: Sächsische Energieagentur GmbH

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Introduction

The Chapter is structured into five sections, each one dedicated to a category of WH/C recovery technology

- **Waste Heat-to-Heat (WHTH)**
- **Thermal Energy Storage (TES)**
- **Waste Heat-to-Cold (WHTC)**
- **Waste Heat-to-Power (WHTP)**
- **Heat Upgrade (HU) technologies**

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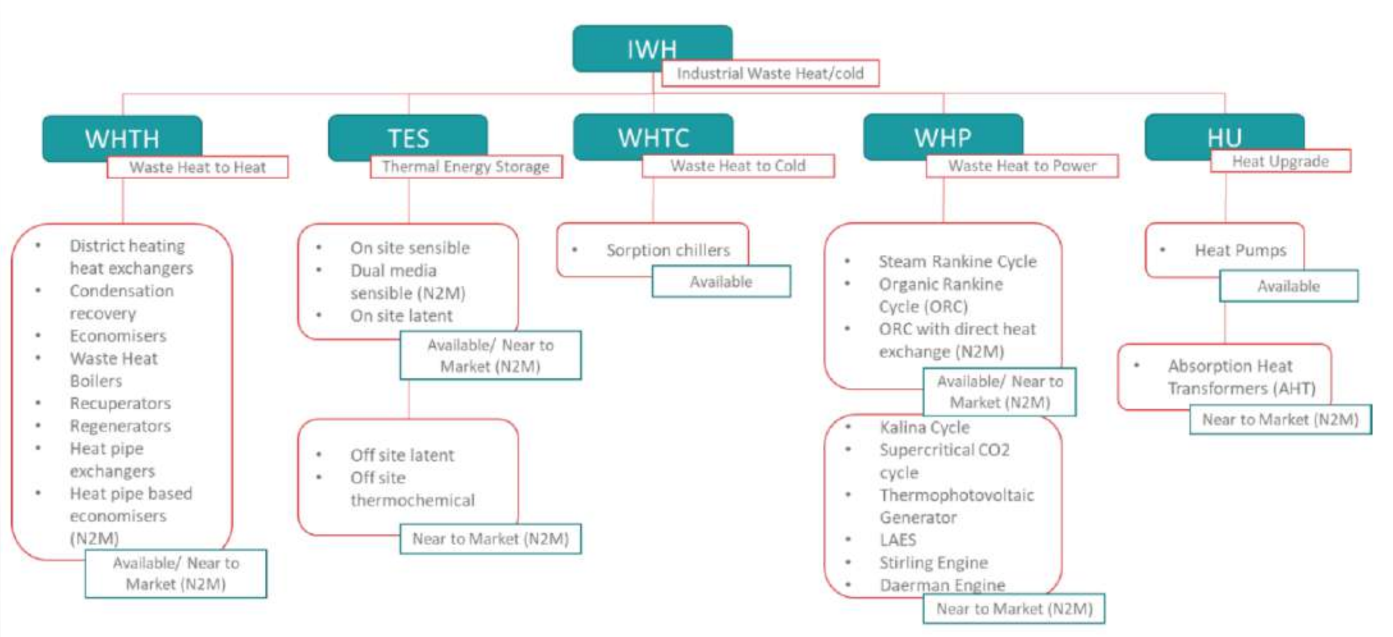
Introduction

The document is structured into five sections, each one dedicated to a category of WH/C recovery technology



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Waste Heat to Heat (WHTH) Technologies

soWHat Training

In this section, passive WH/C recovery technologies designated to transfer heat from a source to a sink are shown

District Heating Heat Exchangers (DH HE)

Technology to recover the waste heat from industrial processes and transfer it to the district heating network (DHN)

Shell and Tube heat exchanger (STHE) and Plate Heat Exchanger (PHE) are the most common.

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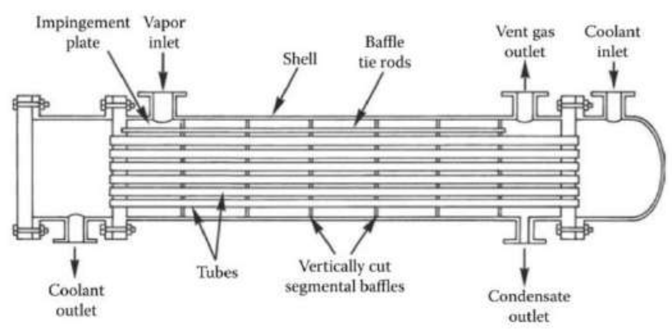
Waste Heat to Heat (WHTH) Technologies

District Heating Heat Exchangers (DH HE)

- STHEs are built of round tubes mounted in a cylindrical shell with the tubes parallel to the shell
- Easier to be cleaned
- Can be designed for high pressures

- PHEs are built of thin plates forming flow channels
- Well suited to liquid–liquid duties
- Not recommended for gas-to-gas applications



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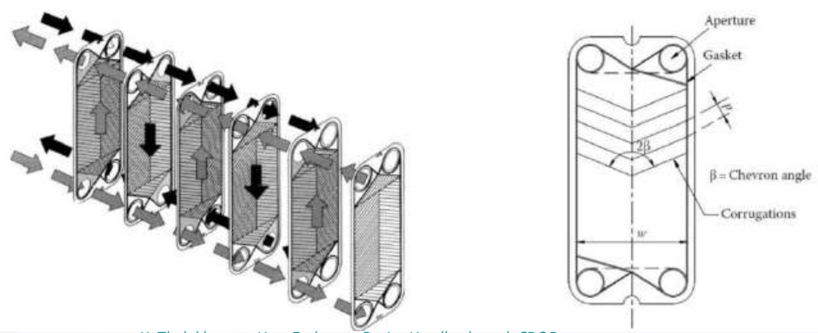

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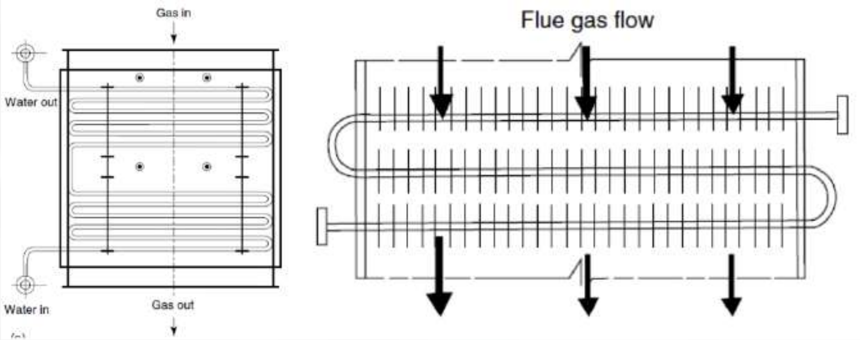
Waste Heat to Heat (WHTH) Technologies

Economizers (ECO)

- Typically used to recover the waste heat from the flue gas at the outlet of industrial boilers around 200-250°C
- Used to preheat the feed water entering the boiler up to 100-150°C
- Thermal duties in the range of hundreds kWs to a few MWs and pressures up to 60 bar



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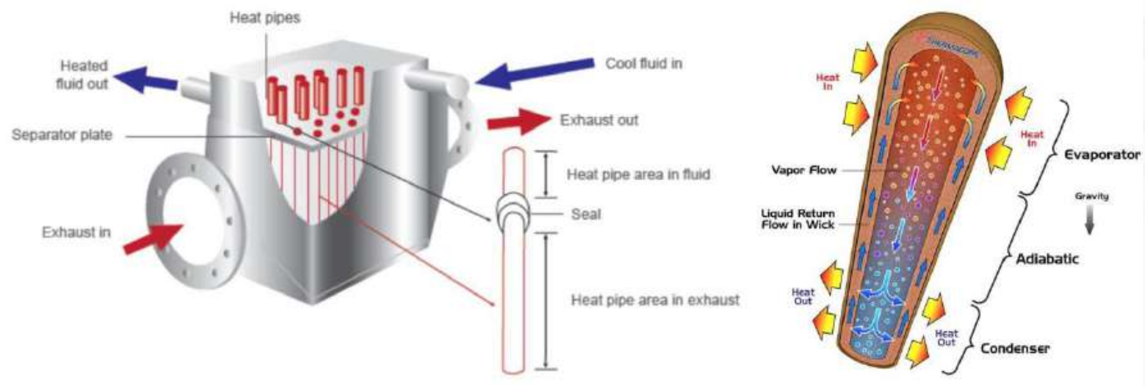
Waste Heat to Heat (WHTH) Technologies

Heat pipe heat exchangers (HPHEs)

- Designed to meet harsh operating conditions, enabling WH recovery in industrial processes where the use of traditional HEs is not viable
- The two streams exchange heat *only* via a series of components called “heat pipes”
- Sealed shell, wick structure and a certain amount of working fluid that transfers heat from the hot side to the cold side through continuous vaporization and condensation



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Thermal Energy Storage (TES)

TES are passive technologies designated to store thermal energy for subsequent use in time, bridging mismatch between thermal energy availability and thermal energy demand.

Sensible thermal energy storage (STES)

- Widely commercialized and used at scale for a broad range of temperatures
- Process: raising or lowering the temperature of a suitable storage medium (liquid or solid) to capture heat from a process (charging) or release it to a process (discharging)
- Water is commonly used up to about 120°C. Diathermic oils for temperature up to 250°C (oils) and molten salts for around 300-400°C

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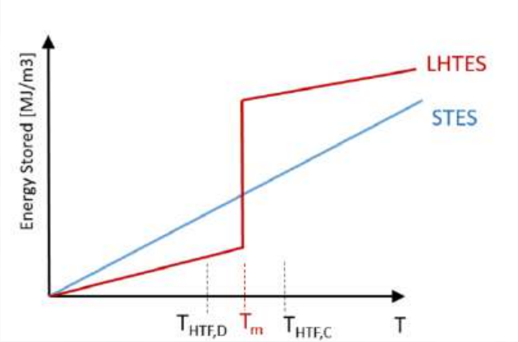
Thermal Energy Storage (TES)

Latent heat thermal energy storage (LHTES)

- Process: melting and solidification of the storage media in order to store heat or cold
- Most of the energy is stored around the melting point of the PCM and in the form of latent heat
- Low temperature (<250°C) range PCMs are mostly constituted by paraffins and fatty acids, molten salts are more common for medium/high temperature PCMs (<450°C) and metallic materials are currently explored as high temperature PCMs



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Waste Heat to Cold technologies (WHTC)

soWHat Training

Active technologies which transform original WH stream to produce cooling will be described in this section

- Cooling based on the gas-on-liquid absorption is widely used for cold production
- Sorption chillers are equipment, that through a sorption process (gas-on-liquid absorption or gas-on-solid adsorption), able to establish two levels of pressure through which the refrigerant can condense and evaporate and therefore produce the required cooling effect
- Water/lithium bromide absorption chiller is the most widespread technology for air conditioning applications
- The absorption chiller uses WH at low/medium temperatures in the range of 65-200°C
- Commercially available absorption cooling systems using lithium bromide-water or ammonia-water working pairs present a thermal COP in the range of 0.7-1.4

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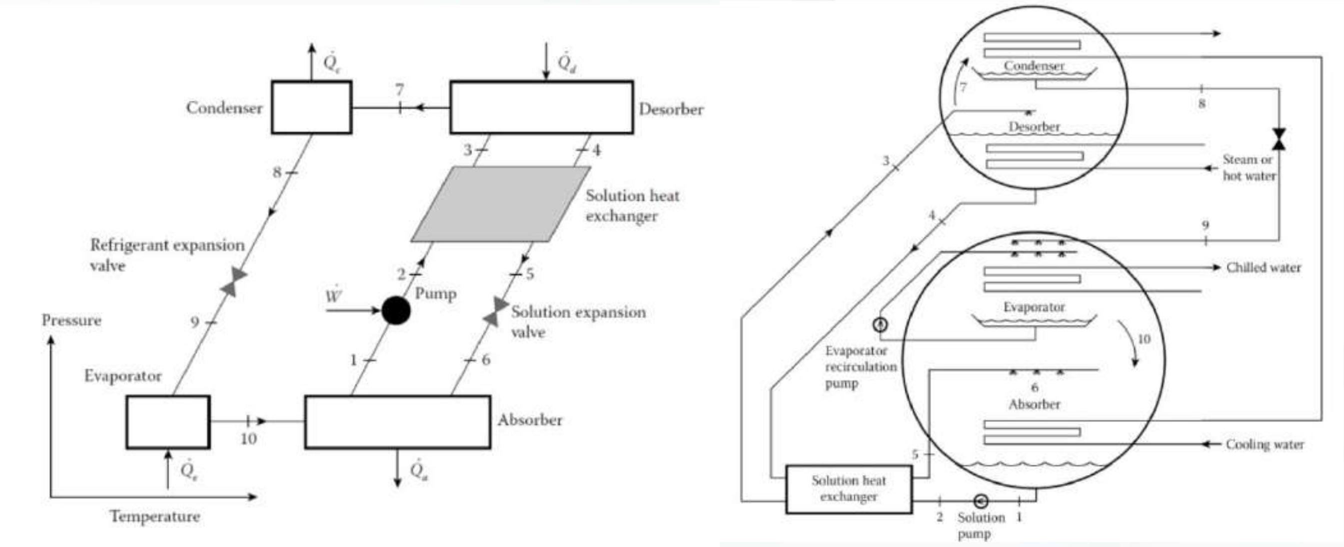
Waste Heat to Cold technologies (WHTC)



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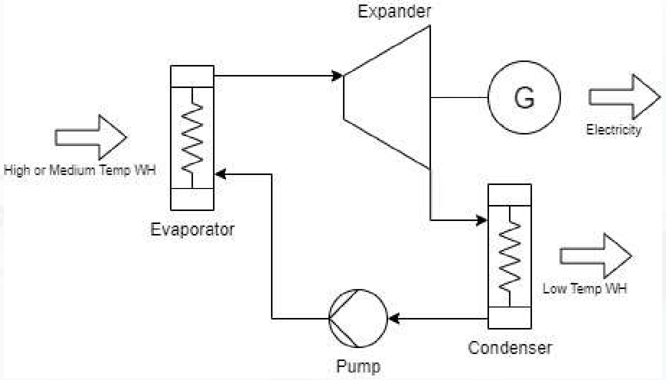
Waste Heat to Power technologies (WHTP)

SoWHat Training

In this section, active technologies which transform a WH stream to an electrical power output driving an energy conversion process will be described

Organic Rankine Cycles (ORCs)

- Identical layout to a conventional Steam Rankine Cycle and comprises pump, evaporator, expander and condenser
- ORC technology uses organic substances as working fluids with lower boiling point than water
- Enables the conversion of low/mid-grade WH in the range 80-300°C into power



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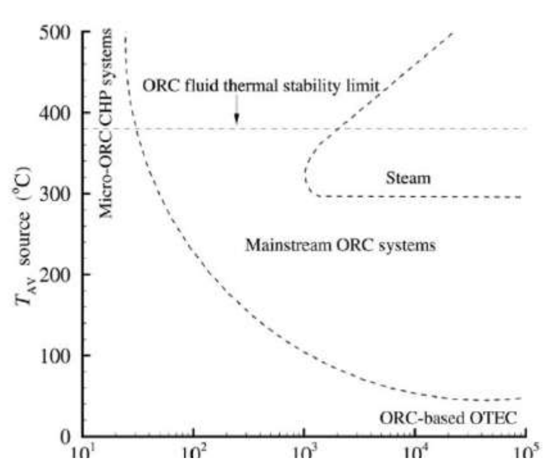
Waste Heat to Power technologies (WHTP)

soWHat Training

Organic Rankine Cycles (ORCs)

- Thermal efficiency of ORCs varies in the range 5-25%. Relatively low due to the low temperature working conditions
- ORCs can be driven by multiple kinds of heat sources. Specifically, thermal energy from stationary ICEs, gas turbines and industrial processes
- Averaging project costs of 3414 €/kW



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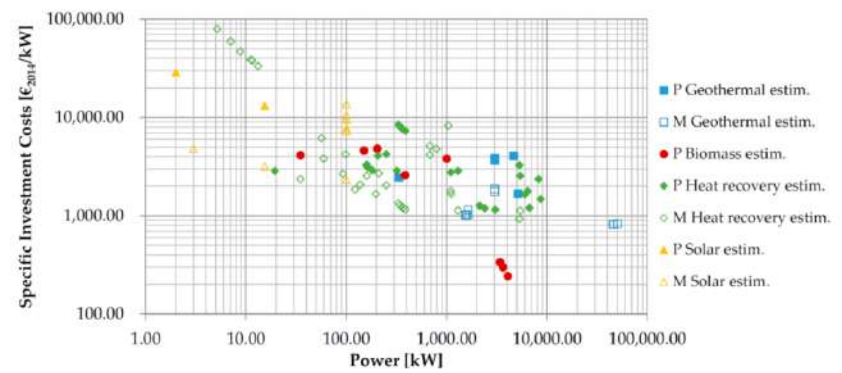

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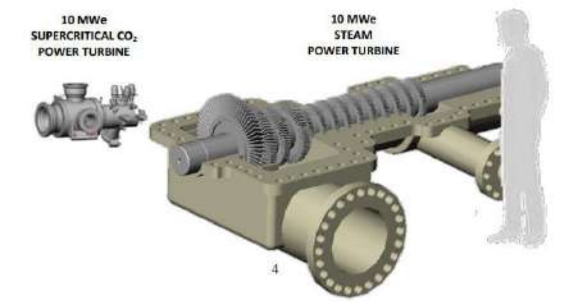
Waste Heat to Power technologies (WHTP)

soWHat Training

Supercritical CO2 power cycles (sCO2)

- Closed Brayton cycle operating with CO_2 as working fluid
- The compressor inlet is close to the CO_2 critical point where a marked reduction in compression work can be achieved
- Higher temperature applications (350-650°C) are of interest as they represent an alternative to the Steam Rankine Cycles
- Energy recovery with efficiencies up to 30%
- Extremely compact and highly efficient turbomachinery designs
- Installation cost is between 1800-1900 €/kW



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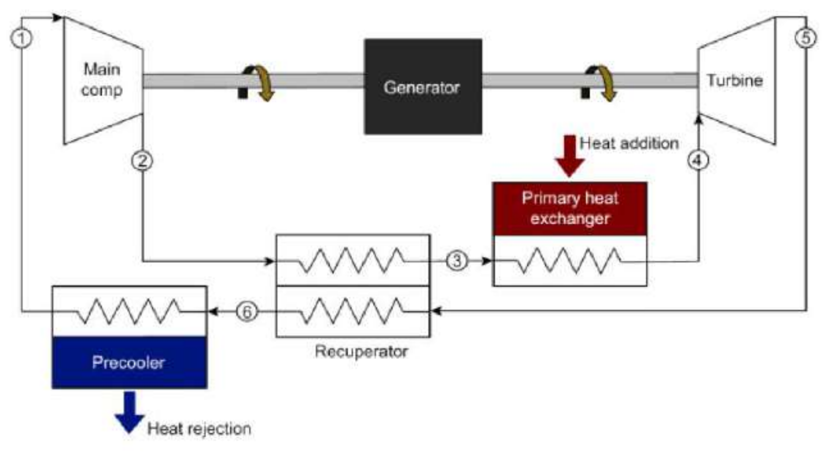
Waste Heat to Power technologies (WHTP)

soWHat Training

Supercritical CO2 power cycles (sCO2)



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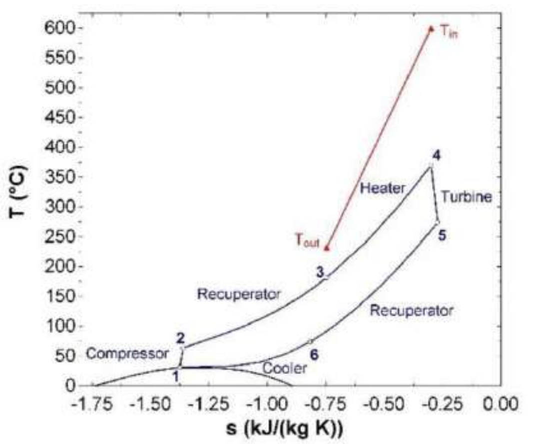

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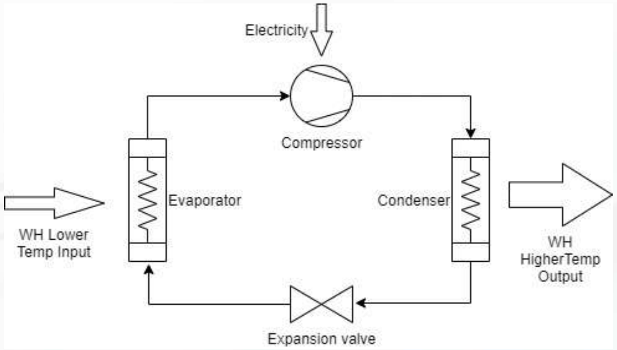
Heat Upgrade technologies (HU)

HU consist on active technologies which alter the conditions of available WH without transforming it into a different form of energy, increasing the performance or usability of the heat flow

Heat Pumps (HP)

- Primary aim: upgrading heat from a heat source to a heat sink at higher temperature
- Working principle of HPs is very similar and to refrigeration or air conditioning systems
- Employed to valorise low-grade WH and upgrade it to higher temperatures
- Crucial parameters are the heat source temperature T_L (WH temperature) and the heat sink temperature T_H (usable heat temperature) across which the HP is capable to operate across.



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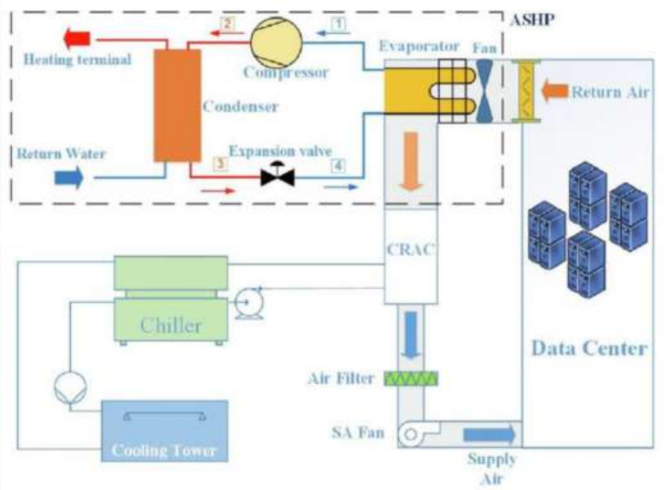
Heat Upgrade technologies (HU)

soWHat Training

Heat Pumps (HP)

Air source heat pumps (ASHP)

- Employ the outdoor air as heat source
- Can upgrade low-grade heat around 20-40°C
- ASHP providing space heating can reach a COP of 5 in some cases



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Heat Upgrade technologies (HU)

Heat Pumps (HP)

Water source heat pumps (WSHP)

- Take advantage of heat sources in form of liquid, in most instances water, rather than outdoor air
- The temperature of the source is relatively more stable and less affected by outdoor conditions
- WSHPs reach higher COPs than ASHPs, often exceeding value of 4-5

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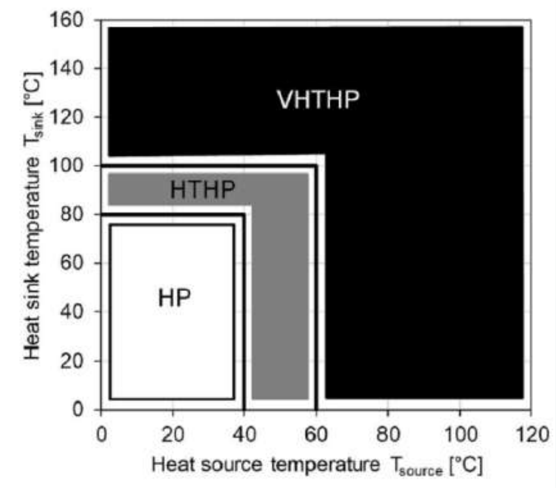
Heat Upgrade technologies (HU)

Heat Pumps (HP)

High temperature and very high temperature heat pumps

- HTHPs commonly refers to HPs capable to reach a maximum temperature of ~100°C at the condenser of the machine, while the concept of VHTHPs push the operational envelop up to ~160°C
- Products ranging from 20 kW to >1 MW
- VHTHPs for heat upgrade above 120°C currently remain subject of R&D. However, they will reach maturity in coming years



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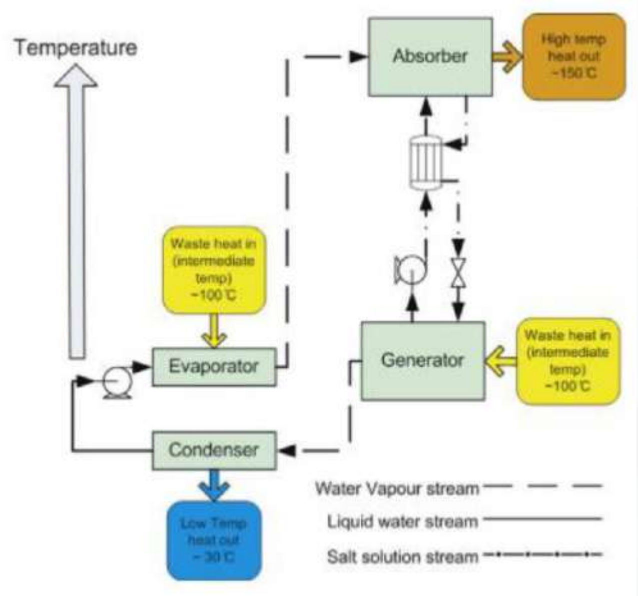
Heat Upgrade technologies (HU)

Absorption Heat Transformers

- Near-to-market technology which uses WH at low/medium temperature typically in the range 60-95°C and transforms it into two separate thermal energy streams: high temperature heat and low temperature heat
- A temperature lift in the range of 30-60°C is typically achieved
- The COP of these machines is less than 0.5
- Economic viability needs to be fully documented: In the range of 190-500 €/kW



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THANK YOU FOR YOUR PARTICIPATION

SOWHAT TEAM

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MODULE 1

CHAPTER 2: ANALYSIS OF WASTE HEAT AND COLD TECHNOLOGIES

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Abbreviations

ASHP: Air Source Heat Pump
AHT: Absorption Heat Transformer
CHP: Combined Heat and Power
COP: Coefficient Of Performance
DH: District Heating
DHC: District Heating and Cooling
ECO: Economizer
EU: European Union
HE: Heat Exchanger
HP: Heat Pump
HPHE: Heat Pipe Heat Exchanger
HTHP: High Temperature Heat Pump
HTF: Heat Transfer Fluid
HU: Heat Upgrade
LHTES: Latent Heat Thermal Energy Storage
ORC: Organic Rankine Cycle
PCM: Phase Change Material
PHE: Plate Heat Exchanger
R&D: Research and Development
RES: Renewable Energy Sources
sCO2: Supercritical CO2
STES: Sensible Thermal Energy Storage
STHE: Shell and Tube Heat Exchanger
TES: Thermal Energy Storage
VHTHP: Very High Temperature Heat Pump
WF: Working Fluid
WH/C, WH/WC: Waste Heat/Cold
WHTC: Waste Heat to Cold
WHTH: Waste Heat to Heat
WHR: Waste Heat Recovery
WHP: Waste to Power
WSHP: Water Source Heat Pump

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1 Introduction

The availability in the market of suitable recovery technologies of waste heat and cold for the identified source is the third component needed to implement a good waste heat and cold recovery project, as described in Chapter 1 and Figure 1.

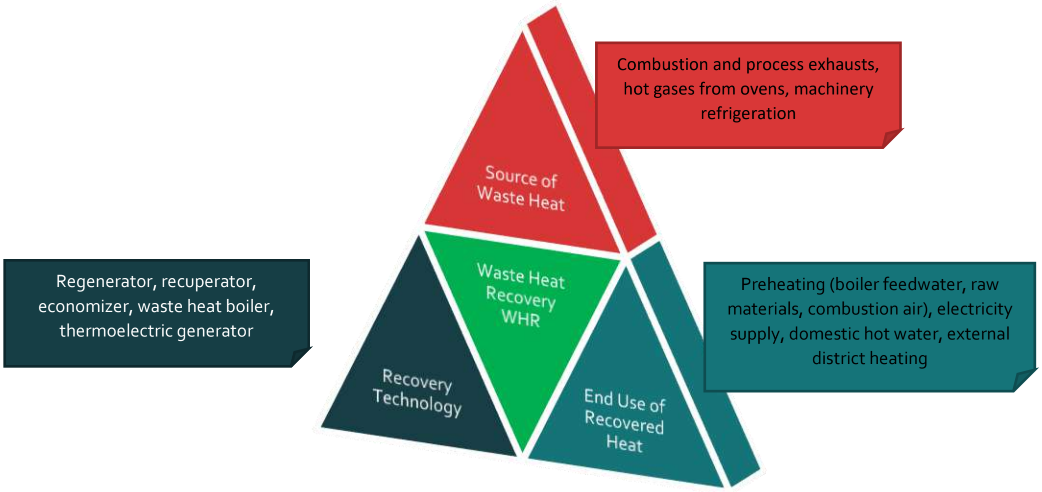

Figure 1: Essential components for Waste Heat Recovery (WHR)[1]

The equipment used for waste heat recovery must take into account parameters such as pressure and temperature operation ranges, waste heat source size (i.e. kW, MW) and waste heat intermittency (i.e. batch process or continuous process). Additional aspects, such as the waste heat carrier (i.e. gas, liquid or solid) and the purity and corrosiveness and of the waste heat streams are interesting to be considered. The existence of impure and/or corrosive products or materials that could lead to phenomena such as fouling, chemical degradation and gradual wear&tear of the heat exchanger surfaces, pipes and auxiliary components (e.g. pumps). The presence of extreme values in any of the above parameters will probably mean the mandatory use of special design and materials and therefore higher implementation costs. In the market, there are different technologies available depending on the type and power of the waste heat source, the temperature ranges and the final use of the energy. Figure 2 shows the main technologies for using waste heat for several ranges of temperature and thermal power.

The document is structured into five main sections, each one dedicated to a macro category of WH/C recovery technology, as they are classified in Figure 3:

1. **Waste Heat-to-Heat (WHTH)**: Passive WH/C recovery technologies designated to transfer heat from a source to a sink.
2. **Thermal Energy Storage (TES)**: Passive technologies designated to store thermal energy for subsequent use in time, bridging mismatch between thermal energy availability and thermal energy demand.
3. **Waste Heat-to-Cold (WHTC)**: active technologies which transform original WH stream to produce cooling.
4. **Waste Heat-to-Power (WHTP)**: active technologies which transform a WH stream to an electrical power output driving an energy conversion process
5. **Heat Upgrade (HU) technologies**: active technology which alters the conditions at which WH is available but do not transform it into a different form of energy

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Within the section of each macro-category, the individual technologies are reviewed with a focus on operating principle, performance and typical applications, prioritizing consolidated technologies available in the market.

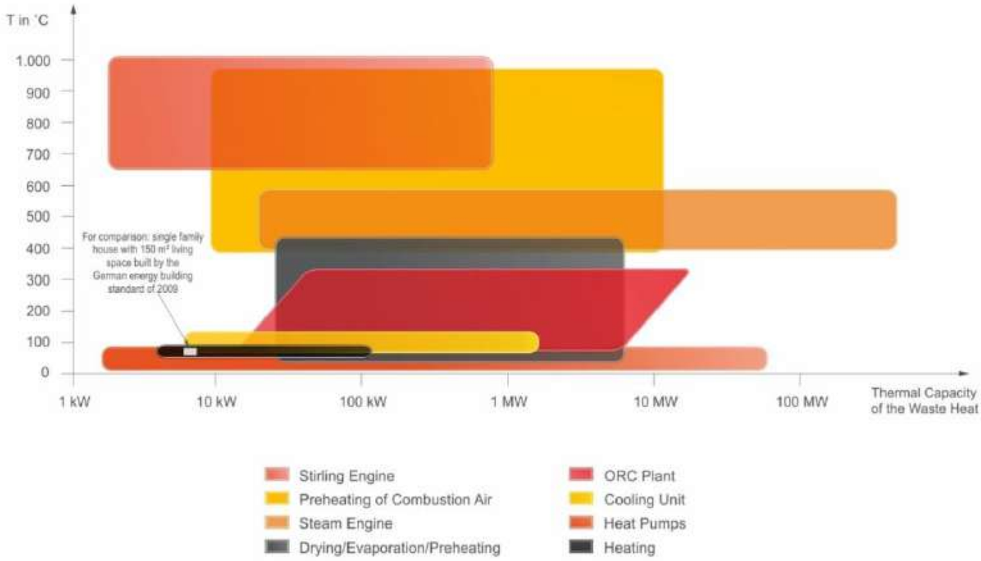

Figure 2: Categorization of waste heat utilization technologies. Source: Sächsische Energieagentur GmbH

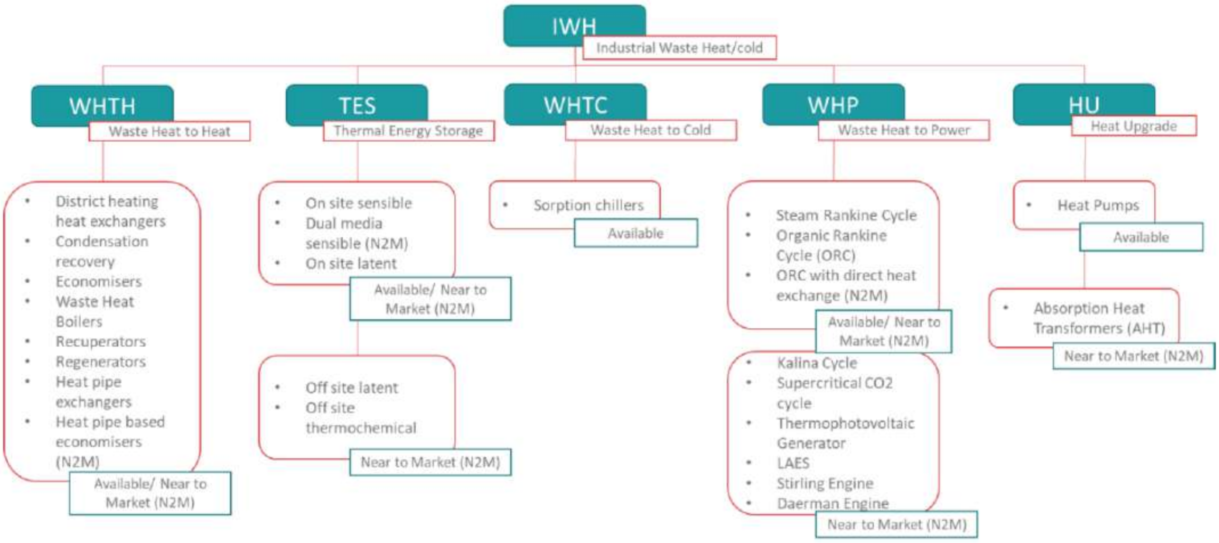

Figure 3: Classification of the technologies for recovery of industrial waste heat and waste cold [2]

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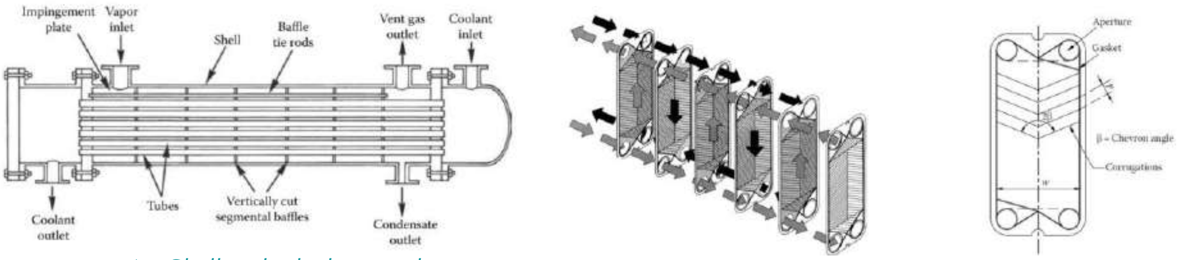
2 Waste Heat to Heat (WHTH) technologies

District Heating Heat Exchangers (DH HE)

According to [3], the fundamental idea of district heating is to use local fuel or heat resources that would otherwise be wasted, in order to satisfy local customer demands for heating, by using a heat distribution network. The enabling technology to recover the waste heat from industrial processes and transfer it to the district heating network (DHN) is the District Heating Heat Exchanger (DH HE). The Shell and Tube heat exchanger (STHE) and Plate Heat Exchanger (PHE) are the most common.

STHEs are built of round tubes mounted in a cylindrical shell with the tubes parallel to the shell. One fluid flows inside the tubes, while the other fluid flows across and along the axis of the exchanger. STHEs provide relatively large ratios of heat transfer area to volume and weight and they can be easily cleaned. They offer great flexibility to meet almost any service requirement. STHEs can be designed for high pressures relative to the environment and high-pressure differences between the fluid streams [4].

PHEs are built of thin plates forming flow channels. The fluid streams are separated by flat plates[4]. They are particularly well suited to liquid–liquid duties, whereas they are not recommended for gas-to-gas applications [5]. The typical industrial applications cover thermal duties in the range hundreds of kWs to a few MWs and water pressures up to 60 bar [6].



a) *Shell and tube heat exchanger*

b) Diagram of gasketed PHE

Figure 4: Diagram of different types of HE [4], [5]

Economizers (ECO)

Economizers (ECO) are devices typically used to recover the waste heat from the flue gas at the outlet of industrial steam boilers at temperatures around 200-250°C to preheat the feed water entering the boiler up to 100-150°C. For every 6°C rise in feed water temperature through an economizer, there is 1% saving of fuel in the boiler [5]. The typical industrial applications cover thermal duties in the range of hundreds kWs to a few MWs and water pressures up to 60 bar [6].

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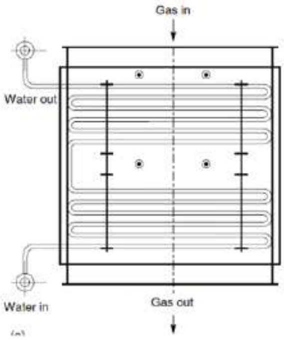
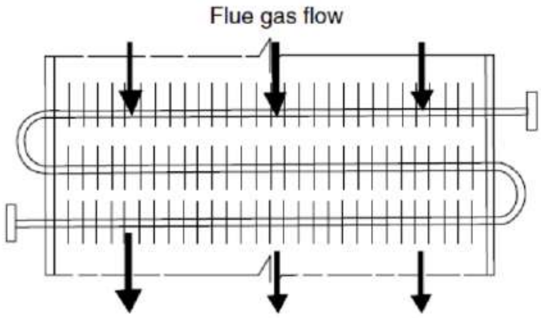


a) Bare tubes ECO



b) Finned tubes ECO

Figure 5: Diagram of different types of ECOs [7]

Heat pipe heat exchangers (HPHEs)

A significant portion of industrial processes generates WH in the form of gas streams (exhausts) under challenging operating conditions such as large mass flow rates, high temperatures or high content of some substances which may cause fouling or wearing in the equipment [8].

Heat pipe heat exchanges (HPHEs) are a class of HEs designed to meet harsh operating conditions, enabling WH recovery in industrial processes where the use of traditional HEs would be technically and/or economic not viable. The main difference between the conventional HEs and HPHEs is that the two streams exchange heat *only* via a series of components called "heat pipes", which are oriented transversally to the flow direction of the two streams. Each individual heat pipe is a passive thermal device. It consists of a sealed shell, a wick structure and a certain amount of working fluid that transfers heat from the hot side to the cold side through continuous vaporization and condensation [9].

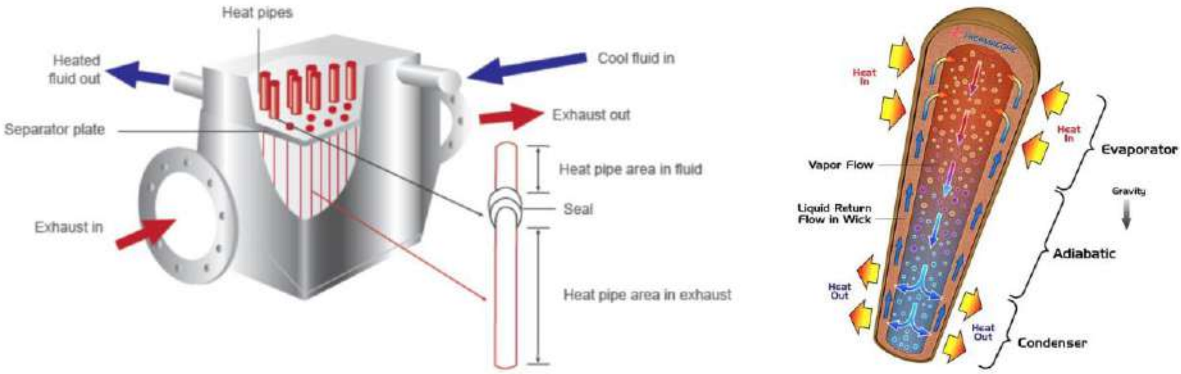


Figure 6: Heat pipe heat exchanger configuration [8] and structure of a individual heat pipe [10]

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3 Thermal Energy Storage technologies (TES)

Sensible thermal energy storage (STES)

Sensible thermal energy storage (STES) is the most deployed TES technology, widely commercialized and used at scale for a broad range of temperatures. All the STES are based on the same operating principles: raising or lowering the temperature of a suitable storage medium (liquid or solid) to capture heat from a process (charging) or release it to a process (discharging) [11]. STES is also suitable for cold thermal energy, where cold is stored by lowering the temperature of the storage medium, and vice versa for release of cold.

Water is the most widely, cost-effective storage medium and it is commonly used up to about 120°C [12], [13]. Diathermic oils and molten salts are adopted as thermal storage media for temperature up to 250°C (oils) [14] and around 300-400°C (molten salts)[15], respectively.

Latent heat thermal energy storage (LHTES)

Latent heat thermal energy storage (LHTES) technology exploits the process of melting and solidification (i.e., phase change) of the storage media in order to store heat or cold. The storage media employed in LHTES are commonly referred as phase change material (PCM) [16], [17] [18]. During the energy storage process, heat transfer occurs between the PCM and suitable heat transfer fluid (HTF). During the charging process heat is supplied by the HTF to the PCM, causing the latter to melt; thermal energy is therefore stored in the form of latent heat of fusion. Conversely, during the discharge process heat is transferred from the PCM to the HTF. This causes the PCM to solidify, thus releasing the corresponding latent heat of fusion. The energy released by the PCM is then carried by the HTF and made available to the end-user.

In LHTES technology most of the energy is stored around the melting point of the PCM and in the form of latent heat (Figure 7). PCM selection it is therefore crucial since it largely dictates the operating temperature of the LHTES system and the energy stored per unity of volume (or mass), that is the energy storage density. In the context of WH/C, storage of waste heat streams requires therefore to match PCM melting temperature with the temperature at which the streams are available.

Broadly speaking, low temperature (<250°C) range PCMs are mostly constituted by organic materials such as paraffins and fatty acids, molten salts populate the class of medium/high temperature PCMs (<450°C) and, finally, metallic materials are currently explored as high temperature PCMs although their commercial application remains prohibitive due to technological and safety issues [19], [20], [21].

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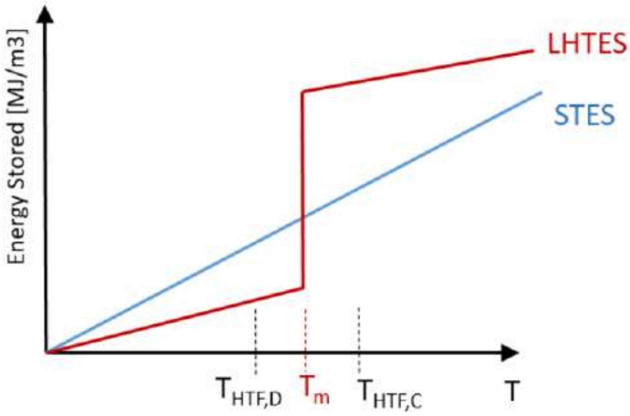
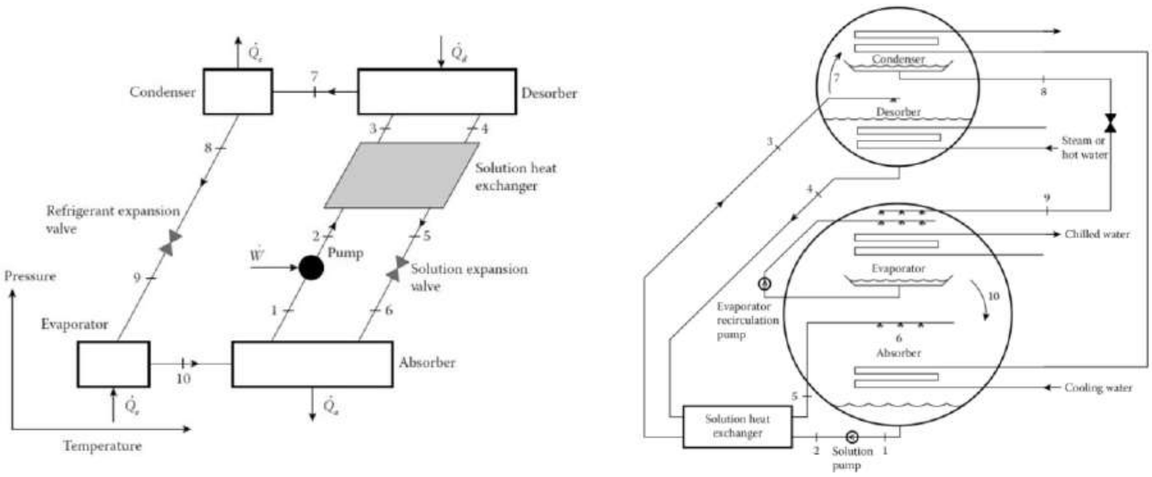


Figure 7: Thermal energy stored versus temperature increase: difference between latent TES (LHTES, red line) and sensible TES (STES, blue line) [1]

4 Waste Heat to Cold technologies (WHTC)

This section aims to present the cold production equipment from waste heat, thus achieving its recovery and valorisation. After a technological review for the production of cold from heat flows, the methods found were clustered in three main categories: sorbent systems, mechanical systems and specific systems. The focus of this Section is on sorbent cooling systems since absorption cooling based on the gas-on-liquid absorption is widely used for cold production.

Sorbents are materials that have the ability to attract and hold other gases or liquids. Sorption chillers can be defined as those equipment that through a sorption process (gas-on-liquid absorption or gas-on-solid adsorption) are able to establish two levels of pressure through which the refrigerant can condense and evaporate and therefore produce the required cooling effect. Figure 8 presents the cycle schematic and hardware schematic of a water/lithium bromide absorption chiller, which is the most widespread technology for air conditioning applications. The absorption chiller uses WH at low/medium temperatures, typically in the range 65-200°C, at the desorber (Q_d) and produces the cooling effect (Q_e) in the evaporator. The low grade heat streams released in the condenser (Q_c) and absorber (Q_a) are commonly rejected to the environment.



a) b)

Figure 8: Single-effect water/lithium bromide absorption chiller: a) Cycle schematic; b) Hardware schematic [22]

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Single effect chillers require lower activation temperatures than double and triple effect chillers. However, double and triple effect chillers have higher values of performance (i.e., higher COP). Additionally some double effect chillers can be used in a dual way. When there is available hot water with waste heat origin (or solar thermal), the machines work as single effect chillers with lower performance but free cost in terms of fuel supply. When the hot water is not available, the machine is equipped with a natural gas direct fired burner that activates the second effect. Therefore, the machines operate with higher performance but with higher economic cost due to the natural gas consumption. Commercially available absorption cooling systems using lithium bromide-water or ammonia-water working pairs present a thermal COP in the range 0.7-1.4.

Absorption chiller emissions depend on the heat producer. If the chiller is integrated with CHP facilities, there are no incremental emissions from the absorption chiller. If the absorption chiller is a standalone unit that is direct fired, emissions will depend on the fuel used to produce thermal energy to drive the system and the specific combustion technology used for direct firing.

5 Waste Heat to Power technologies (WHTP)

Organic Rankine Cycles (ORCs)

In its simplest implementation the ORC layout is identical to a conventional Steam Rankine Cycle and comprises pump, evaporator, expander and condenser, as illustrated in Figure 9. The working fluid with low boiling point is pumped to the evaporator, where it is heated and vaporized by the exhaust heat. The generated high pressure vapour flows into the expander and its heat energy is converted to work. Simultaneously, the expander drives the generator and electric energy is generated. Then, the exhaust vapour exits the expander and is led to the condenser where it is condensed by the cooling water. The condensed working fluid is pumped back to the evaporator and a new cycle begins.

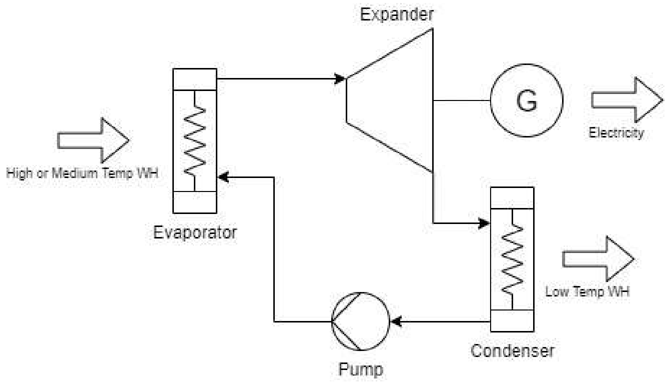

Figure 9: Schematic diagram of the ORC. Source: Own elaboration

ORC technology uses organic substances as working fluids which typically have a lower boiling point and critical temperature than that of water [23]. The low boiling point of ORC Working Fluids (WF) enables the conversion of low/mid-grade WH in the range 80-300°C into power.

Thermal efficiency of ORCs varies in the range 5-25%. Such low values as well as the spread across a relatively large range should not come at a surprise. Indeed, ORC technology convert WH available in a wide temperature range between 80-500°C, and it is inherently less efficient than other power cycles which operate at higher temperatures. The application range of capacities and temperatures

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of the heat source that is conveniently covered by ORCs is usually called "mainstream ORC systems" and it is shown in Figure 10.

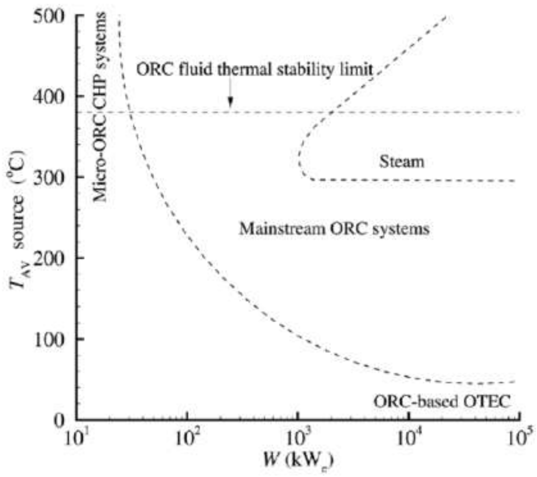

Figure 10: Current and future fields of application of ORC versus SRC in terms of average temperature of the energy source and power capacity of the system [24]

ORCs can be driven by multiple kinds of heat sources and, focusing on WHR, ORCs find application mostly in recovery of thermal energy from stationary internal combustion engines and gas turbines or from a variety of industrial processes. WH recovery from energy intensive processes by ORCs has been demonstrated at MW-scale while small scale ORCs (<100-200kW) remain under research development. The WHR ORC systems, represented in the middle power range of Figure 11, have estimated module costs around 2780 €/kW and averaging project costs of 3414 €/kW.

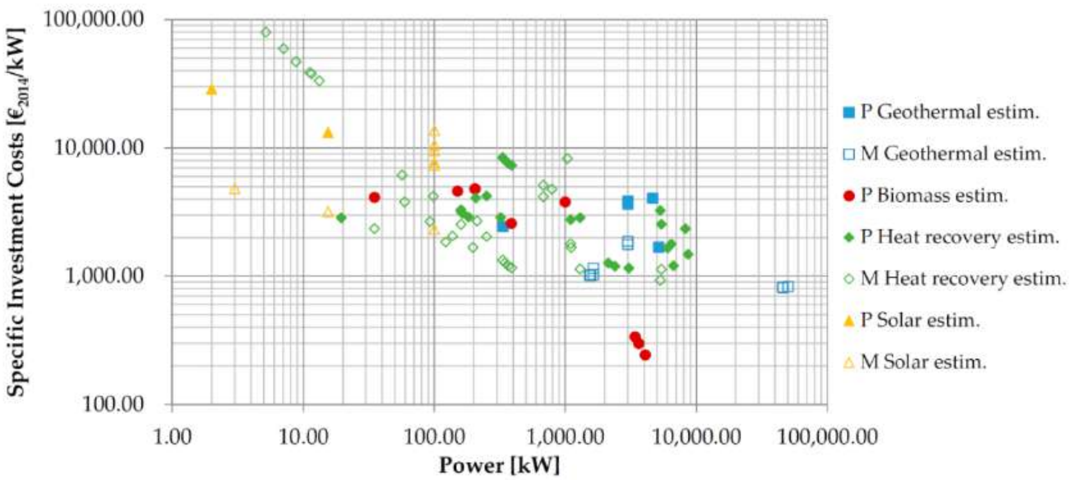

Figure 11: Estimated costs of ORC Projects (P) and Modules (M) in the literature. The WHR applications are reported using green marks *[25]*

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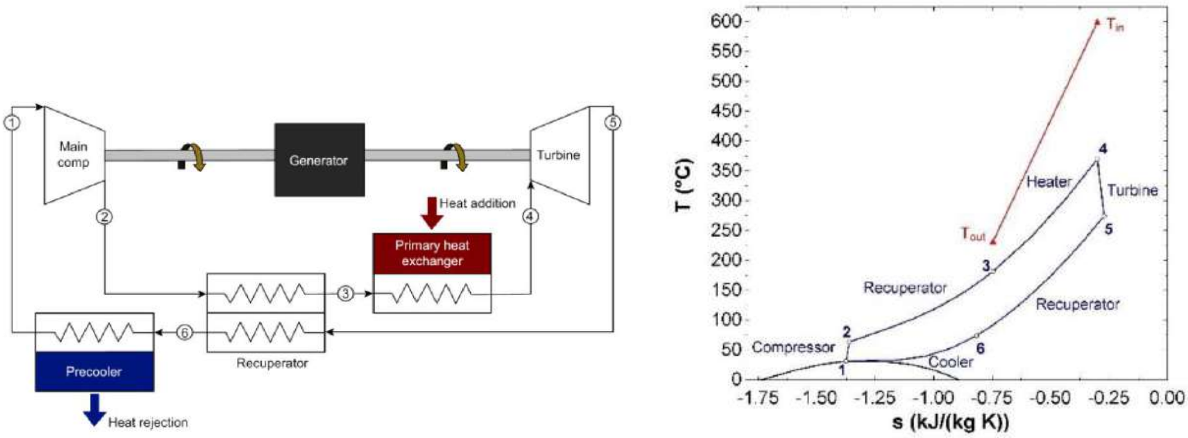
Supercritical CO2 power cycles (sCO2)

The sCO2 power cycle is a closed Brayton cycle operating with CO2 as working fluid. CO2 is compressed, heated up to the maximum cycle temperature, expanded in the turbine and cooled down to the lowest cycle temperature. The compressor inlet state is close to the CO2 critical point (73.8 bar; 30.98°C). In this region the real gas effects are significant and a marked reduction in compression work can be achieved. The flowsheet of the simple sCO2 cycle and the thermodynamic processes in the temperature-entropy (T-s) diagram are shown in Figure 12. The CO2 leaving the compressor is first heated by regenerative heat transfer in the recuperator and then heated up to the turbine inlet temperature by the external waste heat source. Heat energy is introduced through a waste (primary) HE installed into the exhaust stack of a gas turbine or a furnace or the flue gas exhaust of an industrial process with 200°C to greater than 650°C operating temperature range [26]. While the lower temperature applications (200-350°C) are basically a variation of the ORC where CO_2 is used as WF, the higher temperature applications (350-650°C) are of particular interest as they represent an alternative to the Steam Rankine Cycles.



a) b)

Figure 12: sCO2 power cycle: Process flow diagram [27]; b) T-s diagram of the sCO2 cycle and cooling profile of the WH source [13]

The sCO2 heat engine is a platform technology scalable from 250 kW_e to greater than 50 MW_e and is suitable with a wide range of heat sources for energy recovery with efficiencies up to 30%. Compared to ORC and SRC systems, sCO2 can achieve higher efficiencies over a wide temperature range of heat sources with compact components resulting in a smaller system footprint, lower capital and operating costs [26].

The high fluid density of supercritical CO2 enables extremely compact and highly efficient turbomachinery designs with simpler, single casing bodies. Its density makes the dimensions and weight of these compact HEs also much lower compared to a conventional STHE for the same heat duty (Figure 13). Carbon dioxide captures heat from a sensible heat source more effectively compared to water/steam, so a higher fluid temperature and thermal efficiency can be achieved for the same heat source.

On the other hand, operation near critical point is difficult and challenging due to the rapid changes in thermophysical properties of the CO2 near this point and the potential for entering the two-phase dome (gas-liquid) and having both liquid and gas in the flow. Linked to that, a significant drop of performance is to be expected in the warm season.

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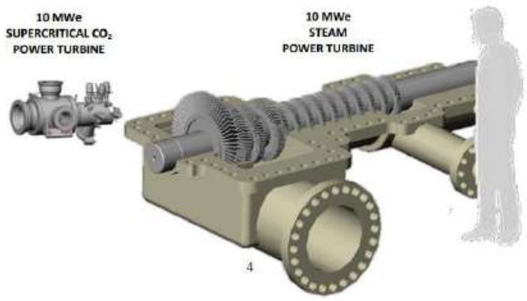

Figure 13: Echogen's 10 MWe sCO2 power turbine compared to a 10 MWe steam turbine [26]

Due to the low cycle pressure ratio and relatively high turbine outlet temperature, the sCO2 system must recuperate a large amount of heat to increase the thermal efficiency. The common HE types are not suitable as recuperators for sCO2 due to their pressure and temperature limitations.

Quite complex sCO2 architectures are required to enable an effective heat extraction from the WH source. These include a higher number of components (e.g., two turbines, two recuperators, two or three heaters) compared to the simple recuperated layout, as well as one or more flow splits. This increase the complexity and cost of the sCO2 systems for WHR.

Focusing on the WHR application, the sCO2 power cycle can provide a higher efficiency compared to the ORC for heat source temperatures higher than 350°C. Moreover, it is preferred to steam when the power output is lower than 20-30 MWe. The applications of this cycle are characterized by heat source temperatures in the range 300-600°C

Only one manufacturer worldwide provides sCO2 cycles for WHR applications. The installation cost is between 1800-1900 €/kW$_e$. The specific investment cost is up to 40% less compared to the more conventional steam bottoming cycle. The lower installed cost is the result of the simplicity of the sCO2 system, its smaller footprint, and reduced auxiliary system requirements.

6 Heat Upgrade technologies (HU)

The focus of this section is on how low grade WH sources can improve the performance or drive these heat upgrade technologies that can provide useful heat not only for the residential/commercial sectors but also for the industrial sector.

Heat Pumps (HP)

A Heat Pump (HP) is an energy device whose primary aim is to upgrade heat from a heat source to a heat sink at higher temperature. This is done in general at the expense of consuming some extra high-quality energy, for example electricity. The working principle of HPs is therefore very similar and for various instances identical to refrigeration or air conditioning systems, with the crucial difference that the amount of upgraded heat is the desired effect in HP systems. HPs can collect heat from a variety of sources, such as air, water and ground to deliver heating for residential and commercial buildings [28]. In the context of WH recovery, HPs are employed to valorise low-grade WH and upgrade it to higher temperatures, and thus making it more utilizable, for example as process heat.

Figure 14 illustrates the principle of HPs utilization for the purpose of WH recovery and valorisation. Crucial parameters are the heat source temperature T_L (WH temperature) and the heat sink

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temperature T_H (usable heat temperature) across which the HP is capable to operate across. Such temperatures largely dictate the type of HP which can be utilized and the type of application.

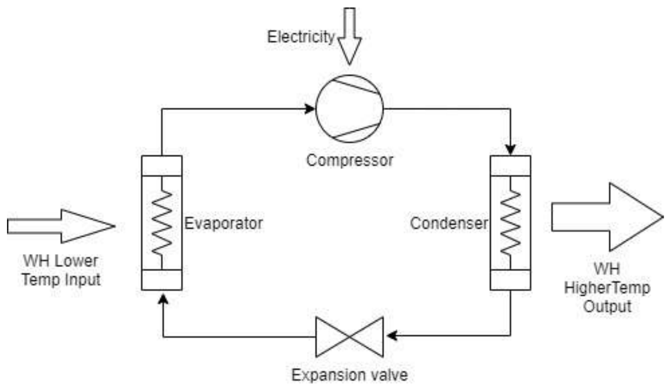

Figure 14: Heat pump utilization in the context of waste heat recovery. Source: Own elaboration

Air source heat pumps

Air source heat pumps (ASHPs) employ the outdoor air as heat source, thus drawing heat from the environment. It can be observed that ASHPs can upgrade low-grade heat around 20-40°C. However, the temperature of heat source greatly impacts on ASHPs performance. It can be noted that the COP reported for ASHPs may vary significantly, from about 1 to above 4, mostly due to the variation of outdoor temperature.

The availability of a low grade WH streams in place of ambient air could markedly improve the COP of the ASHP. In particular, the WH generated in the data centres can be profitably used by AHSP providing space heating for adjacent buildings (Figure 15) reaching a COP of 5 in some cases [29].

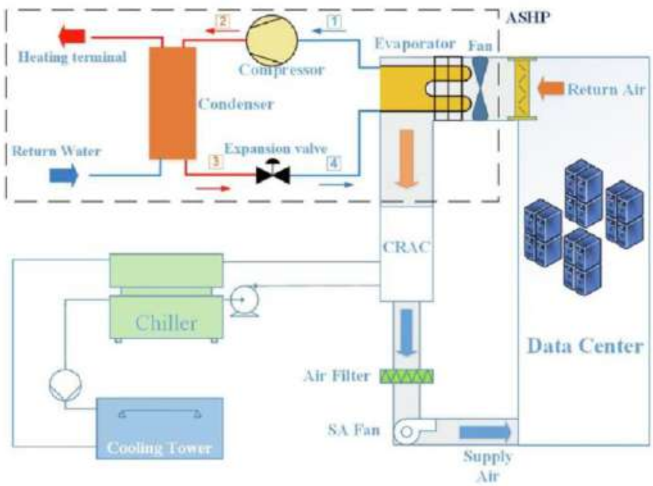

Figure 15: Coupling of an ASHP with the cooling system of a data centre [29]

Water source heat pumps

Water source heat pumps (WSHPs) take advantage of heat sources in form of liquid, in most instances water, rather than outdoor air as in the case of ASHPs. The use of water-based sources has a dual benefit: the temperature of the source is relatively more stable (i.e., smaller fluctuations) and less affected by outdoor conditions (e.g., summer versus winter). Furthermore, yearly averaged temperature of water sources tend to be higher than those of air sources. As a result, WSHPs reach higher COPs than ASHPs, often exceeding value of 4-5 [28], [30]. As a drawback, installation of

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WSHPs is somehow constrained as it clearly necessitates the presence of the water-based heat source.

In the context of WHR and valorisation, the utilization of sewage or wastewater streams as heat sources for WSHPs is of interest. Sewage, wastewater and more generally low-temperature water streams are common carriers of low-grade WH from industrial processes, often difficult to be recovered since typically available in the range 10-30°C [30], [31], [32], [33].

High temperature and very high temperature heat pumps

Air and water source heat pumps utilize heat sources up to ~35°C and upgrade heat to maximum temperature around 70-80°C. Consequently, they are mostly used for valorisation of low grade WH, or in the context of space and water heating. This makes ASHPs and WSHPs unsuitable for upgrade and valorisation of WH to temperatures above 80°C, which are commonly required in industrial sectors such as Pulp & Paper, Food & Beverages, and Textile [34]. In such contexts, high temperature heat pumps (HTHPs) and very high temperature heat pumps (VHTHPs) are of particular interest for industrial applications and upgrade of WH from industrial processes. HTHPs commonly refers to HPs capable to reach a maximum temperature of ~100°C at the condenser of the machine, while the concept of VHTHPs push the operational envelop up to ~160°C (Figure 16).

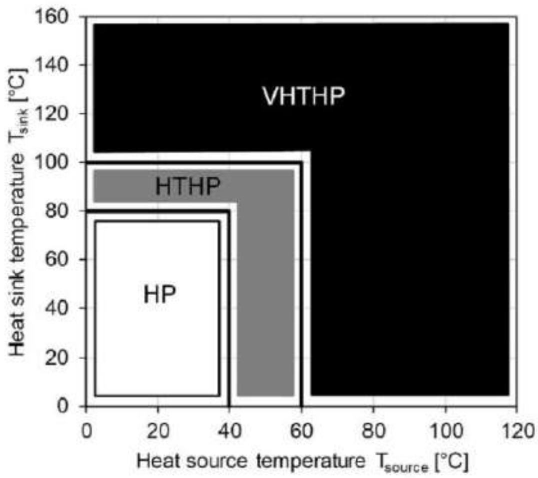

Figure 16: Development of temperature levels for compression heat pumps. HP: conventional heat pump; HTHP: high temperature heat pump; VHTHP: very high temperature heat pump [34].

From technological stand point HTHPs are an established technology and with an established supply chain. Quite manufacturers offer HPs which are able to upgrade heat to at least 90°C with products ranging from 20 kW to >1 MW in heating capacity (i.e., amount of WH upgraded).

VHTHPs for heat upgrade above 120°C currently remain subject of R&D projects and only a handful of commercially viable products are available. However, the considerable number of ongoing R&D projects and a quick evolution in the research field provides evidence that VHTHPs with heat sink temperatures of up to 160°C will reach market maturity in the coming years.

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Absorption Heat Transformers

Absorption heat transformer (AHTs) is a near-to-market technology which uses WH at low/medium temperature typically in the range 60-95°C and transforms it into two separate thermal energy streams: high temperature heat and low temperature heat. Thus, AHTs valorise WH by upgrading part of it to higher temperature, hence making it more utilizable, but also producing a secondary low temperature thermal energy stream which might be used for cooling purposes.

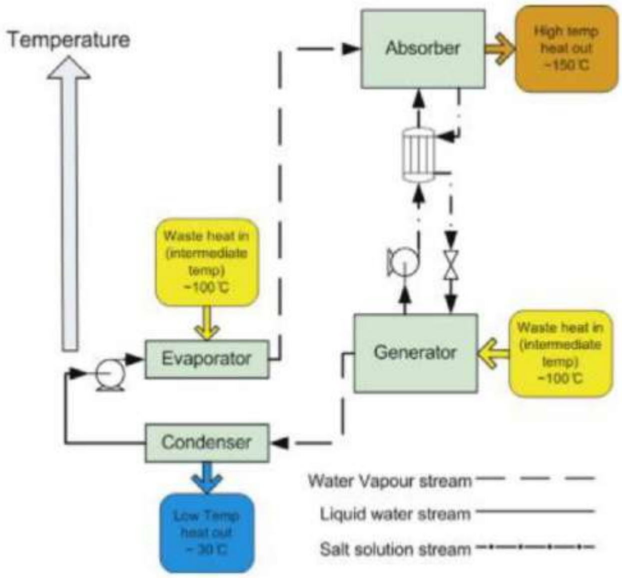

Figure 17: Layout of a single stage AHT [35]

The layout and key components of a single stage heat transformer are presented in Figure 17. A WH source is used to supply heat to the Generator, in which sorbate (more volatile component) is separated from the absorbent. A typical pair utilized in AHTs is LiBr-H_2O solution [36]. The sorbate is then condensed, releasing the corresponding latent heat producing a cooling effect (i.e., low temperature heat source). The sorbate (liquid at the outlet of the condenser) is evaporated (evaporator) and directed to the Absorber where it recombines with the liquid absorbent. The recombination process is exothermic, releasing the heat of absorption. This provides higher-grade heat at the Absorber. A temperature lift in the range of 30-60°C is typically achieved [36]. The cycle is closed by the diluted absorbent flowing back to the Generator. The COP of these machines is less than 0.5.

AHT technology has been demonstrated and fully integrated with the industrial process in a small number of cases. AHT has been reported to deliver significant energy savings, although economic viability still needs to be fully documented, which is in the range of 190-500 €/kW. Commercial uptake has therefore been lagging and it appears that no commercial products are currently available on the market. Furthermore, it has been reported that AHT are still not utilized in industry because "they are still an unknown entity" [35]. On the other side, AHTs are usually robust (low maintenance) and are thermally driven system, with minimal electrical input.

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MODULE 1_DATA COLLECTION AND FORMATTING

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Summary

- Introduction to Energy Audits
- Data Collection Approach
- Data Formats
- Barriers to Data Collection
- Energy Performance Indicators
- Data Sources

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Energy Audit

“an energy audit is a systematic inspection and analysis of the energy use and consumption of a plant, building, system or organisation, with the aim of identifying and reporting on energy flows and the potential for energy efficiency improvements”

(EN 16247-1)

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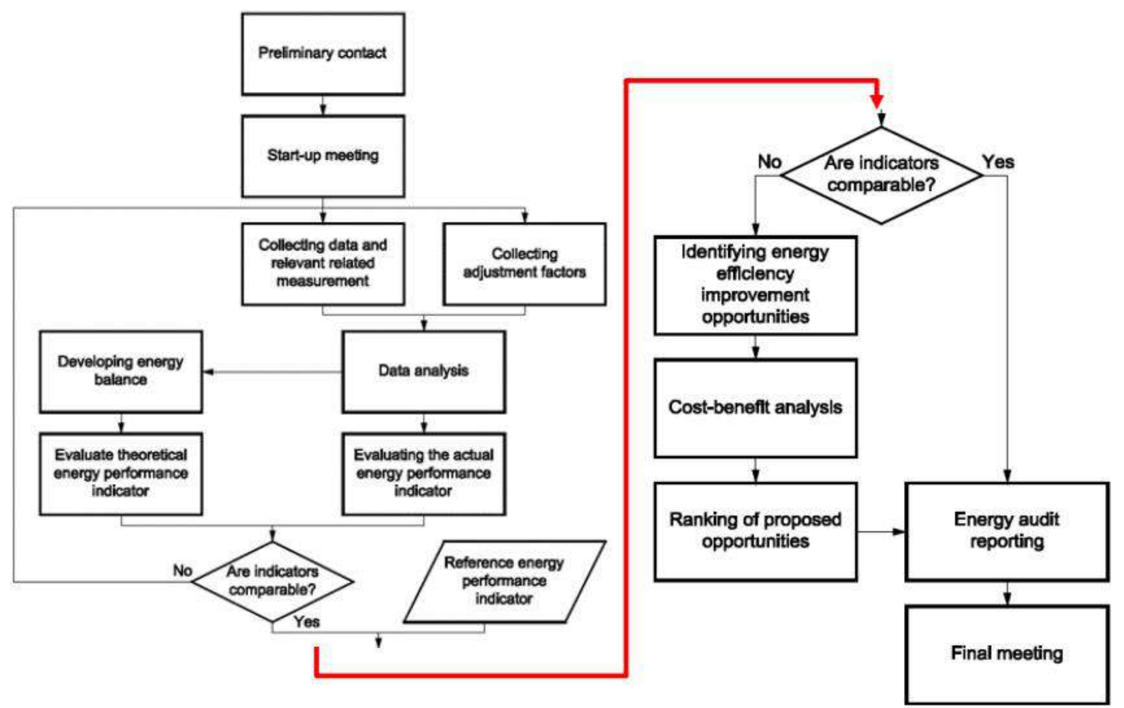
Energy Audit Process

- Kick-off meeting
- Data collection on:
  - energy consumption
  - plant production
  - equipment features
- Site visit
- Analysis
- Reporting
- Final meeting



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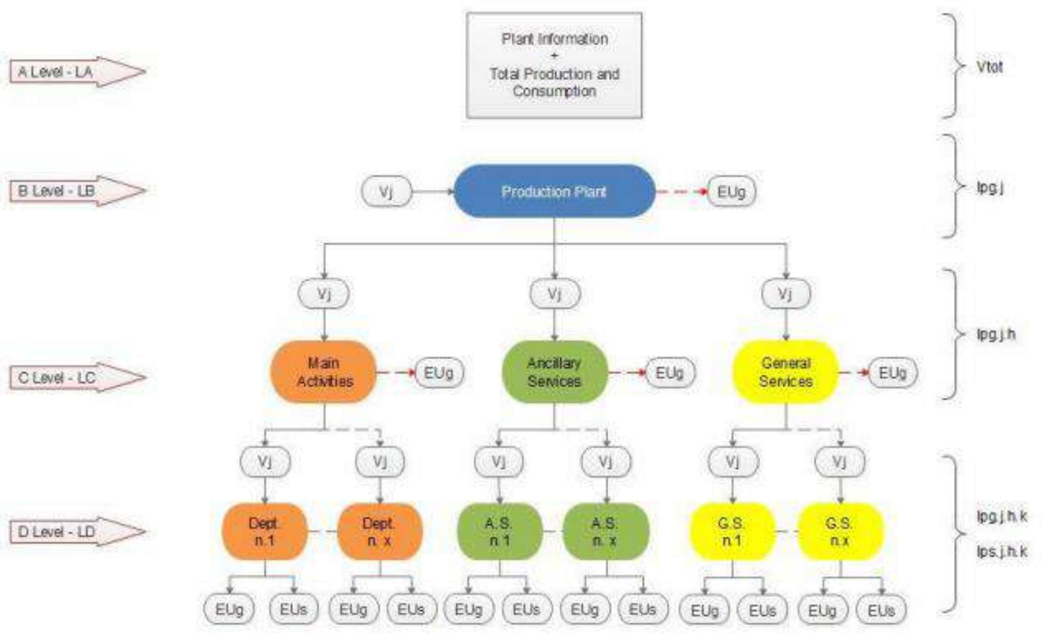
Plant Energy Model

- Plant energy model
- One per each energy carrier (electricity, natural gas, etc.)
- Breakdown into:
  - Main Activities
  - Ancillary Services
  - General Services
- Breakdown by functional area
- Basis to determine energy balances and indicators



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Functional Areas

- **Main activities:** processes related to the specific plant production, e.g. main furnace in a glass plant, kiln system in a cement plant, etc.

- **Auxiliary services:** activities supporting the main ones, e.g. compressed air systems, steam/water boilers, chillers, materials handling systems, etc. → *their consumption is generally proportional to plant production*

- **General services:** activities indirectly linked to the main processes, e.g. lighting, HVAC, offices, etc. → *their consumption is not proportional to plant production*

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SO WHAT Data Collection Approach

1. **Use case identification**
2. **Data collection** according to a dedicated checklist
3. **Data formatting** (if available in different formats)
4. **Data upload** to the tool
5. **Data mapping** according to energy carrier, process, end-use, etc.
6. **Rough-cut profiling** if only low-resolution data are available
7. **Data processing** to achieve energy input/output profiles
8. **Building model** (if needed)
9. **Industrial process component model** (for each department)
10. **Data syncing with process components**
11. **Energy Sankey diagram** to visualize main WH/C sources

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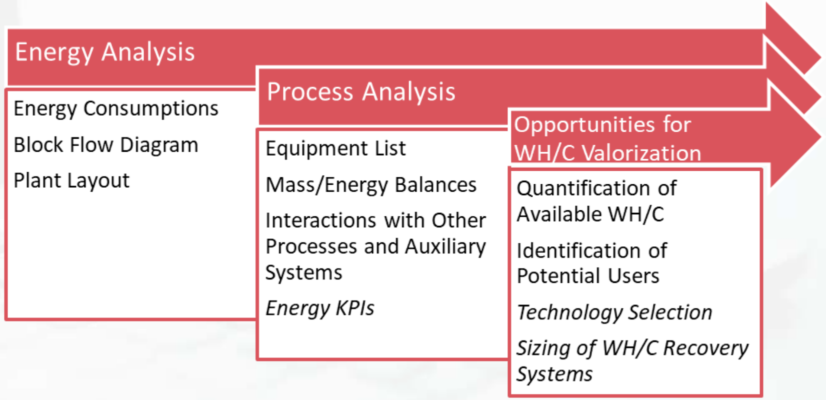
SO WHAT Data Collection Approach

- Energy analysis
  - at plant level
  - general information on processes
- Process analysis
  - at department/process level
  - details on machinery
- Focus on WH/C
  - quantification of available energy
  - identification of potential users
  - selection and sizing of recovery technology



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Data Formats

sоWHat Training

- no standard format exists for input data
- generally information is quantitative or qualitative

Quantitative Information (generally Excel spreadsheets)	Qualitative Information (generally PDF documents)
elaborations on energy consumptions and costs done for energy management or project controlling purposes at corporate level	energy bills and invoices produced by suppliers
output of energy monitoring systems at different time resolutions based on own meters or on suppliers' data	energy audit reports, feasibility studies, design documents for energy-related interventions
list of machines, elaborated for maintenance or asset management scopes, or created on purpose for energy management activities	technical datasheets for installed equipment
data on plant production and raw materials consumption, costs and revenues, etc.	offers and proposals by potential suppliers for new equipment
	scanned versions of drawings, layouts and diagrams realized in the past or made not available in an editable format

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Barrier to Data Collection

- confidentiality issues
- availability of detailed data only on core processes/machines
- lack of monitored data on heat carriers
- lack of detailed information on buildings and H&C demand
- non-standard availability of documents in different plants
- non-standard format of information across different plants

Main Barriers Identified

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Energy Performance Indicators

- Main purposes of EnPI

Energy Modeling

Internal Benchmarking

External Benchmarking

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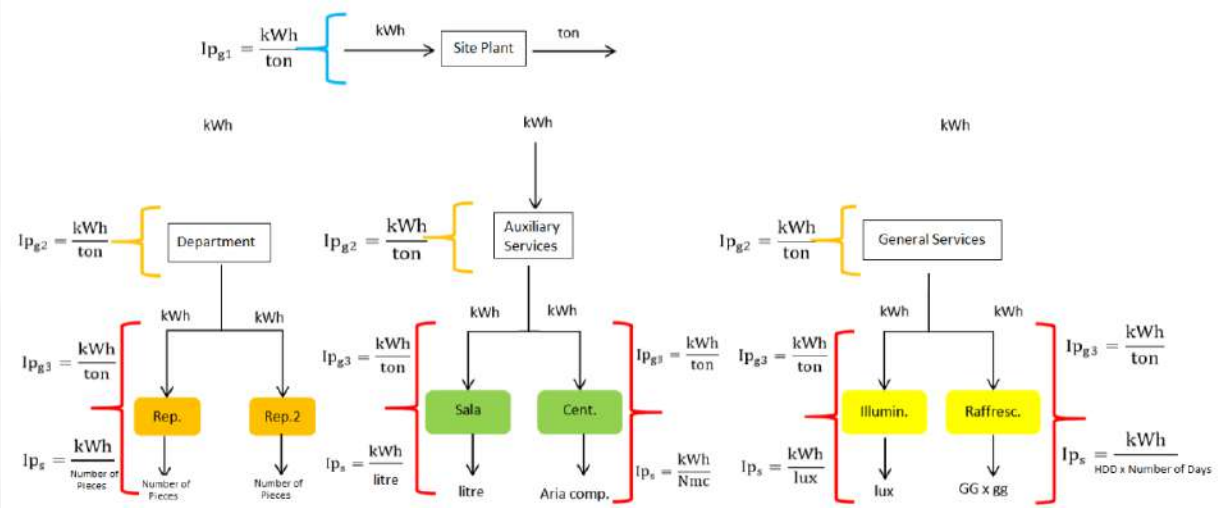
Energy Performance Indicators

- Level A – total energy consumption, whole plant
- Level B – by energy carrier, whole plant
- Level C – by energy carrier, main activities-auxiliary-general services
- Level D – by energy carrier and machine



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Data Sources

Type of Information	Potential Source
Industrial Site Information	• Site layout • Energy audit report • Block flow diagram, P&I diagrams • Asset databases • Technical datasheets
Waste Heat/Cold Recovery & Renewable Heat/Cold and Electricity	• Technical datasheets • Data from sub-metering systems
Industrial Site Processes Information	• Block flow diagram, P&I diagrams • Asset databases • Technical datasheets • Data from sub-metering systems • O&M procedures

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Data Sources

Type of Information	Potential Source
Industrial Site Services Information	• Block flow diagram, P&I diagrams • Asset databases • Technical datasheets • Data from sub-metering systems • O&M procedures
Automated Meter Reading Data and Energy Costs Information	• Energy bills • Data from sub-metering systems • Technical datasheets
General Building Information	• Cadaster data • Energy performance certificate • Technical drawings • Site photographs

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THANK YOU FOR YOUR PARTICIPATION

SOWHAT TEAM

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MODULE 1

CHAPTER 3_DATA COLLECTION AND FORMATTING

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Abbreviations

CHP: Combined Heat and Power

DH: District Heating

DHC: District Heating and Cooling

EU: European Union

GHG: Greenhouse Gas

KPI: Key Performance Indicator

LCOH: Levelized Cost of Heat

RES: Renewable Energy Sources

TES: Thermal Energy Storage

WH/C, WH/WC: Waste Heat/Cold

WHTC: Waste Heat to Cold

WHTH: Waste Heat to Heat

WHR: Waste Heat Recovery

WHP: Waste to Power

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SHORT SUMMARY

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1 Introduction to Energy Audits

According to EN 16247-1 technical standard, "an energy audit is a systematic inspection and analysis of the energy use and consumption of a plant, building, system or organisation, with the aim of identifying and reporting on energy flows and the potential for energy efficiency improvements".

The objective of an energy audit is therefore to take a picture of the baseline energy consumptions and flows, to evaluate consumptions – expressed in terms of indicators, usually with reference to the plant production – comparing them with suitable local and international benchmarks and to identify potential actions for improvement of energy efficiency level, carrying out for each a techno-economic feasibility study and defining an energy efficiency action plan or investment plan.

Figure 1, adapted from EN 16247-1 technical standard, provides an overview of the steps of the energy audit process.

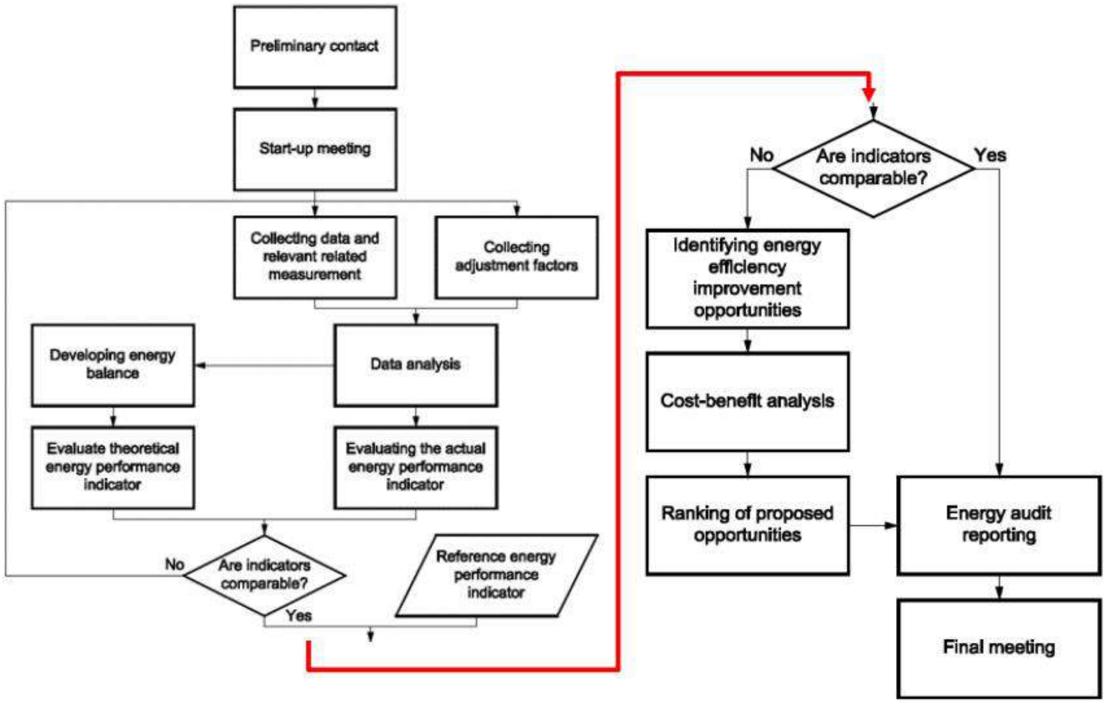

Figure 1 – Energy Audit Process (adapted from EN 16247-1)

According to the same technical standards, the main steps of the energy audit are:

1. introductory contact, aimed at setting the framework of the analysis with the organisation;
2. kick-off meeting, with the aim of identifying data to be collected, measurements to be carried out, measuring equipment to be installed, etc.;
3. data collection, aimed at collecting information and data regarding energy consumption and related costs, characteristics and use of the equipment using energy, general features of the plant, processes and facilities and quantitative plant production data;
4. site visit, whose target is to inspect the plant, assess into further detail the typical energy uses, identify areas and processes requiring additional data collection, carry out spot measurements, preliminarily identify potential recommendations for improvement;

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5. analysis, to evaluate the energy performance of the plant, drawing a breakdown of energy consumption for each energy carrier, calculating indicators and benchmarking with reference values, elaborating detailed proposals for improvement of energy efficiency level;
6. report, which includes a description of general background information about the plant, energy consumption, balances and analysis and an action plan for improving energy efficiency, including recommendations, information about available incentives, profitability analysis, recommendations for monitoring;
7. final meeting, to present to the organisation the conclusions of the energy audit.

The most important part of the energy audit, at least regarding the identification and analysis of the baseline situation, is the construction of the plant energy model. A detailed description of how to build a plant energy model is provided in the Italian Guidelines for Energy Audits in line with Energy Efficiency Directive prescriptions, prepared by ENEA, the Agency in charge of supporting the Italian Government with energy-related topics including the energy audit process.

The plant energy model is defined as the description of the use of each energy vector within the plant boundaries and may have a different level of detail depending on the data available, on the presence of measuring equipment and on the relevance of the area or department.

Figure 2 presents the template of the plant energy model taken from ENEA guidelines.

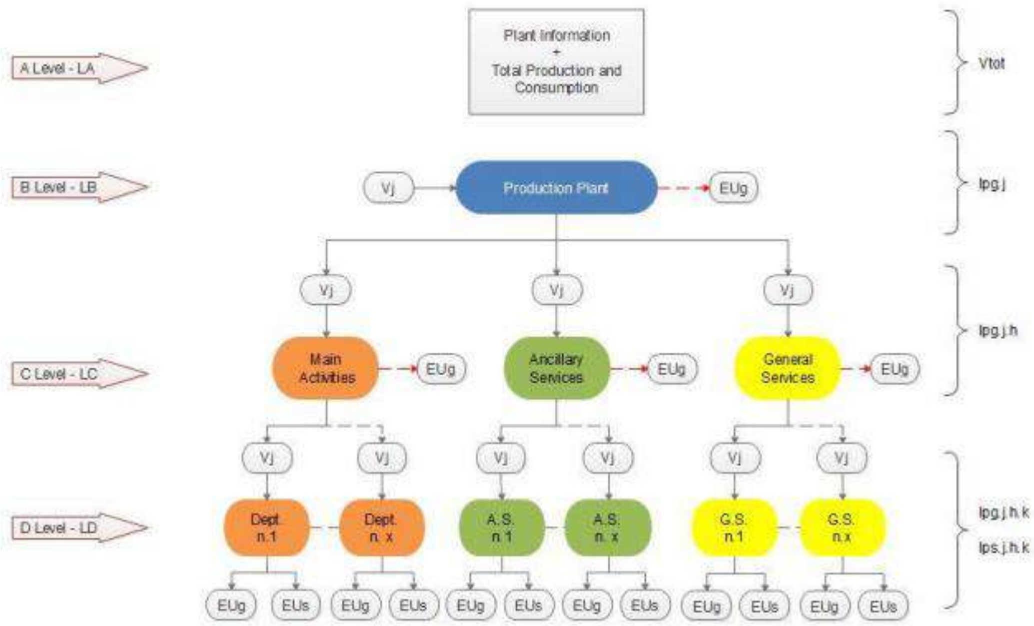

Figure 2 – Template for Plant Energy Model, from ENEA Guidelines

It is highlighted that the tree structure foresees an analysis at different levels:

- Level A only provides the total energy consumption and the total production of the plant;
- Level B analyses the consumption of the specific energy carrier with reference to the production of the plant, calculating a suitable indicator;
- Level C provides the breakdown of consumptions of each vector among three types of users, i.e. "main activities", "auxiliary services" and "general services", which are defined below, and calculates suitable indicators for each area;

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- Level D identifies a further breakdown compared to the previous level, calculating the consumption of each vector for each department/area/service or machine and calculating for each item two suitable indicators, one referring to the total production of the plant and one to the specific production of the department/area/service/machine; e.g. for air compressors that constitute a typical auxiliary service at industrial plants, the calculated indicators are the electricity consumption per unit of volume of compressed air and the electricity consumption for air compression per unit of product of the plant.

As mentioned above, three main types of energy users are identified in the plant energy model:

- Main activities, which are related to the specific plant production such as, for example, the main furnace in a glass production plant or a kiln system in a cement production plant; areas/departments belonging to this category should be clearly identifiable from the point of view of the energy needs and the specific end uses;
- Auxiliary services are all the secondary activities supporting the main ones, such as compressed air systems, thermal power plants, refrigeration units, materials handling systems, etc.;
- General services include all the activities linked to the main production/service process, such as lighting, HVAC, offices, etc.

The data requirements and formats that will be presented in the following chapter will be defined in line with the needs of the above-defined general energy audit process but with a certain degree of customization aimed at the use of the SO WHAT tool.

2 Data Collection Approach

Data collection is the core task of an energy audit and of the identification and assessment of WH/C resource potential. Typically, a data checklist is developed, to gather information on the demo site building (including HVACs), industrial processes and related components, as well as the operation of both the building and the industrial processes.

For the use of the SO WHAT tool, the data collection workflow is articulated into the following steps:

1. **Recommended use case identification**: One of the identified use cases is associated with each demo site, which allows for assessing whether minimum data requirements are met for an assessment of WH/C resource potential;
2. **Data collection**: Available and shareable data, as per data checklist, is collected from demo sites;
3. **Data formatting**: Relevant data is extracted from collected data sources (e.g. energy audit report) and/or data format is adjusted so that it can be integrated into existing SO WHAT modelling tools, in particular for time-series operational data (from utility bills or sub-metering systems);
4. **Data upload**: Formatted time-series operational data is uploaded to online data visualisation and processing platform which is part of existing data-based energy modelling and simulation platform for manufacturing environments;
5. **Data mapping**: Uploaded time-series operational data channels are tagged and mapped across different types of energy (e.g. electricity, natural gas, etc.), process, end-use, etc.;

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6. **Rough-cut profiling**: Where necessary, rough-cut profiling online tool is used to develop more detailed facility's energy consumption profiles (preferably at hourly intervals) from available low-resolution data such as monthly or annual utility bills;
7. **Data processing**: Uploaded time series operational data are processed in order to generate energy input and heat output (including waste heat) profiles for industrial processes and process components of interest;
8. **Building model**: Creation of a building energy simulation model of the facility (construction and HVAC systems, if necessary);
9. **Industrial process component model**: Creation of process models of the internal manufacturing lines of interest, at a component scale;
10. **Data syncing with process components**: Creation and population of process databases, in particular energy inputs and heat outputs (including waste heat) time series operational data;
11. **Energy Sankey diagram**: Creation of Energy Sankey diagram for each demo site in order to identify and assess the most relevant sources of WH/C.

Since the energy model of the industrial site can have different levels of detail depending on the availability of data and also on the interest of an area, department or of an energy vector for the analysis, the data collection approach has been tailored to the main focus of the SO WHAT project, i.e. the identification of the potential opportunities for waste heat and cold valorisation. The approach is top-down, as outlined in Figure 3, with each step characterised by an increasing level of detail.

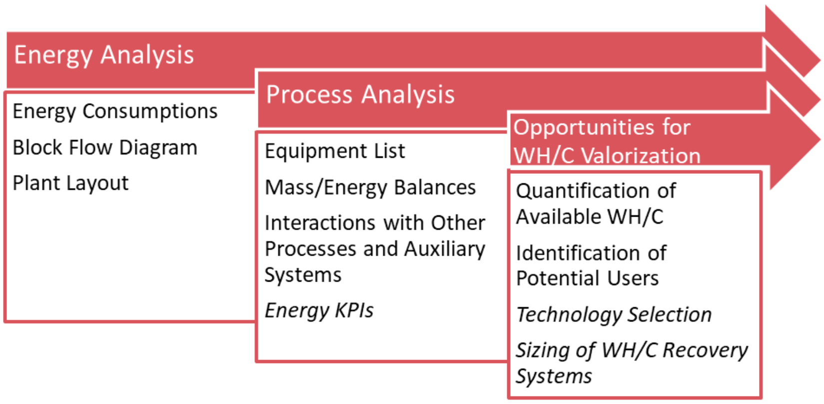

Figure 3 – SO WHAT Overall Data Collection Approach

A brief introduction to the activities foreseen for each data collection step is presented below:

- in the "Energy analysis" step, information is gathered at plant level and covers data on energy consumption, output production and general features of the plant such as working schedule (daily/seasonal), block flow diagram (to identify the main processes and auxiliary/general services and their interactions including material and energy exchanges), site layout (to have information about the location of the main departments and energy users);
- in the "Process analysis" step, based on the outcomes of the previous phase, the main departments/areas of interest are identified and further details are collected, including list of equipment in the area with electrical and thermal power and typical use, complemented with data from an energy monitoring system (if present); mass and energy balances are determined for the areas of interest as well as interactions with other processes and the surrounding environment, and energy KPIs are calculated based on the available data;

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- in the “WH/C opportunities identification” step, thanks to the energy and material balances built in the previous phase for potentially interesting processes, the available waste heat and cold is quantified for all the identified sources, data are collected to identify the potential use of the recovered energy in the surrounding areas (within the plant or externally, through a district heating/cooling network) and then the needed technologies are identified and the sizing of the equipment is carried out.

It is highlighted that the above described data collection approach is tailored on the needs of the SO WHAT tool since it prevents the user collecting and inserting in the software a large amount of very detailed data regarding the whole plant. The plant-level data collection is limited to the minimum parameters needed for an overall characterization of the industrial site, whereas the detailed data gathering is focused on processes and machines of interest for potential waste heat and cold exploitation opportunities.

Specifically, a checklist was developed that lists the main data required for the use of the SO WHAT tool from the industrial side. The checklist includes a significant number of items, since all the parameters needed to model the processes and services of the industry under analysis are present. These data will be used to create a model of the industrial site, breaking down the energy consumptions possibly available from bills at monthly level among different users and at a more refined time scale, based on the features of the different departments and devices, on their typical use, on-off cycles and production schedule, etc.

The checklist is articulated into the following sections:

- Industrial site information;
- Waste heat/cold recovery & Renewable heat/cold and electricity;
- Industrial site processes information;
- Industrial site services information;
- Automated Meter Reading (AMR) data and energy costs information;
- General building information.

It is specified that in case an energy monitoring system is installed at the industrial site, which covers the main processes and services providing historical and live data on their energy consumption, these data could be directly integrated into the SO WHAT tool, thus making not necessary to collect detailed data for all the aspects presented in the checklist.

3 Data Formats

It is clear that no standard format across different industrial sites can be identified for the requested information. Data can be available in different formats and types of documents according to a wide range of internal and external factors, such as company policies and procedures, age, status and location of the plant, operational practices of external suppliers (for energy supply, monitoring systems, production equipment, operation and maintenance, etc.) and consultants, national and local legislative background and requirements, etc.

The most frequent format for data is constituted by Microsoft Excel® spreadsheets, which are used by almost all companies to keep track of energy- and cost-related values and trends but with templates and formats that are generally very different from one company to another; when

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available, data provided in this format can be easily processed by the energy auditor; data available in this format include among others:

- elaborations on energy consumptions and costs done for energy management or project controlling purposes at corporate level;
- output of energy monitoring systems, which may have different time resolutions, ranging from 1 s to hourly or daily scale; it is highlighted that such files may be provided at plant level even by electricity, natural gas or water supplier, typically at hourly or daily scale;
- list of machines, elaborated for maintenance or asset management scopes, or created on purpose for energy management activities;
- data on plant production and raw materials consumption, costs and revenues, etc.

Then, most of the drawings, layouts and schemes of recent realization are realized in AutoCAD® DWG format, which also allows easy processing by the energy auditor for the calculation of distances, areas and volumes, as well as for the identification of further information (e.g.: diameter and type of piping, location of chimneys and other emission points, etc.).

To conclude, many other pieces of information may need to be extracted from a wide range of different documents that are available in PDF format. These may include among others:

- energy bills and invoices produced by suppliers;
- energy audit reports, feasibility studies, design documents for energy-related interventions;
- technical datasheets for installed equipment;
- offers and proposals by potential suppliers for new equipment;
- scanned versions of drawings, layouts and diagrams realized in the past or made not available in an editable format.

The availability of information in many different formats with no standard template across different companies introduces the need of a time-consuming pre-processing phase, whose aim is of gathering all the required information and data and the translation into the desired format. This step is generally done partly by industries (when answering the checklist/questionnaire provided by the energy auditor) and partly by the energy auditor, who generally extracts the required data and information from the documents provided by the industry.

4 Issues and Barriers to Data Collection

Based on the analysis carried out, the following main findings on data collection can be extrapolated:

- energy consumption data for the most important primary energy carriers (i.e.: electricity and natural gas) at plant level are generally available at monthly scale from bills;
- the same data at plant level are not always available at daily/hourly scale because not all suppliers of electricity and natural gas make them available to customers – due to the type of meters installed, to the local legislation or to corporate procedures – but sometimes also because customers do not download such data from the suppliers' portals;
- for other primary energy carriers than main ones (i.e.: diesel/gasoline/LPG or other liquid fuels, coal/biomass or other solid fuels), consumption data may be available on more scattered bases, for example based on refuelling date and amount, which is not completely representative of the distribution of consumptions;

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- for secondary energy carriers (i.e.: heat related ones – steam, hot/superheated water, chilled water, diathermal oil, hot gases – but also compressed air, etc.), monitoring is generally limited to their production and only in seldom cases their distribution and consumption is covered; this means for example that the electricity consumption of the air compressor or the natural gas consumption of the steam boiler are known but the use of compressed air or of steam of a certain department or machine is not and can only be estimated;
- for electricity self-produced internally to the plant, e.g. through a photovoltaic or a cogeneration plant, typically monitoring devices are in place due to the legislative requirement to monitor their production in order to receive the related incentives or quantify the related taxes;
- regarding plant and department production and the consumption of raw materials, data are generally available because correlated with project controlling activities;
- the breakdown of energy consumption among different areas and machines of the plant is generally known only if a monitoring system is present that covers the consumption of one or more energy carriers for the specific department;
- energy consumption indicators are very seldom calculated by industries for external benchmarking purposes, i.e. .for comparison with best practices and identification of potential margins for improvement; it is somehow more frequent that internal benchmarking is applied, i.e. comparison of energy performance indicators of a period compared to the same period of the previous years for energy and process monitoring purposes;
- a full energy audit report is not always available; although the EU Energy Efficiency Directive has introduced the obligation for large companies to carry out an energy audit of their facilities every four years, and this obligation has been transposed into national legislation by all EU Member States, the national implementations foresee that multi-site companies can perform energy audits only on a part of their sites, provided that it is representative of their range of plants for use, size, energy consumption and location;
- a list of machines with nominal data (age, electric and thermal power, nominal output, etc.) is available in most cases for process-related equipment and main auxiliary services but sometimes not for secondary auxiliary equipment and general services (e.g.: HVAC systems, lighting, offices, etc.);
- the records of machines use, in terms of on/off hours, actual load compared to the nominal value, etc. is generally not available unless an energy monitoring system is in place or the machine is provided with a hours-counter due to maintenance reasons (like in the case of diesel-fuelled generators or electric air compressors);
- the breakdown of heating and cooling and/or domestic hot water demand among different areas of the plant is generally not known;
- the layout of the industrial plant is generally available, even for compliance with health and safety and first aid/firefighting legislation, but the indication of the exact location of machines and plants or the layout of the steam/water/compressed air distribution networks is sometimes not available or updated, especially in small and medium-sized industries;
- the characteristics of the building envelope in terms of thickness, materials, presence and features of thermal insulation layers, datasheet of the windows and doors, etc. are not always available, unless the building has recently been constructed and/or a recent energy performance certificate has been issued for the building;
- the location and characteristics (size, gas flowrate/temperature/composition, etc.) of chimneys where exhaust gases are emitted to air may be available from Environmental

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Impact Assessments and/or other permitting documents, if required by the local/national legislation.

Based on the main outcomes of the analysis on data collection presented in the previous section, the following main barriers to data collection were identified:

- confidentiality issues, which obstacle the provision of documents that are available within the plant or the company; this barrier seems to be unjustified when the concerns are related to sharing information with project partners – for which a confidentiality agreement is in place based on the Consortium Agreement – or with an energy consultant, whose role is to support the company in energy-related topics and where needed is ready to sign a non-disclosure agreement based on the needs of the client;
- detailed data available only on core processes and machines; this barrier does not allow a uniformly detailed analysis of energy consumptions and features for example for auxiliary services that usually are those presenting the most important opportunities for waste heat and cold valorisation (e.g.: economizers on steam boilers, heat recovery from compressors' cooling air or water, from chillers/heat pumps, etc.);
- lack of monitored data on heat carriers (steam, hot water, chilled water, hot gases and fluids, etc.), which obstacles the identification of possible users for the potentially recovered waste heat and cold or even of potential opportunities for waste heat and cold recovery;
- lack of detailed information on building characteristics and H&C demand, which obstacles the estimation of the heat demand and consequently like in the previous bullet the identification of possible users for the potentially recovered waste heat and cold;
- non-standard availability of documents in different plants, which constitutes a barrier for the elaboration of data collection strategies and protocols, especially in view of the use in an automated tool;
- non-standard format of information across different plants, with the same effects of the previous barrier.

5 Indicators

As outlined above, the calculation of energy performance indicators and the comparison with relevant local and international benchmarks – especially those related to best practices – is one of the core aspects of the energy assessment of an industry. Indeed, it allows identifying the existing gaps and spotting potential margins for improvement, thus laying the bases for the study of feasibility of potential improvements.

It is understood that benchmarking can be carried out:

- internally, with the aim of assessing the performance of the same plant, process or machine in different years;
- externally, by comparing the performance of the plant with other similar plants – based for example on publications and reports issued by category associations – or with available best practices – based for instance on BREF documents by the JRC of the European Commission for the specific industrial sector).

In both cases, the first required step is to calculate the specific energy consumptions in term of ratio between the input and the output of the system under analysis.

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This can easily be done at plant level (for each single energy carrier or as a whole, converting all inputs into primary energy) considering the total production of the plant, but also for all areas and departments and even for single machines belonging to production departments and auxiliary/general services, following the plant energy model.

Based on the plant energy model built for the specific industrial site, once the consumption of each user (area, production department, process, machine, according to the level of the analysis) has been determined, an indicator representing the specific consumption of the user can be calculated, with reference both to the final product of the plant ("general indicators") and to the product of the single user ("specific indicators"). More in detail:

- for "main activities" general and specific energy performance indicators are both related to the final product of the industrial site;
- for auxiliary services, general energy performance indicators are related to the final product of the industrial site, whereas specific energy performance indicators are related to the output of the service (e.g.: the amount of steam produced by a boiler or of compressed air of a compressor); the two indicators are linked through the consumption of the service output per unit of final product (e.g.: the amount of steam or compressed air used per unit of product, following the examples presented above);
- also for general services, general indicators are calculated with reference to the final product of the industrial site, whereas specific energy performance indicators are correlated with the output of the service (e.g.: illuminance level for lighting systems, heating/cooling degree days for H&C systems, etc.); in this case, there is not always a physical correlation between the general and the specific indicators (e.g.: there is not direct correlation between the illuminance level in the production departments and the production of the industry), but the calculation of the two types of indicators is of interest to evaluate on one hand the share of each general service over the total energy consumption of the site and on the other hand to assess the energy performance of the specific service.

Figure 4, taken from the already mentioned ENEA Guidelines for energy audits, shows an example of the application of the plant energy model approach to the calculation of general and specific energy performance indicators for main activities, auxiliary services and general services.

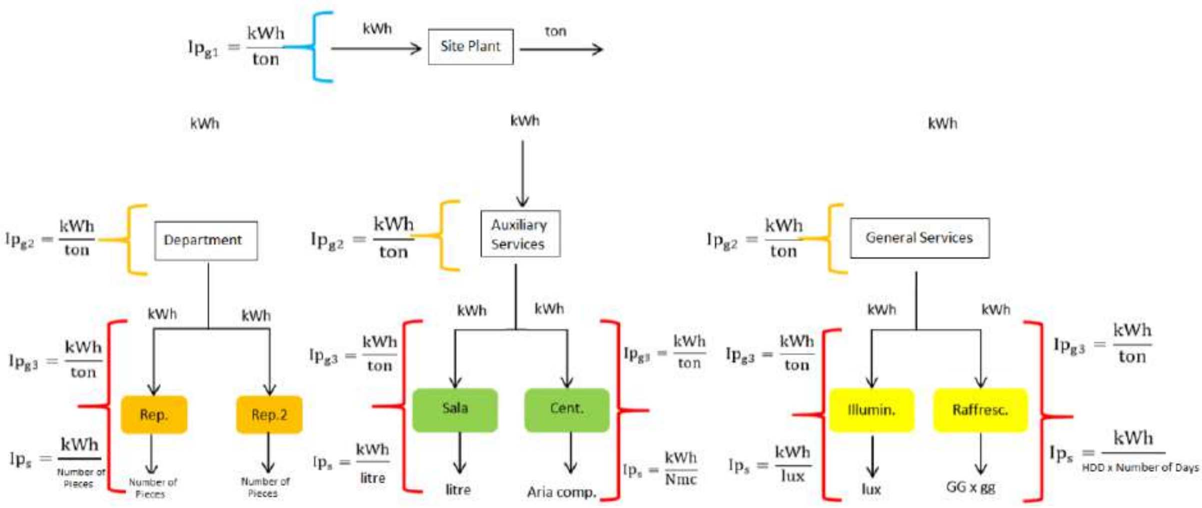

Figure 4 – Example of General and Specific Indicators, from ENEA Guidelines

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A non-exhaustive list of the indicators that can be calculated based on the above presented approach includes the following items:

- electricity consumption;
- natural gas or other fuel consumption;
- thermal energy carrier consumption (e.g.: for thermal energy carriers purchased externally, like in the case of connection to a DHC network, or for internally produced carriers);
- primary energy consumption associated to the use of the above-mentioned energy carriers;
- emissions of greenhouse gases, both direct and indirect, associated to the use of the above-mentioned energy carriers.

The above-listed indicators can be calculated with reference to:

- the output of the whole industrial plant, expressed in a suitable unit (e.g.: mass or volume);
- the output of the single specific department or service, expressed in a suitable unit;
- the efficiency of energy conversion for specific energy-related devices such as boilers, heat pumps or chillers, combined heat and power plants or electricity generators working with conventional or renewable sources, etc.;
- the illuminance level and the footprint area for lighting systems;
- the heating/cooling degree days and the footprint area for H&C systems;
- the building volume and air exchange rate for ventilation/air filtration systems;
- the footprint area, the number of workplaces, the person working hours for offices;
- the distance travelled for transport systems, e.g. company cars/trucks.

6 Data Sources and Processing Protocols

Table 1 summarizes, for each type of information needed for industrial sites, the primary data source whose use is recommended and the backup option to gather the needed data, to be adopted if the primary source is not available.

Table 1 – Typical Data Sources

Information	Primary Source	Secondary Source
Industrial Site Information		
Layout and plans at site level (pdf, dwg, dxf files)	Site layout	HSE plans Cadaster documents
Energy audit report of the site (if available) and year of completion	Energy audit report	None
List of processes and production lines and components (generally provided in form of a block flow diagram or of a P&I diagram)	Block Flow Diagram P&I Diagram	Energy audit report Public information (e.g. website) Scheme by plant management
List of services (e.g.: boilers, chillers, air compressors, etc.)	Maintenance registries Asset databases	Energy audit report List by plant management
List of input and output material types, quantity and ranges of temperature	Invoices/delivery notes	Energy audit report Simplified mass balance

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Information	Primary Source	Secondary Source
List of product types, quantity and ranges of temperature	Sales department data Production management data	Energy audit report List by plant management
Layout and plans at industrial process level (pdf, dwg, dxf files)	Detailed site layout	HSE plans with notes by plant management
Energy storage system type (thermal, electrical, chemical, etc.) and capacity	Technical datasheet	Energy audit report Device label Notes by plant management
Energy storage system location and connection to industrial processes (pdf, dwg, dxf files or other diagrams)	Technical drawings Design documents	Notes by plant management
Process logistics strategy and constraints (e.g.: just-in-time manufacturing, production line shifts, critical operational constraints, etc.)	Operation manuals	Energy audit report Public information (e.g. website) Details by plant management
Final product stock capacity and location on-site (e.g.: final product stock constraints, average final product units stocked on-site, minimum and maximum stock capacities, maximum stock duration, etc.)	Details by plant management	Estimation based on layout, areas and volumes
Presence of energy sub-metering and/or production data monitoring systems – details, characteristics, monitored vector (e.g.: gas, electricity, heat, etc.), boundaries (e.g.: plant level, per process, per machine, etc.) and time resolution (e.g.: daily, hourly, instant, etc.)	Technical drawings Technical specifications Technical proposal/contract	Energy audit report Screenshots of EMS software
Data storage type for sub-metering and/or monitoring systems (e.g.: spreadsheet, online database, etc.)	Technical specifications Technical proposal/contract	Energy audit report Trials on EMS software Indications by plant management
Waste Heat/Cold Recovery & Renewable Heat/Cold and Electricity		
Existing installed waste heat-to-power conversion technologies (including waste cold)	Technical specifications Technical proposal/contract	Machinery labels Notes by plant management
Existing installed waste heat-to-heat recovery technologies (including waste cold)		
Existing installed systems for other renewable energy production (e.g.: Solar Thermal Collector, Cogeneration Heat and Power, Solar Cooling, Solar Parabolic Collector, Solar Photovoltaics, Wind or tidal turbine, etc.)		

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Information	Primary Source	Secondary Source
Document on any waste heat/cold recovery technologies and RES (e.g.: power output and type, energy production, efficiency, etc.)	Sub-metering system	Indications by plant management on working time/load Literature data
Industrial Site Processes Information		
Process name	Block Flow Diagram	Energy audit report Public information (e.g. website) Notes by plant management
Process components name	Machinery list Block Flow Diagram	
Processed product category	Block Flow Diagram	
Processed product name		
Processed product unit		
Processed product maximum flow rate	Technical datasheet	Energy audit report Machinery labels
Production profile for process material inputs and outputs	Sub-metering system	Energy audit report Notes by plant management
Process energy inputs, consumption, peak demand and/or demand profile		
Process inputs from industrial site services (e.g.: steam/hot water/compressed air, etc.)		
Process heat/cold output types (e.g.: air, water, gas, etc.), strategy (e.g.: released into space, extracted, etc.) and temperature ranges	Technical drawings Process monitoring system	Energy audit report Estimation by plant management
Process waste heat/cold types (e.g.: air, water, gas, etc.), uses and temperature ranges		
Presence of process energy sub-metering and/or production data monitoring systems – details, characteristics, monitored vector (e.g.: gas, electricity, heat, etc.), boundaries (e.g.: per process, per machine, etc.) and time resolution (e.g.: daily, hourly, instant, etc.)	Technical drawings Technical specifications Technical proposal/contract	Energy audit report Screenshots of EMS software
Data storage type for sub-metering and/or monitoring systems (e.g.: spreadsheet, online database, etc.)	Technical specifications Technical proposal/contract	Energy audit report Trials on EMS software Indications by plant management
Industrial Site Services Information		
Service name	Block Flow Diagram	Energy audit report Notes by plant management
Service peak operating capacity	Technical datasheet	Energy audit report Machinery label
Service operating hours (day/night, working days only, continuously, etc.)	Sub-metering	Spot measurements Energy audit report Notes by plant management
Service percentage rating (against peak operating capacity) during operating and non-operating hours		
Service idle periods during daily operation (number and duration)		

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Information	Primary Source	Secondary Source
Service production calendar		
Service stop and maintenance periods	O&M Manual	Energy audit report Notes by plant management
Service energy inputs (e.g.: electricity, fuel, etc.), consumption (daily and/or weekly and/or monthly and/or yearly), peak demand and/or demand profile	Sub-metering	Energy audit report Estimation by plant management Literature data
Service output to industrial site process(es)	Sub-metering	
Service heat/cold output type(s) (air, water, gas, etc.), strategy (i.e. released into space or extracted?) and temperature range(s)	Technical drawings Service monitoring system	
Service waste heat/cold type(s) (air, water, gas, etc.), use(s) and temperature range(s)		
Presence of service energy sub-metering and/or production data monitoring systems – details, characteristics, monitored vector (e.g.: gas, electricity, heat, etc.), boundaries (e.g.: per process, per machine, etc.) and time resolution (e.g.: daily, hourly, instant, etc.	Technical drawings Technical specifications Technical proposal/contract	Energy audit report Screenshots of EMS software
Data storage type for sub-metering and/or monitoring systems (e.g.: spreadsheet, online database, etc.)	Technical specifications Technical proposal/contract	Energy audit report Indications by plant management Trials on EMS software
Automated Meter Reading Data and Energy Costs Information		
Fossil fuel consumption at annual level (t/y or Nm^3/y or l/y, and/or corresponding kWh/y)	Energy bills	Energy audit report Sub-metering system Estimation by plant management
Electricity consumption at annual level (kWh/y)		
Electricity bills, to gather data on total energy costs for electricity and breakdown of monthly energy bills in energy and cost terms		Energy audit report Contracts for energy supply
Fossil fuel bills, to gather data on total energy costs for fossil fuels and breakdown of monthly energy bills in energy and cost terms		
Existing energy metering infrastructure (e.g.: smart metering) and characteristics (time and space resolutions, remote data access and sharing, etc.)	Technical drawings Technical specifications Technical proposal/contract	Energy audit report Screenshots of EMS software
Existing energy supply tariffs and schemes (e.g.: ToU tariffs) and/or agreements (e.g.: PPA)	Contracts with authority and/or client	Energy audit report Notes by plant management Literature data

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Information	Primary Source	Secondary Source
Presence of any building energy management system (BEMS) and controlled systems (e.g.: lighting control, HVAC control, etc.)	Technical drawings Technical specifications Technical proposal/contract	Energy audit report Screenshots of software
Presence of any smart sensor in the building (e.g.: temperature, humidity, CO_2 sensors, etc.) and related location		
Data storage type for smart sensors and related systems (e.g.: spreadsheet, online database, etc.)		Energy audit report Trials on EMS software
General Building Information		
Building ID based on cadaster/building database,or internal building ID	Cadaster data	Internal ID
Construction year		Estimation by plant management
Building conditions (bad, fair, good)	Energy Performance Certificate	Self-evaluation by management
Ownership (e.g.: Tenancy, Owner-occupied, etc.)	Company data	Energy Audit Report Public Information (e.g. website)
Hours of use (Morning/Evening/Night, working days only, etc.)		
Building type (e.g.: Office, Warehouse, etc.)		
Address		
HVAC system type (separately for heating, cooling, ventilation)	Technical datasheets Technical drawings	Energy audit Typical HVAC systems for type of building from literature
HVAC fuel or energy carrier used		
Floor area (GIFA / net)	Site layout and drawings Notes by plant management	Estimated by plant management Estimated by energy auditor based on photos, construction period, etc-
Floor plans (pdf, dwg, dxf files)		
Elevation plans (pdf, dwg, dxf files)		
Section plans (pdf, dwg, dxf files)		
Fenestration area		
Construction material type(s)		
Energy Performance Certificate (EPC) level (with recommendations)	Energy Performance Certificate	Energy Audit Report Public Information (e.g. website)
Site photographs	Site photographs	None

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8 References

EN, Technical Standard 16247-1:2012, "Energy audits - Part 1: General requirements", https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT,FSP_ORG_ID:35014,234049&cs=1B2781618A92D90EA1460D4E8A69161CB

BAFA, "Guidelines for Energy Audits", http://www.bafa.de/ea_guidelines

ENEA, "Guidelines for Energy Audits under Article 8 of the EED: Italy's Implementation Practices and Tools", https://www.efficienzaenergetica.enea.it/component/jdownloads/send/40-pubblicazioni/377-guidelines-energy-audits-obligation-in-italy.html

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soWHat

MODULE 1_MAPPING H&C DEMAND AND RES POTENTIAL

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Summary

- Introduction to Mapping
- Mapping Heating and Cooling Demand
  - Top-Down Approach
  - Bottom-Up Approach
- Mapping Renewable Energy Sources Potential
  - Thermal RES
  - Electrical RES

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Introduction to Mapping

- Georeferenced data are an important tool for city- and district-level energy planning
- They allow matching energy demand with potential supply from renewable or sustainable sources in a specific area
- They are particularly useful for high-level planning since they allow identifying areas with a good potential for action but additional evaluations are always needed

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Mapping in SO WHAT

- The SO WHAT tool includes mapping of geographical distribution of the heating and cooling demand and of the potential energy production from renewable energy sources
- Indeed, mapping these two distributions is important in order to evaluate:
  - the possibility of feeding the recovered heat to residential/tertiary buildings through district heating/cooling networks
  - the possibility to integrate the recovered energy with potential further heat or electricity produced from a renewable source

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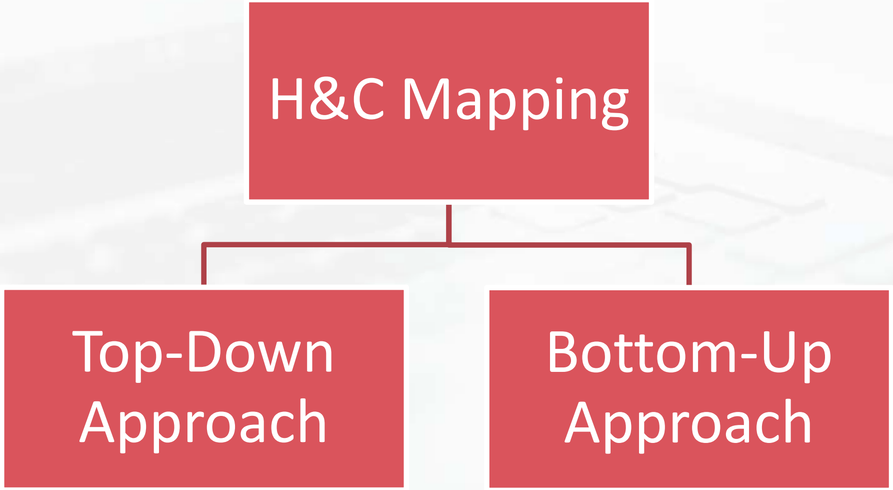
Mapping H&C Demand

- It is needed to determine the space distribution of heating, cooling and domestic hot water demand over a given area, and its time distribution
- Two approaches are available



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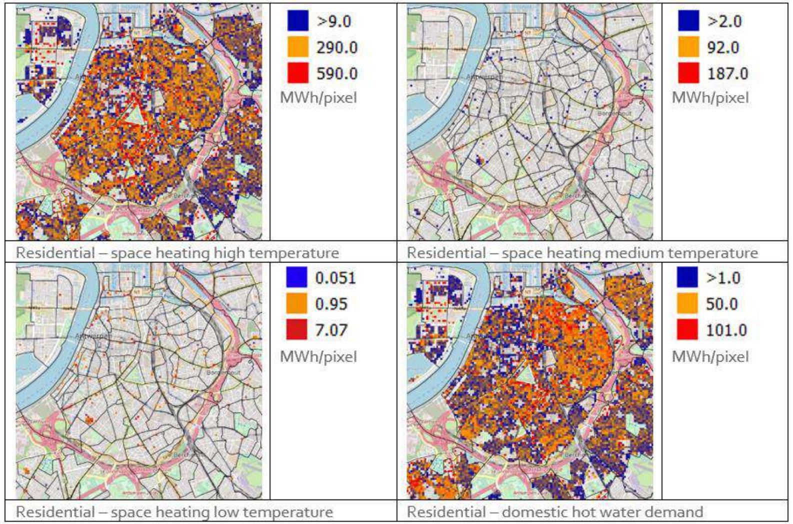
Top-Down Approach

- Works at pixel level
- Maps current annual H&C-DHW useful energy demand
- Requires aggregated input data (at city or district scale)
- Disaggregates the total value based on building/population density data
- Monthly/daily distribution of annual demand can be calculated based on Heating and Cooling Degree Days



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Bottom-Up Approach

- Works at building level
- Maps hourly and annual profile of H&C-DHW useful energy demand
- Requires input data at building level (cadaster or similar)
- Available in a simplified and in a complete version, depending on available information

Use	Construction Period	Number of Buildings	GFA (m²)	Heating Demand (kWh/year)	Cooling Demand (kWh/year)	DHW Demand (kWh/year)
Residential	Pre-1945	534	279,772	20,346,771	473,960	3,888,831
Residential	1945-1969	71	59,463	4,000,259	86,496	826,536
Residential	1970-1979	32	29,703	1,689,811	71,039	412,872
Residential	1980-1989	97	61,734	3,760,774	218,466	858,103
Residential	1990-1999	52	87,441	3,499,476	259,553	1,215,430
Residential	2000-2010	34	37,487	951,556	138,860	521,069
Residential	Post-2010	14	19,677	500,967	67,495	273,510

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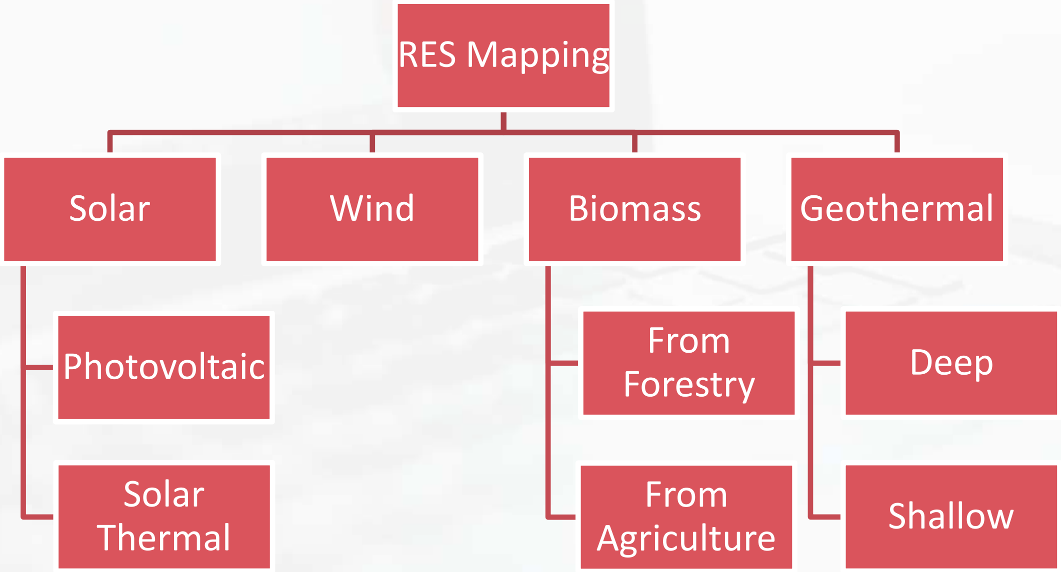
Mapping RES Potential

- Determining spatial distribution of renewable source availability
- For sources with significant variability in time (e.g. solar, wind), determining also time distribution



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What is RES Potential

- Physical Potential
- Geographical Potential
- Technical Potential
- Local Potential

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Mapping Thermal RES Potential

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
Solar thermal energy $E_{pot,solar}$	$E_{pot,solar} = Ir \times Technical\ suitability \times Efficiency \times Available\ Area$ [MWh/yr]	• Ir =Total solar irradiance under flat plane angle [kWh/m^2] • Technical suitability [-]: assumed 40% (1); • Efficiency [-]: assumed 75% (2); • Available area= ○ Footprint of buildings [m^2], ○ Other suitable area [m^2].	• Ir [kWh/m^2]: PVGIS database (https://re.jrc.ec.europa.eu/pvg_tools/it/tools.html#MR); • Footprint of buildings [m^2]: cadaster database or OpenStreetMap (http://www.openstreetmap.org) as an open data alternative; • Other suitable area [m^2]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

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Mapping Thermal RES Potential

Energy source	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
Biomass energy from forestry PE_{FT}	$PE_{FT} = FA \times NAI_{reg} \times PE$ [MWh/yr]	• FA = Forest area of specific forest type: ○ Forest cover [ha], ○ Protected areas or other spatial constrains [ha], ○ Global ecological zones [ha]; • NAI_{reg} = Average stem-wood net annual increment per region [tonnes_{DM}/(ha yr)]: GEZ – Temperate forests: 3.0 to 4.0 • GEZ – Boreal forests: 1.5 to 2.5 • GEZ – Subtropical forests: 0.9 • PE = Primary energy production for every type of forest [MWh/ton_{DM}]: 19.0 to 19.2	• Forest cover [ha]: Corine Land cover (2018) (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018); • Protected areas or other spatial constrains [ha]: Natura2000 areas (2016) (http://ftp.eea.europa.eu/www/natura2000/Natura2000_end2016_Shapefile.zip); • Global ecological zones [ha]: Global ecological zones (2010) (http://www.fao.org/geonetwork/srv/en/main.home?uuid=2fb209d0-fd34-4e5e-a3d8-a13c241eb61b);

Similar correlations for biomass energy from agriculture

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Mapping Thermal RES Potential

Energy source	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
Deep geothermal energy $H_{tech,heat,x\,km}$ **(150m-7km)**	$P_{tech,heat,x\,km} = \frac{T_{x\,km} - T_r}{T_{7km} - T_r} P_{tech,heat,7km}$ [W] $H_{tech,heat,x\,km} = P_{theory} \times lifetime$ [J]	• $T_{x\,km}$ = Rocks' temperature at a specific depth [°C]; • $T_{7\,km}$ = Rocks' temperature at 7 km of depth [°C]; • T_r = Temperature of reinjected water [°C]; • *Lifetime*: assumed 8760 hours a year;	• Spatial constrains: EES-Natura200 areas (http://ftp.eea.europa.eu/www/natura2000 /Natura2000_end2016_Shapefile.zip); • Technical potential deep geothermal energy: database from https://www.thermogis.nl/en/map-viewer; • https://map.mbfsz.gov.hu/geo_DH/ • $T_{x\,km}$, $T_{7\,km}$ [°C]: database from https://www.thermogis.nl/en/map-viewer.

Similar correlations for shallow geothermal energy

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Mapping Electrical RES Potential

Energy source	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input

Photovoltaic energy $E_{pot,ph}$	$E_{pot,ph} = Ir \times Technical\ suitability \times Panel\ Efficiency \times Electrical\ Efficiency \times Available\ Area$
	
	[kWh/yr]
		• Ir =Total solar irradiance under flat plane angle [kWh/m^2]
		• Technical suitability [-]: assumed equal to 40% (1);
		• Panel Efficiency [-]: assumed equal to 30% Invalid source specified.;
		• $Electrical\ Efficiency$ [-]: assumed to be equal to 17%
		• Available area=
		  ○ Footprint of buildings [m²],
		  ○ Other suitable area [m²].
			• Ir [kWh/m^2]: PVGIS database (http://re.jrc.ec.europa.eu/PVGIS5-release.html);
			• Footprint of buildings [m²]: cadaster database or OpenStreetMap (http://www.openstreetmap.org) as an open data alternative;
			• Other suitable area [m²]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

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Mapping Electrical RES Potential

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Energy source	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
Wind energy at a specific height h E_h	$E_h = 8760\,\eta_m\,\eta_{el}\,\eta_{aux} \sum_{w=w_{low}}^{w_{high}} P_h(w) f(w)$ [kWh/yr] $f(w) = \left(\frac{\beta}{\eta}\right)\left(\frac{w}{\eta}\right)^{\beta-1} e^{-\left(\frac{w}{\eta}\right)^{\beta}}$ [-]	• 8760 yearly operative hours of the aerogenerator [h]; • ρ = air density [kg/m³]; • A = area of the aerogenerator that is orthogonal to wind's direction [m²]; • w = wind speed [m/s]; • C_p = power coefficient [-]; • $f(w)$ = Weibull distribution [-]; • β = shape parameter [-]; • η = scale parameter [-]. • Height at which the wind turbine is placed; • η_m mechanical efficiency of the device [-]; • η_{el} electrical efficiency of the device [-]; • η_{aux} auxiliaries' efficiency [-].	• β and η [-]: CENER database (https://globalwindatlas.info/) • Spatial constrains: EES-Natura200 areas (https://www.eea.europa.eu/data-and-maps/data/natura-9/natura-2000-spatial-data/natura-2000-shapefile-1).

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THANK YOU FOR YOUR PARTICIPATION

SOWHAT TEAM

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MODULE 1

CHAPTER 4_MAPPING H&C DEMAND AND RES POTENTIAL

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Abbreviations

CAPEX: Capital Expenditure
CBA: Cost-Benefit Analysis
CHP: Combined Heat and Power
DH: District Heating
DHC: District Heating and Cooling
DLT: Distributed Ledger Technologies
ESCO: Energy Service Company
EU: European Union
GHG: Greenhouse Gas
GM: General Manager
HU: Heat Upgrade
IEC: Integrated Energy Contracting
ICT: Information and communications technology
KPI: Key Performance Indicator
LCOH: Levelized Cost of Heat
OPEX: Operating Expense
R&D: Research and Development
RES: Renewable Energy Sources
REII: Renewable Energy Intensive Industries
SME: Small and Medium Enterprises
TES: Thermal Energy Storage
UI: User Interface
UX: User experience
WH/C, WH/WC: Waste Heat/Cold
WHTC: Waste Heat to Cold
WHTH: Waste Heat to Heat
WHR: Waste Heat Recovery
WHP: Waste to Power

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SHORT SUMMARY

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1 Introduction to Mapping

Georeferenced data are an important tool for city- and district-level energy planning since they allow matching the energy demand (heating & cooling, electricity, etc.) with the potential supply from renewable or sustainable sources in a specific area. Specifically, it is worth highlighting that they are useful for high-level planning since they allow identifying areas with a good potential for intervention but additional evaluations are needed to preliminarily design systems and plants to be installed.

This chapter focuses on the methodology that the SO WHAT tool adopts to determine the geographical distribution of both the heating and cooling demand and the potential for energy production from renewable energy sources. In the context of the SO WHAT tool, whose main focus is on the valorisation of excess heat and cold from industrial sites, mapping these two distributions is important in order to evaluate the possibility of feeding the recovered heat to residential/tertiary buildings through district heating/cooling networks, possibly coupled with heat or electricity produced from a renewable source.

The following two sections focus respectively on mapping the heating and cooling demand and the potential for energy production from renewables.

2 Mapping Heating & Cooling Demand

As mentioned above, in order to enable new business cases for waste heat/cold recovery, it is of paramount importance to analyse and identify the location and the magnitude of Heating/Cooling (H/C) demand in the area surrounding the industrial sites in which Waste Heat/Cool (WH/C) is available.

The methodology adopted in the SO WHAT project for mapping H&C (and DHW) demand is linked to the work made in the previous PLANHEAT project, whose mapping module combines QGIS and a customized software to carry out energy-related computations. The PLANHEAT tool as developed in the project is completely open-source, so such algorithms could be used as relevant starting point for SO WHAT tool too. It is acknowledged that the mapping methodologies hereby presented have been developed by PLANHEAT consortium, in particular by RINA-C and VITO (Top Down approach) and TECNALIA and VITO (Bottom-up Approach).

In order to map H&C and DHW demand, two main approaches can be identified according to the availability of input data, and specifically:

- **Top-Down approach** (pixel level), aimed at mapping the current annual H&C-DHW useful energy demand, provided that aggregated (at city or district scale) input data are available; starting from annual data about final energy consumption aggregated at a certain level (from district up to city aggregation), the algorithm disaggregates them at the desired resolution; the monthly and daily distribution of the annual demand can then be calculated based on the number of Heating and Cooling Degree Days at specific location;
- **Bottom-Up approach** (building level), aimed at calculating and mapping hourly and annual profile of H&C-DHW useful energy demand, provided that input data at building level are available; starting from detailed information at building level the algorithm estimates hourly profiles of H&C demand for each building for which input information is provided.

Due to the high-level target of the tool, whose objective is to quantify H&C-DHW demand in order to identify potential "clients" for WH/C recovered from industries, following methodologies developed

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in the previous PLANHEAT project, the most suitable approach for the SO WHAT tool is the simplified version of the bottom-up approach.

2.1 Top-Down Approach

The top-down approach developed in PLANHEAT WP2 under VITO and RINA-C supervision allocates the heating, cooling and DHW demand of the city based on final energy consumption data inserted by the user and spatial indicators describing the building stock and activities in the city.

The results of the analysis are presented in form of georeferenced maps and also in spreadsheets and tables, describing the demand at city level or at level of other spatial subdivisions of interest to the user. The spatial resolution can be varied by the user, usually in the range between 50 m and 1 km, depending on the size of the city, whereas the time resolution is one year.

The first step of the analysis foresees the conversion of final energy consumption data into useful demand numbers for the residential and the tertiary sector, with breakdown among the following categories:

- space heating at high temperature (>70°C);
- space heating at medium temperature (40-70°C);
- space heating at low temperature (< 40°C);
- domestic hot water;
- space cooling.

Each of the above categories of H&C demand is then spatially distributed according to a "weighted distribution" algorithm based on the most suitable spatial indicators available for the specific location. Examples of such spatial indicators are the spatial distribution of the floor area of the residential buildings within the city (if available from the local cadaster), the footprint of buildings in the city, the employment maps or the spatial distribution of population density. If specific data at local scale are not available, default GIS datasets at European scale can be used (e.g. Corine Land Cover, PVGIS, etc.).

Inputs Needed in the Top-Down Approach

The baseline scenario is assessed in terms of useful energy demand for heating, cooling and DHW for selected areas of the city. The assessment is therefore based on the following input data:

- Final energy consumption of the area of interest;
- Information or assumptions about technologies installed in the area of interest.

Specifically, it is required to provide the breakdown of final energy consumption by:

- **Sector**: Residential and Tertiary;
- **Type of system**: Single Building Solution or District Heating and Cooling Network;
- **Energy end-use**: Heating, Domestic Hot Water and Cooling (the share between heating and domestic hot water is required if the user has available final energy consumption combining heating and DHW);
- **Energy source**: for heating and DHW: natural gas, electricity, fuel oil, other fossil fuels, geothermal, solar, biomass, waste heat; for cooling: natural gas, electricity, waste heat and geothermal.

Information about technologies for each energy source are also required, including:

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- **Technology type** (boilers, combined heat and power generators, compression and absorption heat pumps, electrical heaters, heat exchangers, solar thermal panels);
- **Efficiency** and, for CHP only, utilization factor;
- **Share of technology** type (in terms of share of devices installed for each technology or share of end users supplied).

In case of lack of input data, default values coming from EU databases can be adopted. For instance, data aggregated at national level can be used and downscaled according to the population of the city of interest. In this framework, relevant databases are:

- Heat RoadMap Europe – Data set for Heating and Cooling Demand **Invalid source specified.**;
- European Building Stock Database**Invalid source specified.**;
- European Settlement Map 2015 –release 2019 (2-10m spatial resolution) **Invalid source specified.**;
- Corine Land Cover 2018 map **Invalid source specified.**.

Output of the Top-Down Approach

The outputs resulting from the application of the top-down approach are listed below:

- Residential/Tertiary sector - Single building solution:
  - Useful energy demand per energy source – Heating [MWh/year],
  - Useful energy demand per energy source – DHW [MWh/year],
  - Useful energy demand per energy source – Cooling [MWh/year];
- Residential/Tertiary sector – DHCN solution:
  - Useful energy demand per energy source – Heating + DHW [MWh/year],
  - Useful energy demand per energy source – Cooling [MWh/year];
- Residential/Tertiary sector – Single building solution + DHCN solution:
  - Total useful energy demand per energy source (all temperature levels) [MWh/year],
  - Total useful energy demand per energy source heat supply >70°C [MWh/year],
  - Total useful energy demand per energy source heat supply 40 -70 °C [MWh/year],
  - Total useful energy demand per energy source heat supply <40°C [MWh/year],
  - Total useful energy demand per energy source DHW [MWh/year],
  - Total useful energy demand per energy source Cooling [MWh/year],
  - Share of useful energy demand covered by each energy source [%];
- Raster maps (with resolution defined by the user) with spatial distribution of current useful energy demand for:
  - Residential – space heating high temperature,
  - Residential – space heating medium temperature,
  - Residential – space heating low temperature,
  - Residential – domestic hot water,
  - Residential – space cooling,
  - Tertiary – space heating high temperature,
  - Tertiary – space heating medium temperature,
  - Tertiary – space heating low temperature,
  - Tertiary – domestic hot water,
  - Tertiary – space cooling;

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- Summary of the raster maps in a bar chart and table, subdivided by district or other spatial subdivisions of interest to the user.

Examples of outputs from the top-down approach are presented in Figure 1.

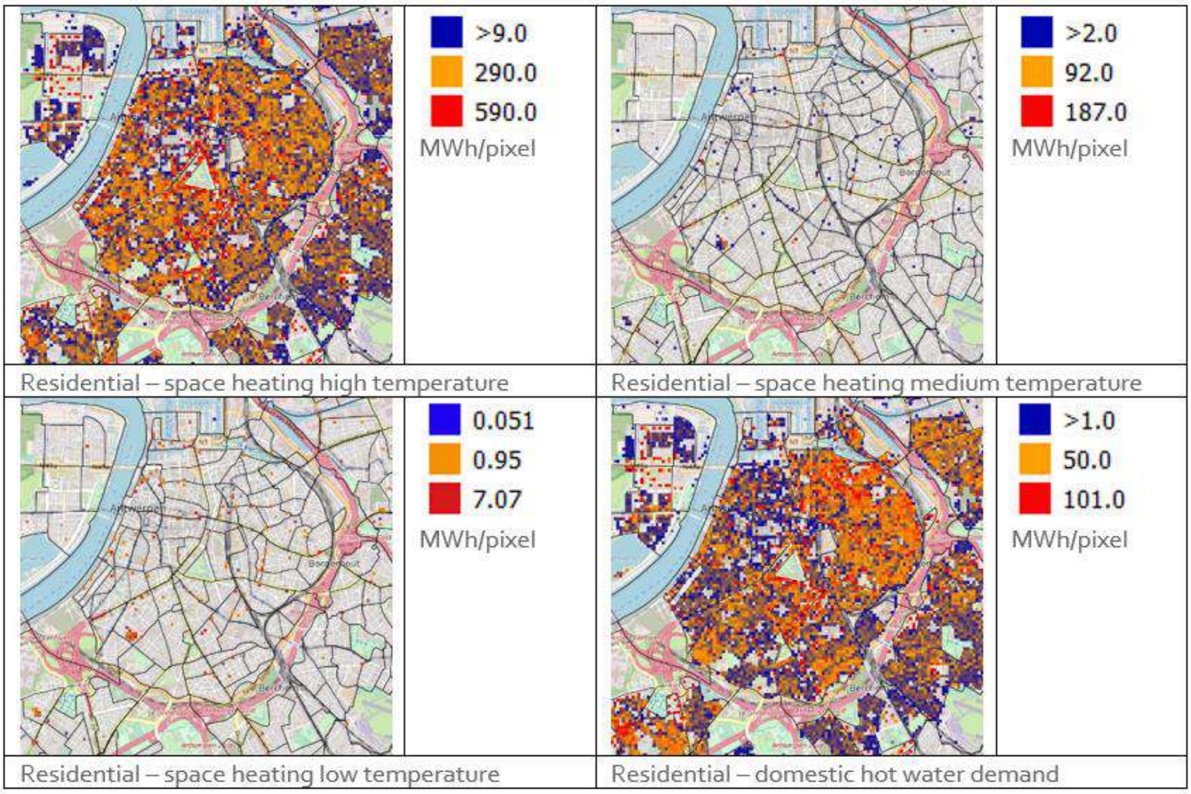

Figure 1: Example of Outputs of Top-Down H&C Demand Mapping Approach – Map View

2.2 Bottom-Up Approach

Developed in PLANHEAT WP2 under VITO and TECNALIA supervision, the Bottom-Up approach is aimed at quantifying and mapping the georeferenced thermal energy (heating, cooling and DHW) demand for each building at district scale.

It starts from different information available for the buildings of the selected area and calculates the useful hourly energy demand, aggregating results at the desired level (per building or per district, per building category in terms of use and/or construction period).

This approach can be implemented, as done in the District Mapping Module of the PLANHEAT project, through a QGIS plugin, which has the benefit to be an open-source GIS cross-platform application.

Inputs Needed in the Bottom-Up Approach

The inputs needed for the bottom-up approach are mainly related to the physical characteristics of the buildings in the area. This information is generally available for local authorities and municipalities, which use it for urban planning and public works, as well as for taxation of urban properties through the cadaster database. A cadaster is available in all EU Member States, although no homogeneous model is available and sometimes data are present only in paper form.

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The bottom-up approach is developed with the aim of basing most of the assessment only on the cadaster information. Based on the level of detail of the information available for the specific municipality, two approaches can be identified: a complete and a simplified one. In addition to cadaster information, only two further types of data may be required: information on building heights (if it is not available from the cadaster, from LiDAR for example) and air temperature data (only for the complete approach).

It is highlighted that the accuracy of the results provided by the bottom-up approach depends on the availability, accuracy and level of detail of data. When the cadastral data is not available or is outdated, an alternative solution is to base the assessment on information from OpenStreetMap**Invalid source specified.** that provides building geometries and attributes based on an open source and active collaborative framework.

Independently from the type of input data source used, a pre-processing phase is always needed. Indeed, the following issues related to data format and availability were identified:

- the information may be not included in a single layer;
- different layers can have different coordinate reference systems;
- different sources do not use the same ID for the same information;
- geometry of buildings might be too complex and need to be simplified;
- the available information is not complete for all buildings;
- data may be inconsistent.

As introduced above, when the height of the buildings is not available in the cadaster, backup information can be taken from LiDAR, which is a system generating a cloud of point covering the ground surface by means of an airborne laser scanner. From LIDAR data, a Digital Surface Model (DSM) and a Digital Terrain Model (DTM) can be derived, the former representing the elevation of the natural and built environment above the earth surface and the latter the elevation of the earth surface.

To conclude, the third type of information for the assessment is the heating and cooling degree days for the specific location, which can be gathered from many online weather services like degreedays.net.

After the pre-processing step, a shapefile is created which includes a unique geometry for each building and the set of information presented in Table 1: building ID, building geometry, footprint area, year of construction, use and building height.

Table 1: Bottom-Up Approach - Inputs to be provided by the End-User

Parameter	Mandatory or Optional	Source	Assessment approach
Building ID	Mandatory	SHP of the District	Complete (C) and Simplified (S)
Project ID	Mandatory	User input	C + S
Study area name	Mandatory	User input	C + S
Country	Mandatory	User input	C + S
Building Geometry	Mandatory	SHP of the District	C + S
Footprint area	Mandatory	SHP of the District	C + S

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Parameter	Mandatory or Optional	Source	Assessment approach
Height	Mandatory	SHP of the District or LiDAR *If the end user does not provide the information about "number of floors"	C + S
Height	Optional	SHP of the District or LiDAR *If the end user provides the information about "number of floors"	C + S
Number of floors	Mandatory	SHP of the District *If the end user does not provide the information about the "height"	C + S
Number of floors	Optional	SHP of the District *If the end user provides the information about "height"	C + S
Hourly outside air temperature	Mandatory	weather webserver	C
Year of construction	Mandatory	SHP of the District	C
Building Use	Mandatory	SHP of the District	C
Gross floor area	Optional	SHP of the District	C
Roof area	Optional	SHP of the District	C

Output of the Bottom-Up Approach

The bottom-up approach provides results at building level and at district level.

At building level, it provides two different results:

- georeferenced generic and energy-related information per building (as shown in Table 2);
- hourly heating, cooling and DHW demand data per each building of the area.

The results will be available in CSV and SHP format, to allow analysis at quantitative and at georeferenced level. The two files contain for each building of the area under analysis the information listed in Table 2.

Examples of outputs from the bottom-up approach are presented in Figure 2 and Table 1.

Table 2: Bottom-Up Approach - Outputs at Building Level

Parameter		Unit	Assessment approach (Complete / Simplified)
Project Generic Data			
	Project ID	Name	Both
	Study area name	Name	Both
	Country	Name	Both
Building Generic Data			
	Building ID	-	Both
	Centroid of the building	Coordinates	Both

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Parameter		Unit	Assessment approach (Complete / Simplified)
	Use	-	Complete
	Footprint area	m²	Both
	Height	m	Both
	Number of floors	-	Both
	Gross floor area	m²	Both
	External opaque facade area	m²	Complete
	Roof area	m²	Complete
	Window area	m²	Complete
	Volume	m³	Complete
	Year of construction	-	Complete
Building Energy Data			
	Annual heating demand	kWh/y	Both
	Annual cooling demand	kWh/y	Both
	Annual DHW demand	kWh/y	Both
	Annual heating demand per square meter	kWh/m²/y	Both
	Annual cooling demand per square meter	kWh/m²/y	Both
	Annual DHW demand per square meter	kWh/m²/y	Both
	Peak heating demand	kW	Both
	Peak cooling demand	kW	Both
	Peak DHW demand	kW	Both

Figure 2: Example of Output of Bottom-Up H&C Demand Mapping Approach – Map View at Building Level

Table 3: Example of Output of Bottom-Up H&C Demand Mapping Approach – Table View at District Level

Use	Construction Period	Number of Buildings	GFA (m²)	Heating Demand (kWh/year)	Cooling Demand (kWh/year)	DHW Demand (kWh/year)
Residential	Pre-1945	534	279,772	20,346,771	473,960	3,888,831
Residential	1945-1969	71	59,463	4,000,259	86,496	826,536

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Use	Construction Period	Number of Buildings	GFA (m²)	Heating Demand (kWh/year)	Cooling Demand (kWh/year)	DHW Demand (kWh/year)
Residential	1970-1979	32	29,703	1,689,811	71,039	412,872
Residential	1980-1989	97	61,734	3,760,774	218,466	858,103
Residential	1990-1999	52	87,441	3,499,476	259,553	1,215,430
Residential	2000-2010	34	37,487	951,556	138,860	521,069
Residential	Post-2010	14	19,677	500,967	67,495	273,510

3 Mapping Renewable Energy Sources Potential

In this section, focus is placed on the mapping of the potential for energy production from renewable sources, useful to identify the opportunities for integration of renewable electricity and heat in the energy systems of the plant under analysis.

The following paragraphs have the objective to provide information on the algorithms that can be used to geo-reference on a map renewable sources for heat supply (solar thermal, geothermal and biomass) and electricity generation (photovoltaic and wind energy). SO WHAT tool is provided with the functionalities of displaying on a geo-referenced map, different potentials of the mentioned sources in order to be useful to different type of end-user at different planning level.

Introduction to RES Potential

Four types of renewable sources potentials have been identified. For each of them, a map can be developed, specifying the annual energy potential in MWh. In addition, for the sources having a significant variation in time (wind and solar), a higher granularity can be achieved and also hourly values can be determined. In particular, hourly profiles can be useful for the modules of the SO WHAT tool that need to analyze the energy performance of the systems hour by hour.

The above-mentioned source potential defined are:

1) **Physical potential:** it represents the maximum amount available for the considered source. It depends on weather conditions (e.g. presence of wind, absence of clouds, etc.) and on type of territory (e.g. suitability for biomass growing). A typical example is the energy coming from solar irradiation on a surface or the energy that is contained in the forestry biomass of a hectare of forest.
2) **Geographical potential:** it represents the amount of energy that is available to be effectively exploited and that is less than the physical potential since it depends from different constraints that can limit its exploitation such as availability of surface for technology installation or limitation of biomass extraction from a forest. Also for this case, the geographical potential is expressed in MWh/y.
3) **Technical potential:** it represents the energy that is provided by an energy source after the application of a technology, therefore the thermal energy that is transferred to an intermediate medium to heat up or cool down the air of an internal space or the electricity that is produced to cover a demand. The process of transferring and transforming energy is always subject to an efficiency and part of the initial energy is lost. To consider this aspect, to each geographical potential for each source a transformation efficiency will be applied through the selection of a

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technology form the SO WHAT tool library. In order to represent the technical potential on a map, an annual value will be produced for each source after the selection of the appropriate technology. In this case, an average or seasonal efficiency will be used to provide an estimation of the technical potential that is possible to obtain from a source. In the Manufacturing and Community modules of SO WHAT tool, a more precise calculation at hourly level of technology efficiency will be done to provide more accurate results about the utilization of local sources.

4) **Local potential:** it represents local potential demand and will be evaluated in the section dedicated to the calculation of the energy demand at building level of the different modules.

In the following paragraphs, the algorithms proposed for the SO WHAT tool for the geo referenced evaluation of the annual physical, geographical and technical potentials of different local sources are described. These algorithms are implemented in the different modules of the SO WHAT tool to be used by the end-user as a support for the evaluation of the energetical potential of the territory under investigation.

Inputs for Mapping RES Potential

In the SO WHAT tool all the georeferenced information that are needed to provide the annual amount of local energy sources come from existing databases that represent the basis for the calculations of the three levels of potential that are the object of this paragraph (physical, geographical and technical).

In Table 4, for each local source considered, the external databases that can be used are mentioned. For some of them (e.g. those related to solar thermal) the information provided already represents the physical potential, for the others, various pieces of information are required to evaluate the physical, the geographical and the technical potentials.

Table 4: Databases to identify SO WHAT tool resources

Energy source's type	External database to provide default values for RES resources
Solar thermal energy (solar thermal heat and photovoltaic)	• PVGIS database. Hourly radiation data by location. Spatial resolution of 6 km. (http://re.jrc.ec.europa.eu/PVGIS5-release.html); • MERRA-2 RE-ANALYSIS. Hourly radiation data by location. Spatial resolution approx. of 50 km (http://www.soda-pro.com/fr/web-services/meteo-data/merra). • HELIOCLIM-3 REAL-TIME AND FORECAST. Hourly radiation data by location. Spatial resolution approx. of 100 m (http://www.soda-pro.com/fr/web-services/radiation/helioclim-3-real-time-and-forecast). • GLOBAL SOLAR ATLAS (https://globalsolaratlas.info/map). Daily and yearly radiation and potential values. Spatial resolution approx. of 250m.
Biomass	• Corine Land Cover suitable forest and agricultural areas [m²] (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018). • Forest type [m²] (https://land.copernicus.eu/pan-european/high-resolution-layers/forests/forest-type-1/status-maps/2015).
Geothermal (shallow and deep)	• Geothermal Heat (https://heatroadmap.eu/peta4/). Temperatures at different depths. • Shallow geothermal potential in W/mK (http://www.hotmaps.eu/)

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Wind	• https://globalwindatlas.info/ Wind resource mapping at 250 m horizontal grid spacing. Wind resource mapping at 10, 50, 100, 150 and 200 m above ground/sea level.
Industrial Excess Heat	• E-PRTR (European Pollutant Release and Transfer Register) database (https://prtr.eea.europa.eu/#/home)

In addition to these databases, specific local data are needed, such as cadaster data of the city with footprint of buildings. To this aim, the layer Buildings of OpenStreetMap (http://www.openstreetmap.org) can serve as an open data alternative. Moreover, EES-Natura200 areas database (https://www.eea.europa.eu/data-and-maps/data/natura-9/natura-2000-spatial-data/natura-2000-shapefile-1) can be useful to check the presence of constraints that may obstacle the realization of plants in a given area.

A summary of the technical information required from the end-user of the SO WHAT tool are provided in Table 5. For each parameter, a default value will be presented for calculation, but the related field of input opens to be edited.

Table 5: default efficiencies related to different technologies for the technical potential mapping

Source	Technology	Default for efficiency
Thermal RES		
Solar thermal energy	Flat plate solar collectors	50% th.
	Evacuated tube solar collectors	70% th.
	Concentrating collectors	80% th.
Forestry biomass	Hot water boiler	85% th.
	Steam boilers	85% th.
	Gasifiers (cogeneration)	70% th – 20% el.
	ORCs (cogeneration)	65% th. – 18% el.
Agricultural biomass	Hot water boilers	80% th.
Deep geothermal	Heat exchanger	90% th.
	HRSG (cogeneration)	45% el. – 40% th.
	ORC (cogeneration)	40% el. – 40% th
Shallow geothermal	Compression heat pump	300%
	Absorption heat pump	150%
Electrical RES		
Photovoltaic energy	Polycrystalline	17% el.
	Monocrystalline	15% el.
	Amorphous	13% el.
	Thin film	10% el.
Wind energy	Horizontal axis	30% el.
	Vertical axis	45% el.

Mapping Thermal RES Potential

The thermal RES considered in SO WHAT tool are solar thermal, biomass (from forestry and agriculture) and geothermal (shallow and deep), being the most widely available and mature. Table 6 summarizes the algorithms and the databases used to evaluate the potential for these sources.

Table 6 : Thermal RES Potential – Algorithms and Reference Sources

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input

Solar thermal energy $E_{pot,solar}$	$E_{pot,solar} = Ir \times Technical\ suita \times Efficiency \times Available\ Area$ [MWh/yr]	• Ir =Total solar irradiance under flat plane angle [kWh/m²]
		• *Technical suitability* [-]: assumed 40% (1);
		• *Efficiency* [-]: assumed 75% (2);
		• *Available area*=
		  ○ Footprint of buildings [m²],
		  ○ Other suitable area [m²].
			• Ir [kWh/m²]: PVGIS database (https://re.jrc.ec.europa.eu/pvg_tools/it/tools.html#MR);
			• *Footprint of buildings* [m²]: cadaster database or OpenStreetMap (http://www.openstreetmap.org) as an open data alternative;
			• *Other suitable area* [m²]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Biomass energy from forestry PE_{FT}	$PE_{FT} = FA \times NAI_{reg} \times PE$ [MWh/yr]	• FA = Forest area of specific forest type:
		  ○ Forest cover [ha],
		  ○ Protected areas or other spatial constrains [ha],
		  ○ Global ecological zones [ha];
		• NAI_{reg} = Average stem-wood net annual increment per region [tonnes$_{DM}$/(ha yr)]: GEZ – Temperate forests:
		  - Coniferous: 3.0
		  - Broadleaf: 4.0
		  - Mixed C-B: 4.0
		GEZ – Boreal forests:
		  - Coniferous: 2.5
		  - Broadleaf: 1.5
		  - Mixed C-B: 1.5
		GEZ – Subtropical forests:
		  - Coniferous: 0.9
		  - Broadleaf: 0.9
		  - Mixed C-B: 0.9
		• PE = Primary energy production for every type of forest [MWh/ton$_{DM}$]:
			• Forest cover [ha]: Corine Land cover (2018) (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018);
			• Protected areas or other spatial constrains [ha]: Natura2000 areas (2016) (http://ftp.eea.europa.eu/www/natura2000/Natura2000_end2016_Shapefile.zip);
			• Global ecological zones [ha]: Global ecological zones (2010) (http://www.fao.org/geonetwork/srv/en/main.home?uuid=2fb209d0-fd34-4e5e-a3d8-a13c241eb61b);
			• NAI_{reg}

Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
		- Coniferous: 19.2 - Broadleaf: 19.0 - Mixed C-B: 19.1	[tonnes$_{DM}$/(ha yr)]: IPCC database (based on global ecological zones); • PE [MWh/ton$_{DM}$]: IPCC database.
Biomass energy from agriculture PE_{AG}	$PE_{AG} = Straw\ Yield \times Technical\ avaib \times Energy\ Content \times Available\ Area$ [MWh/yr] $StrawYield = CropYield \times 0.769 - 0.129 \times arctan[(CropYi - 6.7)/1.5]$ [ton/ha]	• Straw yield [ton/ha]; • Technical availability [-]: assumed 50%; • Energy content [MWh/ton]; • Available area [ha]; • Crop Yield [ton/ha].	• Straw yield [ton/ha]: equation in the BEE Best practices and methods handbook; • Energy content [MWh/ton]: BEE Best practices and methods handbook; • Available area [ha]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018); • Crop Yield [ton/ha]: NUTS Crop production from Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?daset=apro_cpnh1&lang=en); • Annual area with production of specific crops: NUTS database on Crop production from Eurostat (http://appsso.eurostat.ec.europa.eu/nui/show.do?daset=apro cpnh1&lang=en).
Deep geothermal energy $H_{tech,heat,x\ km}$ (150m-7km)	$P_{tech,heat,x\ km} = \frac{T_{x\ km} - T_r}{T_{7km} - T_r} P_{tech,}$ [W] $H_{tech,heat,x\ km} = P_t \times lifetime$ [J]	• $T_{x\ km}$ = Rocks' temperature at a specific depth [°C]; • $T_{7\ km}$ = Rocks' temperature at 7 km of depth [°C]; • T_r = Temperature of reinjected water [°C]; • *Lifetime*: assumed 8760 hours a year;	• Spatial constrains: EES-Natura200 areas (http://ftp.eea.europa.eu/www/natura2000/Natura2000_end2016_Shapefile.zip); • Technical potential deep geothermal energy: database from

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
			https://www.thermogis.nl/en/map-viewer; • https://map.mbfsz.gov.hu/geo_DH/ • $T_{x\,km}$, $T_{7\,km}$ [°C]: database from https://www.thermogis.nl/en/map-viewer.
Shallow geothermal energy E (15m-150m)	$E = \rho \times V \times C \times \Delta T$ [kWh]	• ρ = Density of rocks [kg/m3]: average value equal to 1750kg/m³; • V = Volume of rocks [m3]; • C = Specific heat of rocks [J/(kg)]: average value equal to 1500J/(kg K); • ΔT = Difference between water inlet and outlet [°C].	• ρ [kg/m3] and C [J/(kg K)]: JRC – soil type map (http://esdac.jrc.ec.europa.eu/content/european-soil-database-v2-raster-library-1kmx1km); • Spatial constrains: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Mapping Electrical RES Potential

The electrical RES considered in SO WHAT tool are solar (photovoltaic) and wind: **Errore. L'origine riferimento non è stata trovata.** summarizes the algorithms and the databases used to evaluate the potential for these sources.

Table 7 : Electrical RES Potential – Algorithms and Reference Sources

Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
Photovoltaic energy $E_{pot,ph}$	$E_{pot,ph} = Ir \times Technical\ suitabilit \times Panel\ Efficiency \times Electrical\ Efficien \times Available\ Area$ [kWh/yr]	• Ir =Total solar irradiance under flat plane angle [kWh/m²] • *Technical suitability* [-]: assumed equal to 40% (1);	• Ir [kWh/m²]: PVGIS database (http://re.jrc.ec.europa.eu/PVGIS5-release.html); • *Footprint of buildings* [m²]: cadaster database or OpenStreetMap (http://www.openstreetmap.

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input

		• $Panel\ Efficiency$ [-]: assumed equal to 30% **Invalid source specified.**;
		• $Electrical\ Efficien$ [-]: assumed to be equal to 17%
		• $Available\ area$=
		  ○ Footprint of buildings [m²],
		  ○ Other suitable area [m²].
			org) as an open data alternative;
			• *Other suitable area* [m²]: Corine Land cover (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018).

Wind energy at a specific height h E_h	$E_h = 8760\ \eta_m\ \eta_{el}\ \eta_{aux} \sum_{w=w_{low}}^{w_{high}} P_h(w) f(w$ [kWh/yr] $f(w) = \left(\frac{\beta}{\eta}\right)\left(\frac{w}{\eta}\right)^{\beta-1} e^{-\left(\frac{w}{\eta}\right)^{\beta}}$ [-]	• 8760 yearly operative hours of the aerogenerator [h]; • ρ = air density [kg/m³]; • A = area of the aerogenerator that is orthogonal to wind's direction [m²]; • w = wind speed [m/s]; • C_p = power coefficient [-]; • $f(w)$ = Weibull distribution [-]; • β = shape parameter [-]; • η = scale parameter [-]. • Height at which the wind turbine is placed; • η_m mechanical efficiency of the device [-]; • η_{el} electrical efficiency of the device [-];	• β and η [-]: CENER database (https://globalwindatlas.info/) • Spatial constrains: EES-Natura200 areas (https://www.eea.europa.eu/data-and-maps/data/natura-9/natura-2000-spatial-data/natura-2000-shapefile-1).

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Energy source's type	Algorithms [unit]	Inputs [unit]	External database [unit] to provide default values for algorithms' input
		• η_{aux} auxiliaries' efficiency [-].	

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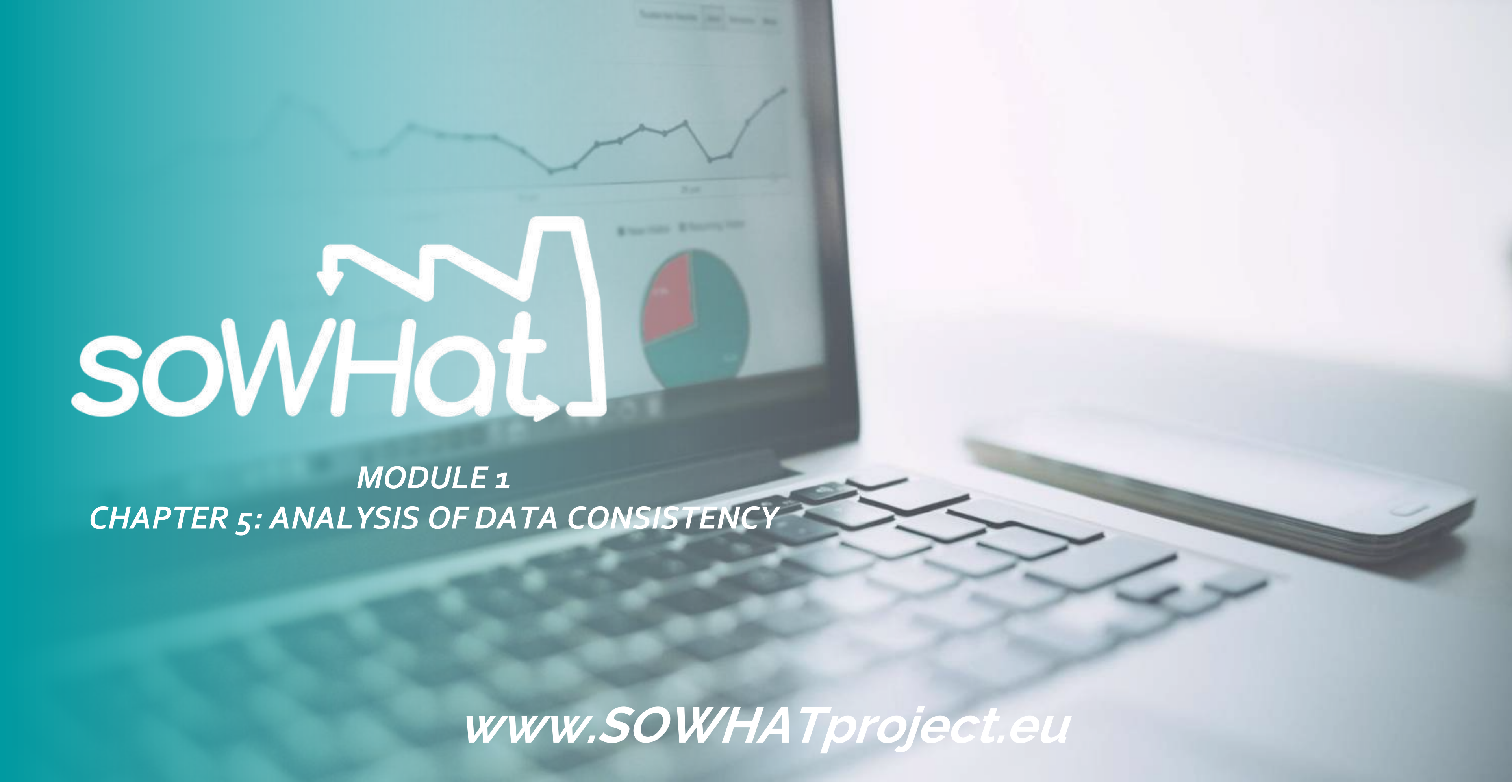

MODULE 1

CHAPTER 5: ANALYSIS OF DATA CONSISTENCY

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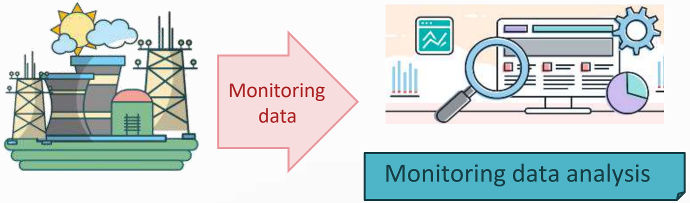
Introduction

- High-level information and details linked to the simulation environment of industrial waste heat and cold recovery
- Possible checks and evaluation of the consistency of data.



study & understanding of the demo

Data analysis and error correction

Adaptation to required formats

- This phase is crucial to obtain high-quality data
- In this module simulation environment, data will be adequate to analyse the heat potential of that particular industry and indeed, to be able to generate a real quality thermal production profile based on that waste heat monitoring data.

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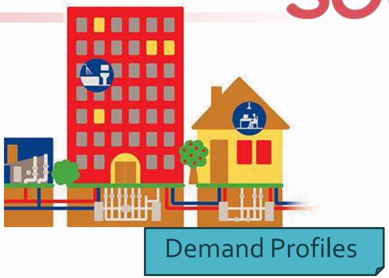
Introduction

soWHat Training

Demand profiles for different type of consumers (residential, services, industrial…) who will benefit from this waste heat can be predicted (in the event that real profile demands were not given).

Analyzed Monitoring data



focuses more on a detailed building model

based on the demand of people behaviour of the household

Demand forecasting tools

City Energy Analyst

LoadProfileGenerator

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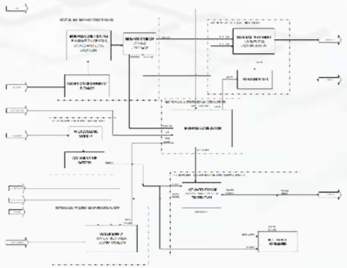
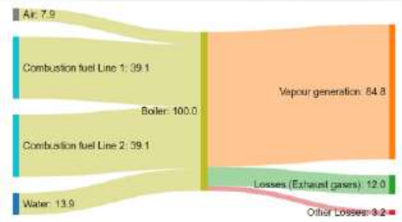
First study of the simulation environment

- Quality and quantity of explanatory documentation provided with monitoring data
- Level of complexity of the industrial settles
- Standardization of the production process of the industry
- Professional background of people in charge of the study

Methods and sources for this first study

- Consultations to **energy audits**
- Organization with **flow diagrams**
- **Sankey diagram** elaboration





I. Bernal and F. Morentín, "'Monitoring Management System', SO WHAT H2020 Project, Deliverable 5.1," 2022. [Online]. Available: www.sowhatproject.eu.

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Data analysis and error correction

Monitoring data analysis

- Definition of the **format** in which data is received
- Establishment of an **operation schedule**
- Adaptation and standardization of the **frequency** of monitoring data
- **Quality preliminary** analysis of the data
- Data **consistency** analysis
- **Error correction**

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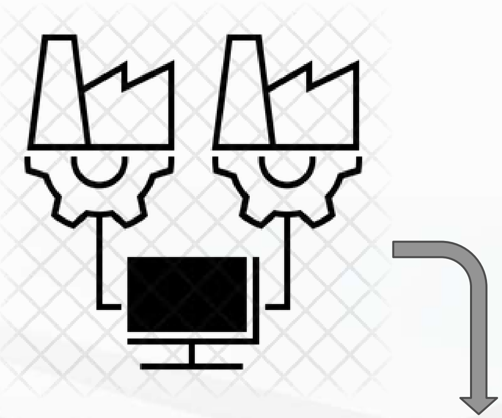
Data analysis and error correction

Definition of the format in which data is received

Data is originally generated in some type of Supervisory Control and Data Acquisition (SCADA) characteristic of each industry or software programs in the same line.

The process usually follows the same steps:

- Data is collected in some Data Base (DB)
- After that, it is exported from there in a manual or automatic way (In some cases the exportation is done directly from this SCADA)



Possible barriers with data directly from SCADA

- Not an ease of understanding the data written
- Number and variables names
- Frequency in which they are recorded

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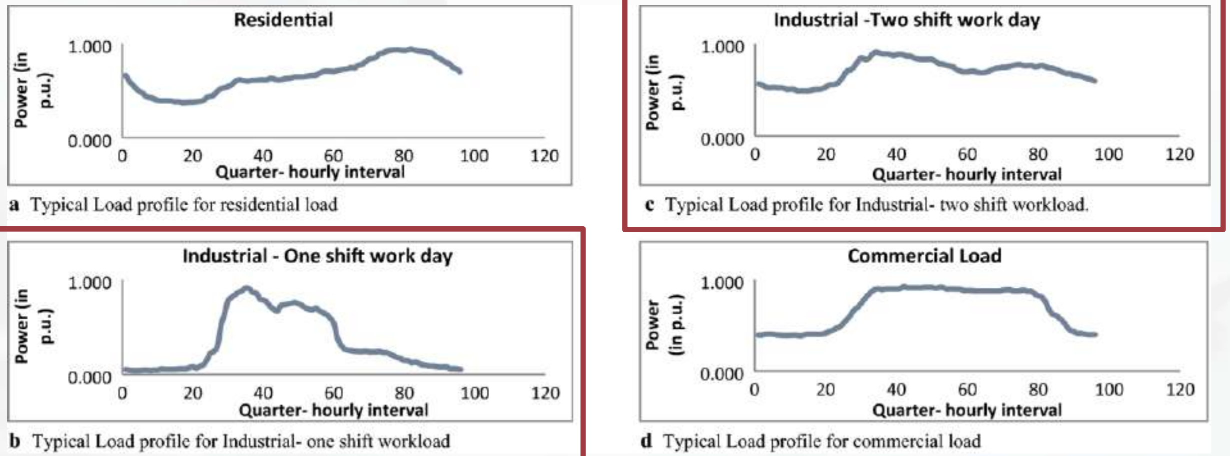
Data analysis and error correction

Establishment of an operation schedule

- Establish the particular industry operating schedule
- Take into account suspensions for maintenance and upkeep stops
- Also work regime (shifts) and holidays or vacations



a Typical Load profile for residential load
c Typical Load profile for Industrial- two shift workload.
b Typical Load profile for Industrial- one shift workload
d Typical Load profile for commercial load

A. Jain, A. Mani, and A. S. Siddiqui, "Network architecture for demand response implementation in smart grid," Int. J. Syst. Assur. Eng. Manag., vol. 10, 2019, [Online]. Available: https://link.springer.com/article/10.1007/s13198-019-00891-w/figures/5.

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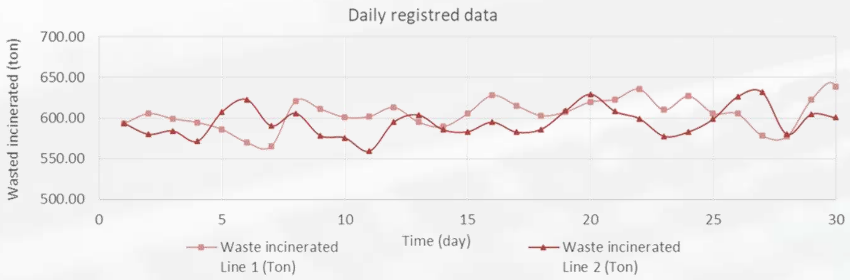
Data analysis and error correction

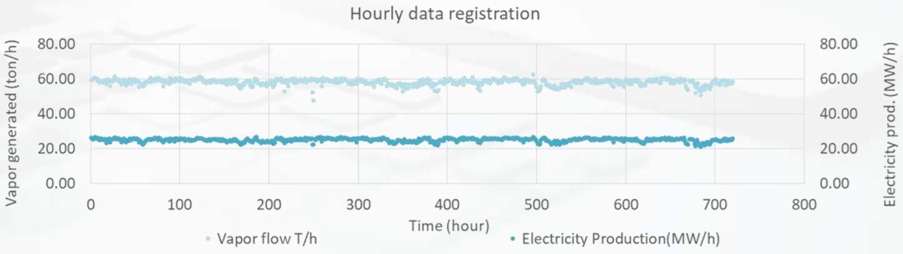
Adaptation and standardization of the frequency of monitoring data

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

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



Variable with low variability (recorded with lower frequency)



Variable with high variability (recorded with higher frequency)

I. Peña and F. Morentín, "'Monitoring Management System', SO WHAT H2020 Project, Deliverable 5.1," 2022. [Online]. Available: www.sowhatproject.eu.

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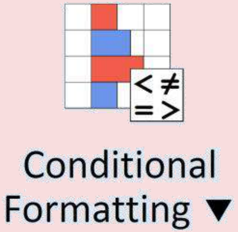
Data analysis and error correction

Quality preliminary analysis of the data

It is important to develop a first variability check of each of the variables to check for significant imbalances

This would show if the data have different orders of magnitude and negative values where it does not make sense.



USEFUL TIP:

Use of color conditional formatting to highlight information in Excel (or other software available) and is very useful for a quickly analyzing of variability of the data, relation between variables, sudden changes in the list, values that are not in appropriate range, etc.

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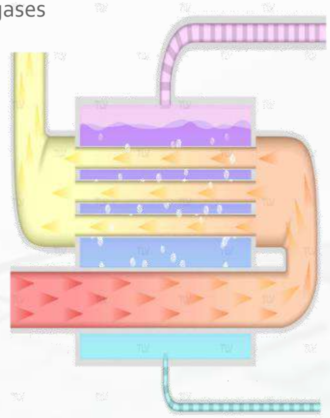
Data analysis and error correction

Data consistency analysis

- Study of the consistency in the data between actions in the process that occur simultaneously or actions that are dependent on others
- Consistency in the inlets and outlets flows;
- Understand and pay attention to the trends of related variables (e.g. energy produced and consumed);
- Special attention to the seasonality (summer vs. winter) this is important to understand if the process and the monitoring data are valid for the aim of the project.



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Data analysis and error correction

Error correction

- For those errors that have been due to the manual process of exporting the database, the first step will be to re-request a dump of that data
- Missing data of a period of time from the complete list
- Estimation of variables with approximated correction.
- Construction of simulated data from other variables to fill in gaps.

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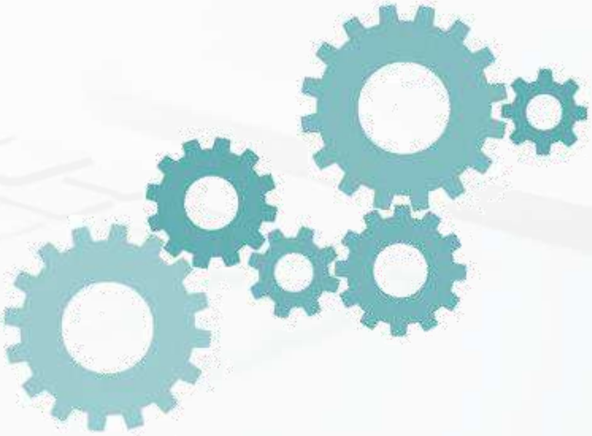
Adaptation to appropriate formats

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



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Estimation of users demand

soWHat Training

Once industry capacity has been analyzed and its heat generation potential, demand forecasting tools are recomended to create users energy profiles, so a comparition between energy production and demanded is establish.

LoadProfileGenerator (LPG) tool

City Energy Analyst (CEA) demand profile generator

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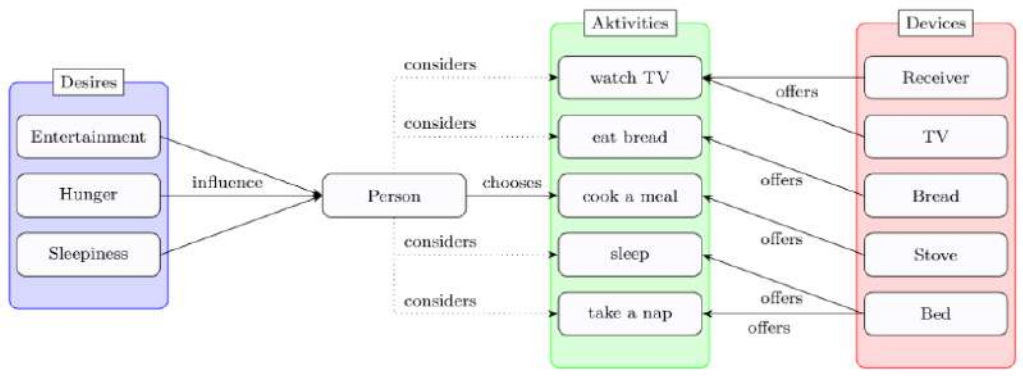
Estimation of users demand

LoadProfileGenerator tool (LPG)

LoadProfileGenerator creates load profiles based on a behaviour simulation of the people in a household. This means that the programme estimates what people are doing at each point in time and based on that, it calculates device usage and the resulting energy usage.

- More than 100 devices pre-configured based on market research
- The profiles are generated for hot water, cold water, electricity and gas
- For heating and cooling demand there is a simple degree day model



"LoadProfileGenerator official page," 2020. https://www.loadprofilegenerator.de/ (accessed Jul. 02, 2022).

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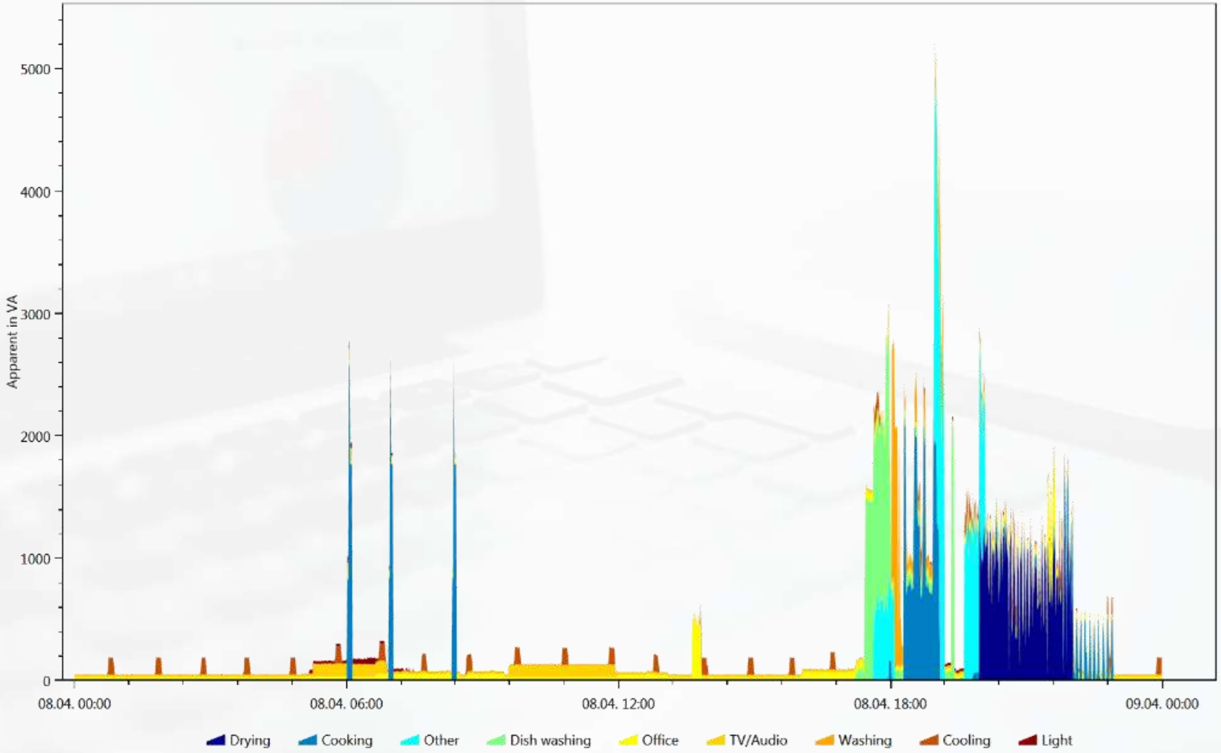
Estimation of users demand

LoadProfileGenerator tool (LPG)



LoadProfileGenerator
example of demand profile

"LoadProfileGenerator official page," 2020. https://www.loadprofilegenerator.de/ (accessed Jul. 02, 2022).

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Estimation of users demand

City Energy Analyst (CEA) demand profile generator

City Energy Analyst is an urban building simulation platform that combines knowledge of urban planning and energy systems engineering in an integrated simulation platform.

Collection of tools for the analysis of urban energy systems, one of the tools useful for this training module es the **dynamic demand forecasts**.

Inputs for data management: archetypes, weather, surroundings, terrain and street helper

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Estimation of users demand

City Energy Analyst (CEA) demand profile generator

Inputs for demand forecasting: building solar radiation, building schedules

Types of uses profiles such as: **coolroom, residential, foodstore, gym, hospital, hotel, industrial, laboratory, library, museum, office, parking, restaurant, school, swimming and university.**

Default monthly/ yearly multiplier schedule (Hospital use-type)

HOSPITAL	1	2	3	4	5	6	7	8	9	10	11	12
Monthly multiplier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Default day/ hourly occupancy schedule (Hospital use-type)

HOSPITAL OCCUPANCY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Weekday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Saturday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Sunday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4

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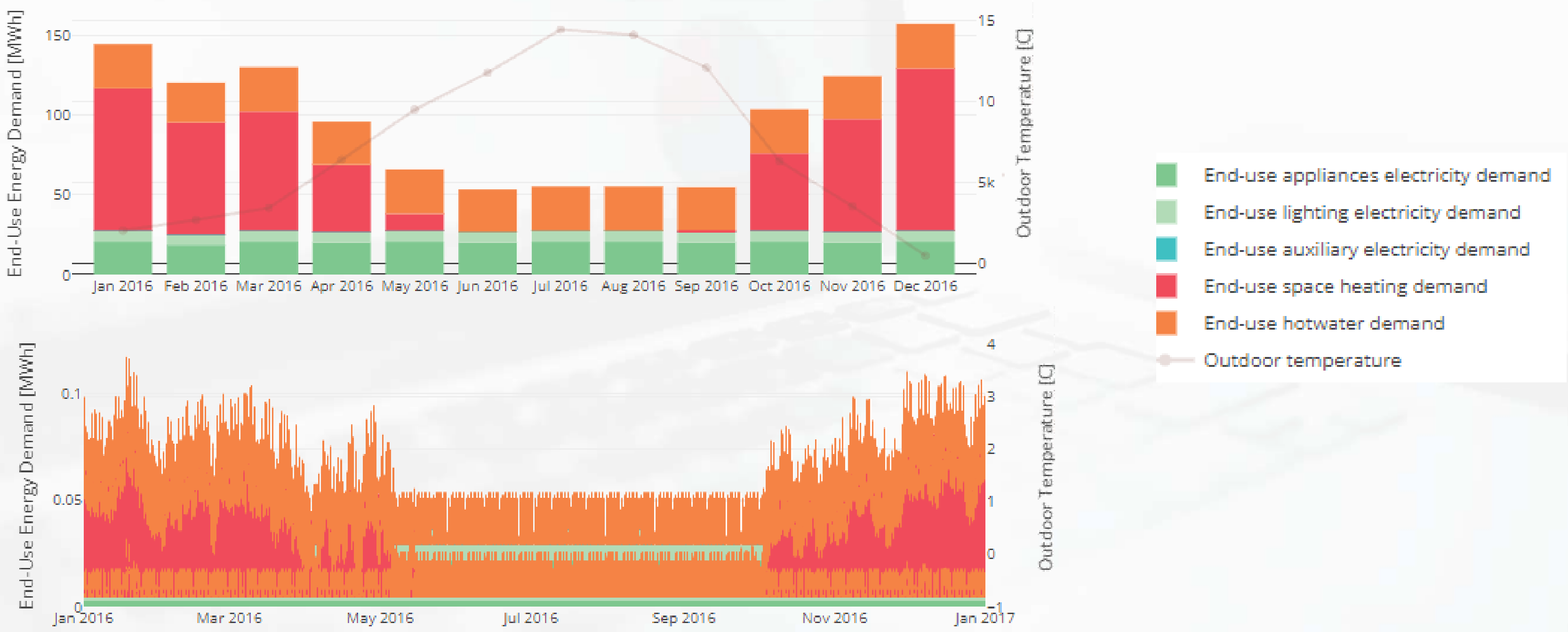
Estimation of users demand

City Energy Analyst (CEA) demand profile generator



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MODULE 1

CHAPTER 5. ANALYSIS OF DATA CONSISTENCY

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Abbreviations

CEA: City Energy Analyst

DH&CN: District Heating & Cooling Network

LPG: Load Profile Generator

RES: Renewable Energy Sources

SCADA: Supervisory Control and Data Acquisition

WH/C: Waste Heat/Cold

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Short summary

In this module, it will be given a detail explanation of the methodology followed to analyse the consistency and availability of monitoring data in order to simulate possible waste heat recovery scenarios. The main objective of this module as part of SOWHAT project is the identification of strategies and procedures to collect data for mapping and quantifying the potential for waste heat and cold recovery and valorisation and for integration of renewables in industrial contexts.

The main inputs at this document come from the study conducted within SOWHAT project in WP1, WP2 and WP5 and have a relationship with the next activities in the project:

- **Task 1.1/ D.1.1** Report on Industrial Site Demo Assessment. This deliverable is associated to the assessment on waste heat potential and evaluate which are the main algorithms to model industrial energy processes and those ones related to the evaluation of potential local waste heat and cold. This quantification of the WH/C streams at the industrial demo sites are very useful for the demo sites interpretation and to evaluate the data received from the 3 industries.
- **Task 1.2.** Overcoming barriers in data collection and data format required, whose aim is to identify strategies and procedures to overcome barriers and criticalities in the collection of relevant data for mapping and qualifying the potential for WH/C recovery and RES integration.
- **Relation with the D1.4 and D1.5,** where importance of Energy Audit is explained. The deliverable **D1.4** focuses on requirements for data for SO WHAT tool, which globally coincide with data that are required for an energy audit of an industrial plant. It is therefore useful to provide an overview, in this chapter of the energy audit process and of the required input data and **D1.5** introduce this kind of document as a main in the information of every Industrial site.
- **Task 5.1/D5.2** Report on the instrumentation installation and commissioning. It is the deliverable that present the accuracy of the tool and its impact on the demo sites. Deliverable of report format and confidential only for members of the consortium.
- This document is related as well to the **work package 2** (Specification of the tool and common IT framework), where a definition of technical requirements for the SO WHAT Tool is studied.

This module will address the topics related to general aspects of the above-mentioned pillars and it will provide technical inputs to the trainee and a solid basis for the prosecution of the training activities. The handbook structure is here reported:

1) Chapter 1: Description of the waste H/C: how it is generated and where it can be seen most in the industrial plants.
2) Chapter 2: Analysis of WH/C technologies.
3) Chapter 3: Insights into the data needed to be collected to run the simulations and the related formats.
4) Chapter 4: Inputs related to the mapping, the tool's needs to map local RES and municipality or an industrial plant feature.
5) **Chapter 5: High-level information and details linked to the simulation environment, including possible checks and evaluation of the consistency of data.**
6) Chapter 6: The cause-effect relation between input data and outputs will be introduced in terms of qualitative and quantitative information.

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1 Introduction

The following training module presents high-level information and details linked to the simulation environment of industrial waste heat and cold recovery, including possible checks and evaluation of the consistency of data. In this module the first half of the document will be structured in three sections (Figure 1). After that, a guide based on modelling different demand profiles will be presented.

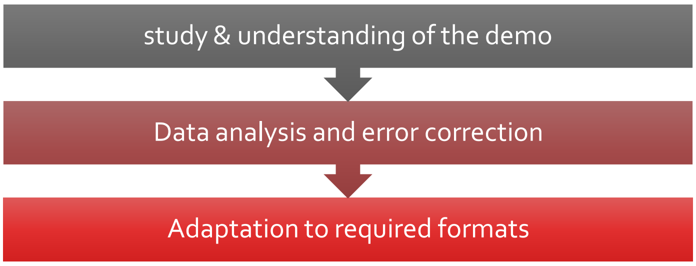

Figure 1: SO WHAT data monitoring methodology main steps

The *first step: study and understanding of the industry* is the industry study (from whom the monitoring data has been obtained) and understanding exercise is going to be required. For this training, this section will stay in the background, giving more importance to the second step.

The *next step: data analysis and error correction* the main part of all the chapter andi t can be divided into more phases.

A data analyst's job is to understand the objective and its goals in enough depth that they can frame the problem the right way. After defining the aim of what it want to be solved with that data, it will be continued with the different steps of adaptation of the monitoring data and study of its consistency.

Figure 2: phases for general data analysis and error correction process [1]

This second phase (see Figure 1) is crucial for making sure that the data used is high-quality for its application. Finally, a correct representation of the data can show a global view to end the analysis process. Fixing a strategy for the complete process can help in order to replicate the procedure followed for different types of data. Extrapolating this generic method to this module simulation environment, data will be the adecuate to analyse heat potential sources in a particular industry and indeed, to be able to generate a real quality thermal production profile based on that waste heat monitoring data.

And the *last step: adaptation to required formats* depending on the objective behind the monitoring data use or where that dataset is going (SCADA systems, data analysis and visualization tools…), adaptation of the format takes place, in order to facilitate its application.

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In this part of the process, type of consumers (residential, services, industrial…) who will benefit from this waste heat should be known so their temporal demand profiles (hourly, daily…) can be predicted, in the event that real profile demands were not given. To complete this guide for future applications in the same environment, examples of *demand forecasting tools* are recommended in this chapter.

Among current demand forecasting tools, these

Figure 3: demand forecasting tools

These two tools have been selected because they encompass ways of defining demand from two perspectives: *LoadProfileGenerator (LPG)* is based on the demand of people behaviour of the household and *CityEnergyAnalyst (CEA)* focuses more on a detailed building model.

2 First study of the simulation environment

In the field of industry, any type of process with heat excess can be a potential source of heat recovery. Although it may seems obvious, it is wise to note that before proceeding to analyze the data and correct errors, a demo study and understanding exercise is going to be required. It will be difficult to perform a good fault detection on the received monitoring data if the physical system associated with the received monitoring data is not fully understood.

This actions are developed in complex industrial plants with much distinction between its applications. Therefore, there is no easy replicability in the location of possible heat/ cold recovery points within the process. As with the whole process in general, this study and understanding process must be customized for each specific case depending on multiple factors such as:

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

For this reason, a few methods and sources of information are proposed for this study that will help tu understand the process and to proceed with the data analysis such as: *energy audits* where its energy situation is directly connected to the identification of potential heat/cold recovery sources, *flow diagrams* which is an effective procedure that can be helful to understand an industrial process with its visual representation and *Sankey diagram elaboration* for representing an entire input and output energy flow that allows the location of potential sources of residual heat precisely and easily.

3 Data analysis and error correction

A Data Analyst collects, treats and analyzes large data sets. Their role is to discover how data can be used to answer questions and solve problems. They are expected to collect and assemble data and process it to discover trends and insights useful to the business.

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

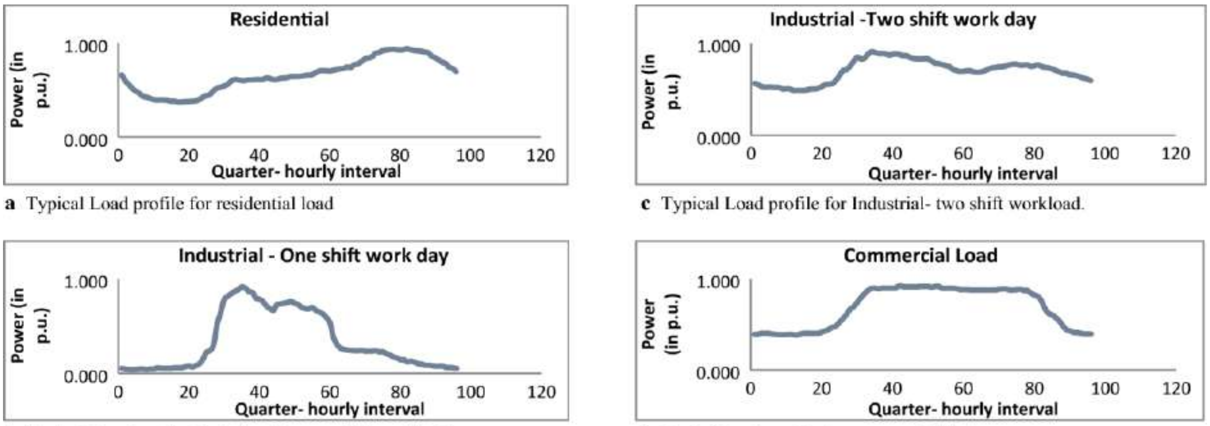
3.1. Definition of the format in which data is received

Data is originally generated in some type of Supervisory Control and Data Acquisition (SCADA) characteristic of each industry or software programs in the same line. The process usually follows the same steps: data is collected in some Data Base (DB) and then it is exported from there in a manual or automatic way. In some cases the exportation is done directly from this SCADA and this can cause problems such as: the ease of understanding the data written, the name and number of variables and the frequency in which they are recorded, this can lead to a very large file size for some software (special attention to the selection of the program used for the analysis), computer file format (potential data in DB format).

3.2. Establishment of an operation schedule

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

It is also crucial to establish the type of industry, from where data is monitorized, to analyse the data received. For example, it is not the same an industry with two shift work days, than one with one shift work or the ones with 24/7 schedule. It will be easier to interpret the changes in the load with this previous information.



a Typical Load profile for residential load
c Typical Load profile for Industrial- two shift workload.
b Typical Load profile for Industrial- one shift workload
d Typical Load profile for commercial load

Figure 4: a) Typical load profile for residential load. b) Typical load profile for Industrial-one shift workload. c) Typical load profile for Industrial—two shift workload. d) Typical load profile for commercial load [2]

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

This gives weight to the previous documentation section (preliminary knowledge of the operation calendar) where useful information should be gather before. However, if this information is not available, monitoring data will have to be interpreted because they will reflect these operation schedules. In other words, the study of the monitoring data will allow stablishing the operation

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calendar, but in some cases it will be difficult to distinguish between unexpected stop situations and lack of data situations.

3.3. Adaptation and standardization of the frequency of monitoring data

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

Figure 5: variable with low variability (recorded with lower frequency)

Figure 6: variable with high variability (recorded with higher frequency)

For example, the input of fuel (into the boilers for steam production), such as municipal waste, are very large loads that do not require very high data collection frequencies (Figure 5), that is why the data has a total daily record, while the value of steam that is introduced into a turbine to produce electricity in a power generation plant will require a higher registration (Figure 6).

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

3.4. Quality preliminary analysis of the data

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

It is important to develop a first variability check of each of the variables, recording the maximums and minimums to check for significant imbalances. This would show if the data have different orders

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of magnitude (that do not coincide with the expected response, taking into account the seasonal time and operational schedule) and negative values where it does not make sense.

Talking about an analysis of numerical values, another tool that is very useful for a quickly analysing of variability of the data (apart from maximums and minimums) is the application of color scales to long list of different variables values. Color conditional formatting allows to highlight relation between variables, sudden changes in the list, values that are not in appropriate range, etc.

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

Figure 7: use of color conditional formatting to highlight information [3]

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

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

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

3.5. Data consistency analysis

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

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

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

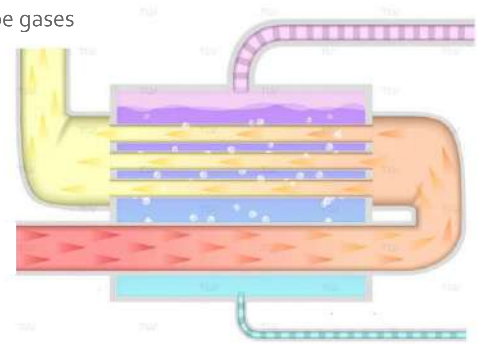

Figure 8: example of heat exchanger with waste heat for steam formation [4]

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

3.6. Error correction

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

- For those errors that have been due to the manual process of exporting the database, the first step will be to re-request a dump of that data, because it could be an error when taking or writing that data in the sent file. Another option would be to ask for another period of time if it is available. In the end, the objective is usually to work with a year of monitoring data and it is not necessary for it to be from January to December of that same year. The important key is to have all the data for every month or the frequency required;
- In the hypothetical situation of missing data of a period of time, the approximated correction could be solved filling in empty data with data that is available. For example, if a week is missing (for whatever reason) it can be copied the data from another week (as close as possible) to occupy that blank space;
- When two variables are related, one with correct data and the other with erroneous data during a section, the missing information can be obtained with the equation of relation between both variables. The trend of the correct data of one variable against another (not

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including those that are not correct) will be obtained and an equation will be obtained that can be used in the section for which adequate information is not available;

- **Construction of simulated data from other variables** to fill in gaps. Sometimes, as mentioned before, there are not enough sensors to calculate all the variables in order to calculate the potential sources of heat recovery, but there will be other variables that, by means of mathematical methods, consistent assumptions or thermodynamic and physical equations, will be able to find these lost variables.

For example, the heat generated is not available, but the electrical energy produced or the amount of fuel (municipal waste, biomass, gas) consumed is available. Another example could be that the number of pieces produced in that industry is available and the average energy cost per piece can be extracted (from other periods) in order to do an estimation of the consumption from the production data.

4 Adaptation to appropriate formats

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

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

5 Estimation of end users demand

Though waste heat/ cold has its origin in different industrial environment with a wide variety of generation profiles, consumers could be any user connected to the district heating. Flows from the DH&CN will follow demand curves depending on the use of the building, so that's why tools that can create flexible profiles are required. The ones selected to help with this module are *LoadProfileGenerator (LPG)* and *City Energy Analyst (CEA).* Both works in a different way depending on the approach the user wants to give to the demand model, LPG is based on people behaviour of the household and CEA focuses more in a detailed building model.

4.1. LoadProfileGenerator Tool (LPG)

LoadProfileGenerator [5] creates load profiles based on a behaviour simulation of the people in a household. This means that the progamme estimates what people are doing at each point in time, based on that it calculates device usage and t he resulting energy usage. Is a tool for MS Windows to generate load profiles for households for electricity, gas, hot water and cold water.

In the LPG there are more than 100 devices pre-configured based on market research. These devices are arranged together with load curves into actions. From this energy load curves are calculated by adding up the energy use of each device at each point in time. The profiles are generated for hot

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water, cold water, electricity and gas. For heating and cooling demand there is a simple degree day model to help generate a rough estimate of the consumption.

This is not a building simulator though, and if you need a detailed building model, other software might be the better choice. The focus of the LPG is the human behavior.

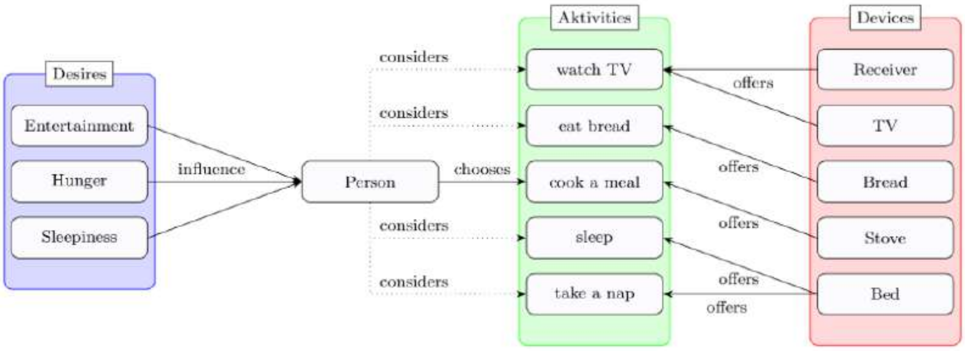

Figure 9: example of human behaviour simulator that can be modelled by LPG [6]

The limitation of this tool is that it can only generate residential profiles, nonetheless it offers a detail level that are not possible in other tools. An example of demand profile is presented in the next figure.

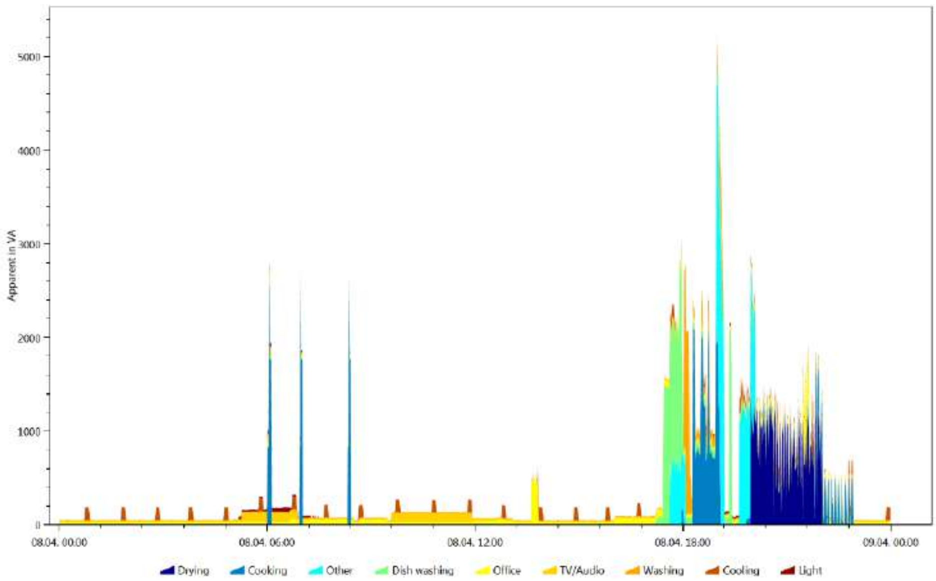

Figure 10: load profile generated in LPG [6]

4.2. City Energy Analyst demand profile generator

City Energy Analyst is an urban building simulation platform started in 2013 that combines knowledge of urban planning and energy systems engineering in an integrated simulation platform. This allows to study of the effects, trade-offs and synergies of urban design options and energy infrastructure plans. CEA consists in a collection of tools for the analysis of urban energy systems, one of the tools useful for this training module es the **dynamic demand forecasts**. This can be obtain following steps of the building specification that will be explained below.

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4.2.1. Inputs

During the definition of the buildings selected a **set of inputs** are needed to be obtain before being able to run the demand. In every step of the modelling there is an option to add more advanced parameters, depending on the level of detail desired from the simulation.

DATA MANAGEMENT

Archetypes Mapper: level of detail of the assign building properties and systems types from the archetypes database

Zone weather: sets the weather file to use for simulation for a scenario, the user can insert a weather file or use name of the wather files contained within the CEA database

Surrondings helper: query geometry of surrounding buildings from Open Street Maps. Users can define the perimeter buffer length to the surrounding area, the average height of buildings withing the surrondings and average number of floors above ground of all buildings within the surrondings. The default data comes from Open Street Maps.

Terrain helper: query topography with a fixed elevation

Steets helper: query streets geometry from Open Street Maps

Figure 11: buildings studied (left), surroundings (middle) and streets (right). Example in CEA Dashboardn

DEMAND FORECASTING

Building Solar Radiation: CEA uses DaySim to calculate solar radiation for a scenario. Daysim is a validated daylighting analysis software that calculates the annual daylight availability in arbitrary buildings based on the radiance backward raytracer, it uses the lightswitch occupant behaviour model to mimic occupant use of personal controls and to predict energy savings from automated lighting controls. User can modify the simulation parameters.

Building schedules: use CEA models and input schedules to estimate the occupancy profile of buildings. The next example represents a typical Hospital schedule, in CEA there are different types of uses profiles such as: *coolroom, residential*, *foodstore*, *gym*, *hospital*, *hotel*, *industrial*, *laboratory*, *library*, *museum*, *office*, *parking*, *restaurant*, *school*, *swimming* and *university*. In addition, new use-types can be created if it is needed. An example of the schedule for the hospital use type is presented in Table 1 and Table 2.

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Table 1: default monthly/ yearly multiplier schedule (Hospital use-type)

HOSPITAL	1	2	3	4	5	6	7	8	9	10	11	12
Monthly multiplier	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Table 2: default day/ hourly occupancy schedule (Hospital use-type)

HOSPITAL OCCUPANCY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Weekday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Saturday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4
Sunday	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.6	0.8	1	1	0.9	0.7	0.8	1	0.9	0.8	0.6	0.4	0.4	0.4	0.4	0.4	0.4

Not only occupancy is scheduled for the 3 types os profile (weekday, saturday and sunday), but also the following thermal and electrical loads are replied: *appliances*, *lighting*, *water*, *heating*, *cooling*, *processes*, *servers* and *electromobility*. Furthermore, it includes the necessary parameters to take into account the indoor comfort and the internal loads depending on the use profile. After following all the steps mentiones and linking every building with its corresponding schedule according to its particular use, the simulation is ready to calculate the demand. First the specifications for the processing, the different variables and finally the time step resolution output are selected. Figure 12 and Figure 13 show two examples of plots generated in CEA, however, there are many representation possibilities.

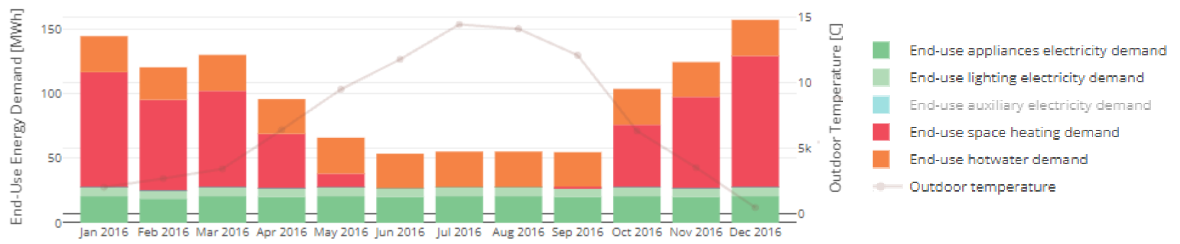

Figure 12: load curve for district (monthly) generated in CEA

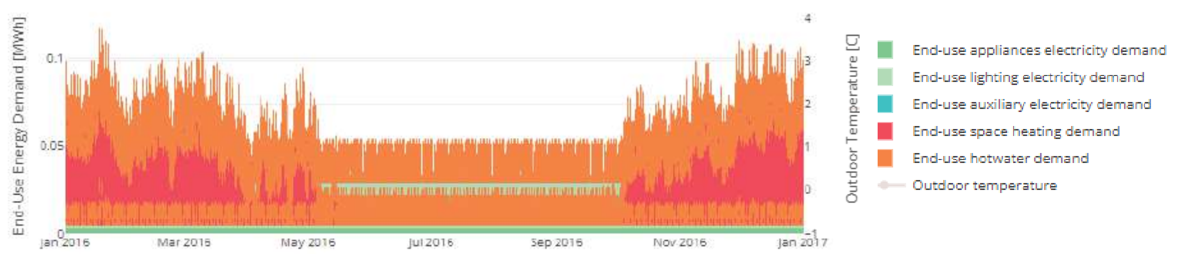

Figure 13: load curve for one of the buildings (Hourly) generated in CEA

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6 References

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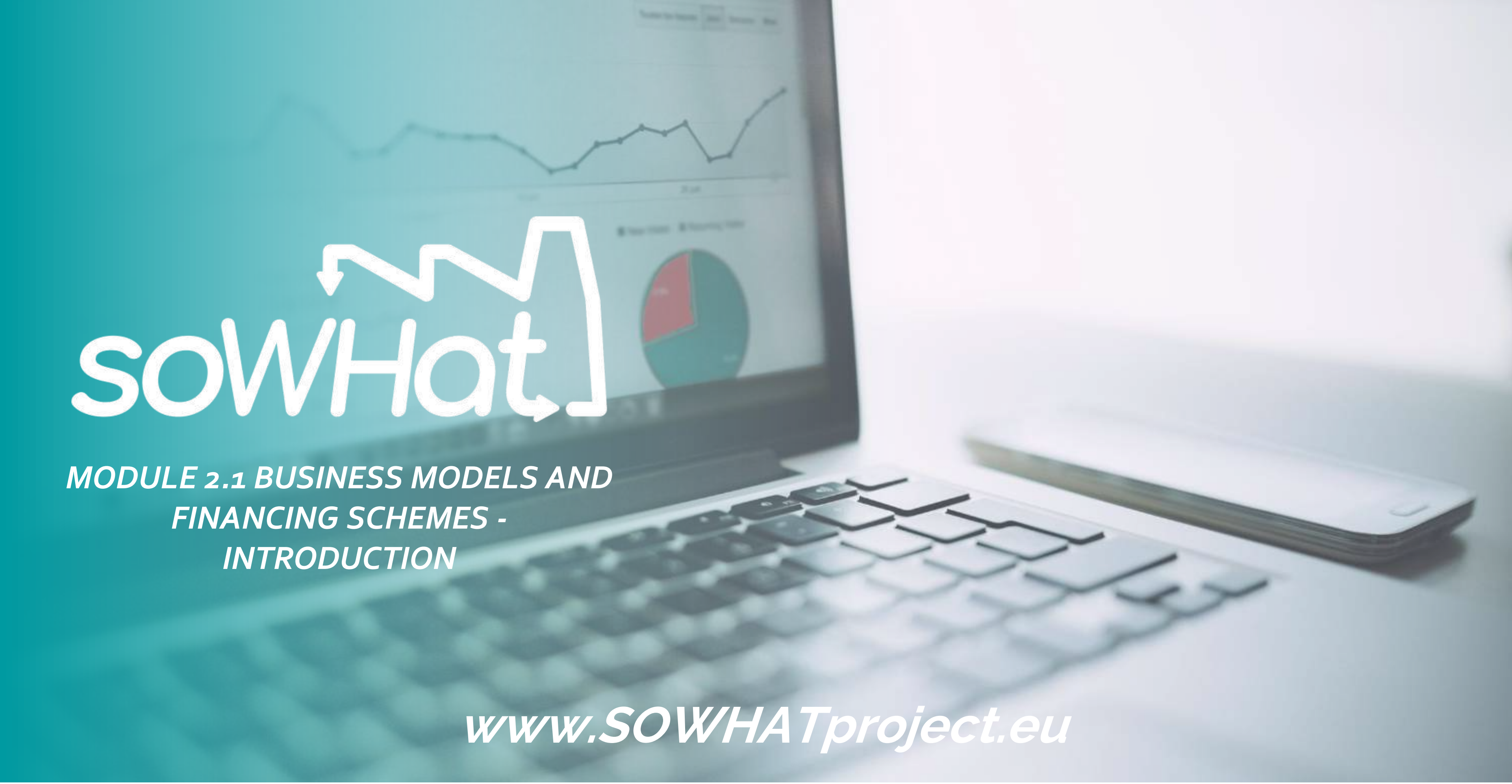

soWHat

MODULE 2.1 BUSINESS MODELS AND FINANCING SCHEMES - INTRODUCTION

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Recap from Module 1

In the previous module, Module 1, you could learn about:

- How to audit the energy consumption at an industrial site
- Potential ways to exploit waste heat and cold
- Waste heat and cold recovery technologies

In Module 2, we will add an economic perspective on industrial waste heat and cold recovery.

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Attain a viable business case

Business models and financing schemes are important for attracting financing and to attain a viable business case.

To choose the most suitable business setup for a waste heat and cold project, several aspects needs to be considered: business risks and possible contractual arrangements to overcome these, the costs and benefits of the investments as well as ways to finance the investment.

In this module the different aspects related to this are presented. The module consists of two parts presented on the following slides.

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Module 2.2

soWHat Training

Drivers and barriers

- Efficient resource use, reduced cost and emissions – win-win
- High initial cost, difficulty to agree on pricing, ownership and responsibilities

Business risks

- Dependence on external partners
- Lack of know-how and legal framework in some countries

Contractual arrangements

- Ownership and responsibilities
- Time of commitment
- Exit paragraph

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Module 2.3

soWHat Training

Levelized Cost of Excess Heat (LCoEH)	• Economic assessments of excess heat • Facilitates the pricing of excess heat and the economic comparision of different heating alternatives
Cost-Benefit Analysis (CBA)	• Socio-economic assesments of the costs and benefits from investments in excess heat and cold recovery technologies • Useful for making decisions on large public sector investments and to attract financial support
Financing schemes	• Different types of financing schemes, with special focus on ESCO models • Facilitates the viability of an investment

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WELCOME TO EXPLORE MODULE 2!

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MODULE 2

CHAPTER 1 CURRENT BARRIERS TO INDUSTRIAL WH/C RECOVERY AND EXPLOITATION

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ABBREVIATIONS

BF-BOF: Blast Furnace and Basic Oxygen Furnace

EAF: Electric Arc Furnace

ESCO: Energy Service Company

EU: European Union

LNG: Liquefied Natural Gas

ORC: Organic Rankine Cycle

RES: Renewable Energy Sources

WH/C, WH/WC: Waste Heat/Cold

WHR: Waste Heat Recovery

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SHORT SUMMARY

This report is an extract of the public deliverable D3.1. Barriers to industrial waste heat and cold (WH/C) recovery and exploitation based on the experiences of the SO WHAT demo sites are presented.

Previous studies show that barriers could be of different character depending on the location and specific prerequisites of the industrial sites. Sometimes the prerequisites deteriorate the business case, but even when a good business case is present there can be barriers of non-economical character.

Interviews were conducted in the framework of the task to collect relevant information, both within the Swedish lighthouse cluster and the other national clusters involved in the SO WHAT-project.

Major barriers that deteriorate the business case are low costs of alternative heating, particularly natural gas, and the high initial investment cost for piping and other technology. It is important to focus on finding a win-win collaboration opportunity considering both costs and benefits of the potential partners. Since cooling currently is performed by electric chillers in most cases and the electricity price is much higher than the gas price across central and southern Europe, it appears efficient to examine the opportunity to use excess heat for cooling, e.g. through absorption chillers.

Other major barriers, apart from the economic ones are the lack of understanding of the involved parties (e.g. heat provider and energy company) systems and lack of trust between the partners.

In the countries where district heating is not an established technology, the lack of technical know-how and lack of regulatory procedures are significant barriers.

Taking the identified barriers into account it is shown that the SO WHAT is important to expand waste heat recovery in Europe. It can be used to identify and mitigate barriers by identifying profitable business cases. Mutual gain among the possible partners involved in the collaboration is key for success focus on the gain can be achieved by expanded system boundaries in the SO WHAT tool. By considering the total region and system at once, instead of one subsystem (the industry, the district heating system etc), gains that are otherwise not identified can be indicated.

The SO WHAT tool can also be used to increase understanding of the different stakeholders' systems.

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1 Introduction

In this report, barriers to industrial waste heat and cold (WH/C) recovery and exploitation based also on the experiences of the SO WHAT demo sites are presented.

Experiences from the Swedish lighthouse cluster have been collected from Varberg Energi and Göteborg Energi and served as the departure point for the analysis. Information is also collected from the REUSEHEAT project (coordinated by IVL) on urban waste heat recovery (waste heat of lower temperatures) and literature within the field.

2 Methodology

The work has been performed stepwise. An overview of the methodology of the study is presented in Figure 1.

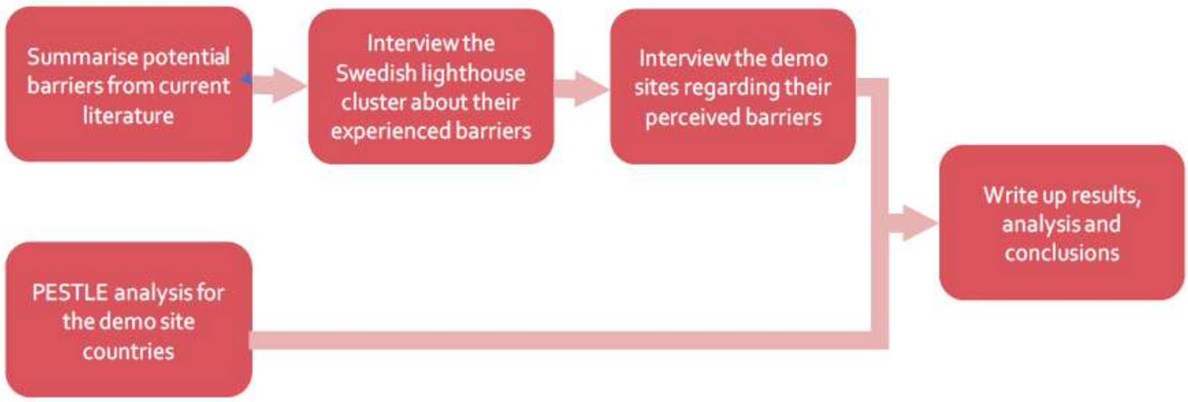

Figure 1 Overview of the methodology of the study

Firstly, a literature review was made on barriers to industrial excess heat collaborations. The potential barriers were listed and categorised. In parallel, a macro-market analysis was performed to understand the potential market update for the technologies in SO WHAT. It entails an analysis of political, economic, social, technological, and environment aspects (PESTLE) and provides valuable insights on the barriers for waste heat recovery investments.

To collect data interviews were conducted with the Swedish lighthouse cluster and the SO WHAT demo sites. The interviews were semi-structured following a questionnaire (enclosed as Appendix A). The questionnaire was sent to the respondents before the interviews. The Swedish lighthouse cluster (Göteborg Energi and Varberg Energi) was interviewed jointly at the IVL offices in Göteborg in December 2019. Information from the other demo sites were collected through web-based interviews with the demo site responsible partner in each demo site country in January and February 2020. The demo site responsible partners gathered input from the relevant demo sites before the interview occasion. The data collected from the interviews was written down in conjunction to the performance of the interviews.

Finally, the results were described in this report and an analysis was performed. Conclusions were drawn in order to provide input to the SO WHAT tool.

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3 Nature of barriers

The current knowledge concerning barriers to industrial excess heat recovery in district heating systems has been summarised in scientific articles and reports - e.g. Lygnerud and Werner (1), who focus on risks with industrial excess heat recovery in district heating systems in Sweden, Päivärinne et al (2), who identifies both success factors and barriers to WH collaboration in Sweden and Oldershaw et al (3) who describe factors that act as barriers or enablers to heat collaboration in the UK. The barriers from literature have served as a basis when gathering information from the demo sites.

In general, the barriers identified in the scientific literatuer can be divided into two main categories:

1. Barriers which deteriorate the business case
2. Non-economic barriers

The first category includes factors such as lack of existing infrastructure (e.g. no district heating network to recover the heat in), low prices for the competing energy sources and that current policy incentives promotes other forms of heat supply (1). Additional technical obstacles that could deteriorate the business case are long distance between supply and demand, supply and demand not matching (in volumes and/or time), not sufficiently high-grade heat, and varying seasonal demand (the demand for heat is usually low in summer) (2). The risk that the excess heat provider will terminate its industrial activities is often found to be a barrier to collaboration (1). This risk is often mentioned as a main barrier to waste heat recovery investments. In (1) a first assessment of the risk is made based on operational data in Swedish waste heat recovery investments during 1974-2014. In the study, it was shown that the risk of termination of the waste heat recovery is linked to the size of the heat recovery and to the inclusion of heat pumps. Small heat recovery investments appear to be more risky than large ones and the added dependency on electricity when including heat pumps leads to greater risk exposure. Lygnerud and Werner highlights a common barrier that the provider and the district heating company hold different views of the quality of the excess heat (1). A finding in the REUSEHEAT-project is that the different stakeholders have different views of the value of the heat (4). Due to seasonal variation in heat demand, the heat is regarded to have a lower value in the summer by the end user, but the excess heat deliverer might still need to cool off as much heat independent on season. This kind of disagreement of the price of the waste heat is a known deal breaker.

The second category includes barriers which in neoclassical economic theory are called "market failures". In neoclassic economic theory, it is assumed that the actors are perfectly economic rational and are fully informed. As expressed by E.Roy Weintraub, the neoclassic economics rests on three assumption (5):

1. People have rational preferences between outcomes that can be identified and associated with values.
2. Individuals maximise utility and firms maximise profits.
3. People act independently on the basis of full and relevant information.

Hence a profitable collaboration should always be carried out, otherwise a market failure must be there to hinder. Market failure is the failure of the free market to allocate resources efficiently.

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According to political economy, these barriers should be removed with the help of policy instruments as far as possible. However, barriers which are not "true" market failures, should not be tackled by public authorities since that would risk causing market imbalance.

In terms of barriers to waste heat recovery Oldershaw et al describe that the availability of capital expenditure (CAPEX) funds could be a barrier to industrial waste heat exploitation, particularly for smaller companies (3). Lack of financial funding is mentioned by Päivärinne et al as well (2). When profitable investments are not made due to funding shortage it is a sign of an imperfect financial market.

The neoclassic economists assume that man always acts in an economically rational way. However, behavioural economists nuance the assumption of the perfectly economic rational actor. Richard Thaler founded this new economic discipline, inspired by the work of Kahneman and Tversky (6; 7). The latter had researched the idea of human limits to rationality and had shown that decisions were not always optimal. For example, our willingness to take risks is influenced by the way in which choices are framed. In addition, it is common that organisational barriers affect the investment decisions.

Companies prioritise core-business investments even though excess heat collaboration has a good business case which could be categorised as an organisational barrier. This barrier is described in different ways by several authors and is regarded as a main barrier. For example, Oldershaw et al describes: "The extent to which energy is a corporate priority and the resources companies commit to monitoring energy consumption influence the willingness and ability of companies to make progress at each stage of the heat recovery journey" (3). Lygnerud and Werner describes that competition with alternative use for investment capital is a main barrier to waste heat collaboration (1).

In addition, the interorganisational relations are essential for exploitation of industrial excess heat. Lack of trust and communication difficulties are examples of barriers related to this (2). Lygnerud and Werner highlights a common barrier that the provider and the district heating company hold different views of the quality of the excess heat (1). As mentioned before, a finding in the REUSEHEAT-project is that the different stakeholders have different views of the value of the heat (4).

There are also examples from literature of barriers caused by imperfectly informed actors. Päivärinne et al highlights lack of knowledge about heating issues, lack of knowledge about the amount of excess heat and lack of knowledge about business agreements as common barriers to waste heat collaboration (2).

Even for the heat recovery investments that have positive net present value, the payback periods are long due to the high initial costs in excess heat recovery. Therefore, requirement for a short payback period for investments is an organisational barrier. Particularly private enterprises tend to have a requirement for shorter payback periods than public entities. In the REUSEHEAT-project it was found that the payback periods for urban waste heat recovery installations were 15 years or longer (4).

To summarise, the barriers found in earlier studies are:

1. Barriers which deteriorate the business case

- Lack of existing infrastructure
- Low prices for the competing energy sources
- Current policy incentives promote other forms of heat supply

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- Long distance between supply and demand
- Supply and demand not matching, not sufficiently high-grade heat, and varying seasonal demand
- Risk that the excess heat provider will terminate its industrial activities

2. Non-economic barriers

- Lack of financial funding
- Low priority to non-core business
- Lack of trust between the stakeholders
- Different views of the value of the heat
- Lack of knowledge about heating issues
- Lack of knowledge about the amount of excess heat
- Lack of knowledge about business arrangements
- Requirement for a short payback period

4 PESTLE analysis

In this chapter a summary of the macro economic analysis performed for considering market uptake of new products performed. It was done using the logic of PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis for each of the countries engaged in the SO WHAT-project. The full text PESTLE analysis is attached in Appendix B PESTLE analysis. The presented PESTLE includes aspects that may create opportunities and barriers for waste heat and cold recovery from industries, as well as the waste heat and cold integrated with RES, and results from it are relevant for this deliverable.

4.1 Belgium

Political - Belgian policy is mainly pushing for the investment in solar thermal, heat pumps and CHP. District heating is indirectly pushed for in policies for zero-emissions new buildings. Residual heat and cold is not mentioned in policy and RES targets are relatively moderate compared to other EU Member States.

Economic - Natural gas, and other fossil fuels, are the strongest competitors to waste heat and waste cold in the thermal sector. The lack of existing infrastructure to recover waste heat and cold induces large investments cost and longer payback times which could discourage investors.

Social - The price and availability of energy are the two aspects that Belgians are most concerned about when it comes to energy. Main health issues today are particulate matter and NOX emissions from fossil fuels in urban areas.

Technological - The potential for RES is low, especially in the heating and cooling sector, so waste heat and cold coupled with RES is not such a viable option. However, there is large technical potential for waste heat in Belgium. District heating is in a developing phase.

Legal - Social tariffs and taxes primarily incentivize natural gas as an energy carrier.

Environmental - Environmental concerns mentioned in the heating and cooling sector are mainly GHG emissions, such as CO_2 and NOX, and particulate matter as well as soil pollution from leaking heating oil tanks.

4.2 Italy

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Political - New policies proposed in the National Energy and Climate Plan targets biomass-fired, individual heating systems to become more efficient, renovation of the building stock and solar thermal and district heating. There are currently several different policies related to heating and cooling, mainly incentivizing solar thermal, heat pumps, geothermal and biomass. Technologies such as CHP and district heating are also covered by support schemes. As the development of photovoltaics has exceeded the initial national targets PV is exempted from most of the RES electricity support schemes, there is however support for other types of RES. Waste thermal energy is not explicitly mentioned in policy.

Economic - Natural gas, and to a lesser extent other types of fossil fuels, are the main competitors to an increased waste energy recovery in the thermal sector. A large share of the heat and cold is supplied from individual solutions. Natural gas is cheaper than district heating and the profitability of district heating networks is strongly dependent on the existence of incentives for co-generated electricity.

Social - The share of the population that claim that they are unable to keep their homes warm are higher than the EU average. Italy is also experiencing a high level of heat-related effects on daily mortality, both hot temperatures and overall summer temperatures. In addition to this primary and secondary pollutants, associated with health issues, is an issue in the major cities and areas with intensive industrial and agricultural activities. Biomass combustion in individual heating systems also contributes to this issue.

Technological - Around 5% of the population is served by district heating networks and there are some district cooling networks available as well. Biomass is playing a major role for the RES share in the energy sector and is the major supplier to the district heating together with waste incineration and natural gas co-generation. The potential for waste heat recovery has been assessed in different studies but the role of waste heat in reaching a larger share of RES in the heating and cooling sector is unclear.

Legal - There is an obligation to include RES or district heating in buildings to be granted a building permit, but compliance with this is generally ensured particularly by solar PV and solar thermal. Legislation also required all new buildings within one km of district heating system to be connected to it, that all municipalities above 50,000 inhabitants establish development plans for heating and cooling networks and that all companies obliged to carry out an energy audit in compliance with the EU Energy Efficiency Directive to carry out a feasibility study for the connection to a DH network, if available within a few kilometres.

Environmental - Environmental concerns associated with heating and cooling are mainly related to emissions from biomass-fired, individual heating systems. There are also risks associated with heat pumps that uses groundwater.

4.3 Portugal

Political - There is no direct push for the recovery of industry excess heat and cold in the Portuguese energy policy. The focus is on electrification, solar thermal, heat pumps and biomass.

Economic - Gas, coal and oil dominate the heating and cooling supply in Portugal. Process heating contributes to the largest demand before space heating. The demand for space heating and cooling is in general low in relation to other countries in Southern Europe, thanks to Portugal's mild climate.

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Social - No social aspects were found through literature review or in the responses to the questionnaire.

Technological - Portugal has a large RES potential, especially heat from cogeneration with renewable origin and biomass could contribute to the heating sector. The share of district heating is very low, and the potential is also low due to low demand. There is some potential for waste heat and cold recovery, mainly from industrial sites and thermal plants.

Legal - Buildings codes are pushing for solar thermal for heating domestic water, rather than district heating and excess heat recovery.

Environmental – As in most European countries, the energy sector is one of the main contributors to the Portuguese GHG emissions.

4.4 Romania

Political - There is an existing state aid program giving incentives to investments in efficient cogeneration from residual industrial process heat. Investments in district heating and cooling is identified as one way to reach energy efficiency objectives.

Economic - District heating has historically been a large part of the thermal supply in Romania but is in decline due to several reasons and competes with individual heating solutions, mainly with natural gas as the energy carrier.

Social - Fuel poverty as well as health and safety risks associated with the widespread individual heating solutions are among the greatest Romanian social concerns linked to the thermal sector.

Technological - The excess heat potential is considerable and combined with RES, mainly firewood and agricultural waste, it could heat a large share of the population. However, the district heating system, which is currently in decline, needs to be developed to make use of the potential.

Legal - There is a lack of regulation promoting waste heat and cold recovery.

Environmental - As in most European countries, the energy sector is one of the main contributors to the Romanian GHG emissions.

4.5 Spain

Political - Electrification and RES in the thermal sector (mainly heat pumps) are considered key for decarbonization and pushed for while residual heat and cold is mentioned but not explicitly pushed for. Support schemes exist for district heating and cooling on national, regional and local level.

Economic - The main competitor to waste heat is gas, mainly used in individual solutions. Investment costs in heat and cold recovery are high and the incentives are low today, especially for industries that does not have a CHP plant already.

Social - Public concerns mainly focus on energy price and comfort levels. Energy poverty affecting the populations ability to keep warm during the winter, CO poisoning and issues with excessive temperatures are some of the health and safety issues associated with the current thermal energy system.

Technological - Individual solutions still dominate the thermal sector. District heating is getting more and more attention but represents a very small share. The lack of DHC infrastructure, in combination

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with the seasonality of demand, pose technical challenges to make use of the large waste heat potential.

Legal - New regulations are expected to boost a shift from gas heating to electric heat pumps. There are also European regulations mentioned that could possibly affect the waste heat recovery by restricting the use of the heat pumps using fluorinated greenhouse gases.

Environmental - GHG emissions are the most commonly mentioned environmental impact from the Spanish energy system. However, the energy sector is also the main contributor to several types of emissions, among them SOX and PM2,5. With the increased recovery of waste heat there is a risk of a more extensive use of fluorinated gases which may exist in the heat pumps used, these are potent GHGs.

4.6 Sweden

Political - Swedish policy is pushing for a decarbonization of the energy sector, e.g. with CO_2 taxation and a renewable electricity certificate scheme. In parts thanks to the taxation on heating oil, individual oil boilers in single family houses have been substituted by heat pumps and biofuels to a large extent. Energy Efficiency Directive (EED) Article 14.5 has been implemented for plants larger than 20 MW.

Economic - A large share of the thermal energy is used for space heating, especially in the residential sector. Electricity and district heating contribute to major share of the heating and cooling in the residential and tertiary sectors, while biomass is the largest source for heating and cooling in the industrial sector. Fossil fuels have almost been phased out.

Social - Social concerns include risks for heating customers with a dependence on a single supplier and the absence of price regulation. Health and safety concerns include anticipated effects from climate change, such as the increased heat-related mortality and spread of infectious diseases.

Technological - The Swedish district heating is dependent on renewables such as biomass and waste and focus for future technological development is increased system efficiency. The availability of district heating is widespread, and there are also some district cooling networks. Sweden is leading in heat recovery and excess heat is 9 % of the total district heating supply, mainly from pulp and paper, steel and chemical industries.

Legal - The District Heating Act forces the district heating companies to investigate the economic viability of waste heat recoveries whenever such are possible. If the recovery is not deemed economically viable the investment is not a legal requirement.

Environmental - The introduction of district heating has reduced the local emissions in cities caused by solid fuel combustion. Regulations have also forced DH companies to reduce the nitrogen dioxide emissions and the use of fossil fuels. Climate change has replaced clean air as the dominating environmental issue associated with the thermal sector.

4.7 United Kingdom

Political - The UK policies mainly focus on supporting energy efficiency improvements and low-carbon technologies, such as heat pumps, biomass boilers and solar thermal, for heating of homes and businesses. There is also support for new heat networks to be built. Article 14.5 of EED has been transposed and a cost-and-benefit assessment of waste heat recovery used for cogeneration or connection to a district energy network is now required for being granted an environmental permit.

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Economic - Natural gas is the main competitor to an increased waste energy recovery in the thermal sector. Other economic barriers to waste energy recovery are lack of CAPEX funds for smaller companies and relatively long payback periods compared to other investments. The lack of confidence in heat recovery technologies is affecting the pay-back calculations negatively. Companies also gives energy efficiency measures a lower priority.

Social - Raising energy bills are high on the political agenda and a concern of the public. Heat network customers are in general more positive about the price they pay than non-heat network customers. Air pollution from the burning of fossil fuels and biomass is of a health concern as this could be attributed to premature deaths, especially in the larger UK cities.

Technological - Progress with more renewables in the heating sector has been more challenging than in the electricity sector where the UK has large potential especially in wind. Possible low carbon technologies in the thermal sector are heat pumps, hydrogen, biogas, industrial excess heat and energy from waste. There is potential for more waste heat and cold recovery. District energy networks available are mainly supplying a single building.

Legal - There are suggestions for regulations on low carbon heating in homes. New legislation is also pushing for more efficient boilers in homes.

Environmental - GHG emissions from the energy sector in general, as well as leakages of the global warming potent F-gases from refrigerants used for space cooling specifically, are some of the environmental concerns associated with the heating and cooling sector.

4.8 Conclusions from the PESTLE

Natural gas is the main energy carrier in the European thermal sector and district heating as well as renewables make up a very small share of the heating and cooling demand in the EU28 countries. EU policy and legislation focuses on increasing the share of renewables and to decrease the demand for space heating in building. Excess heat and cold from industries are mentioned but no specific technology or application is promoted. The estimated EU technical potential is 300 TWh/year for waste heat, mainly from iron and steel industry, and 64 TWh/year for waste cold, LNG and WtE plants giving the highest potential.

In the SO WHAT deliverable 1.2 (8), the potential of the industrial sectors WH/C recovery potential is calculated by two methods. The results per country according to the study is shown in Figure 2, in comparison with the total final heat demand in 2015.

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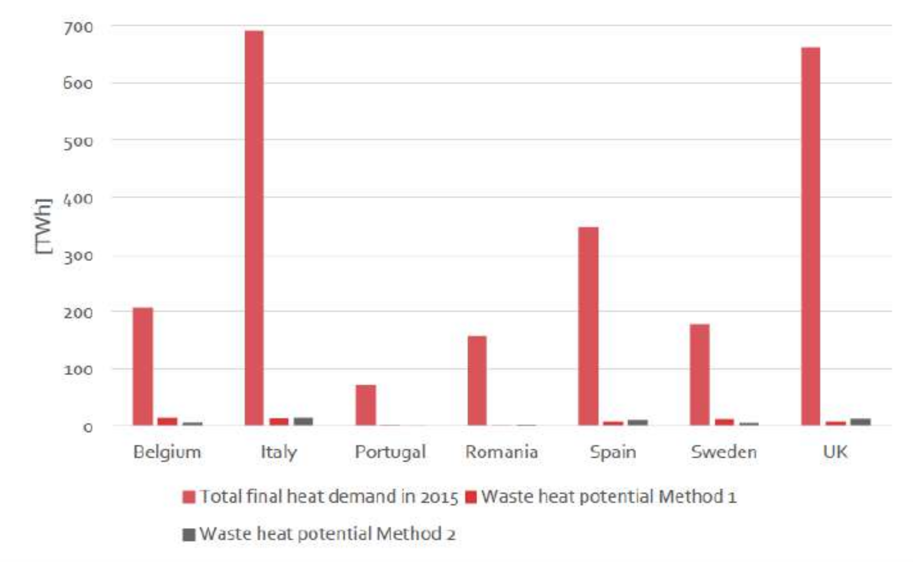

Figure 2 Comparison of heat demand in 2015 and waste heat potential per country. Data sources: Total final heat demand from Heat road map (9), Waste heat potential from SO WHAT D1.2 (8)

In Figure 3 the total final heating demand, by energy carrier, is presented for the countries covered by the SO WHAT-project. In relation to the other countries, Sweden has a low percentage of natural gas and a high percentage of district heating. Romania has the second biggest share of district heating of the studied countries, after Sweden. The share of district heating in Spain is marginal, and the other countries have small shares. UK is the country with the largest percentage of natural gas. Portugal, Romania and Sweden have the biggest shares of biomass when comparing the seven countries.

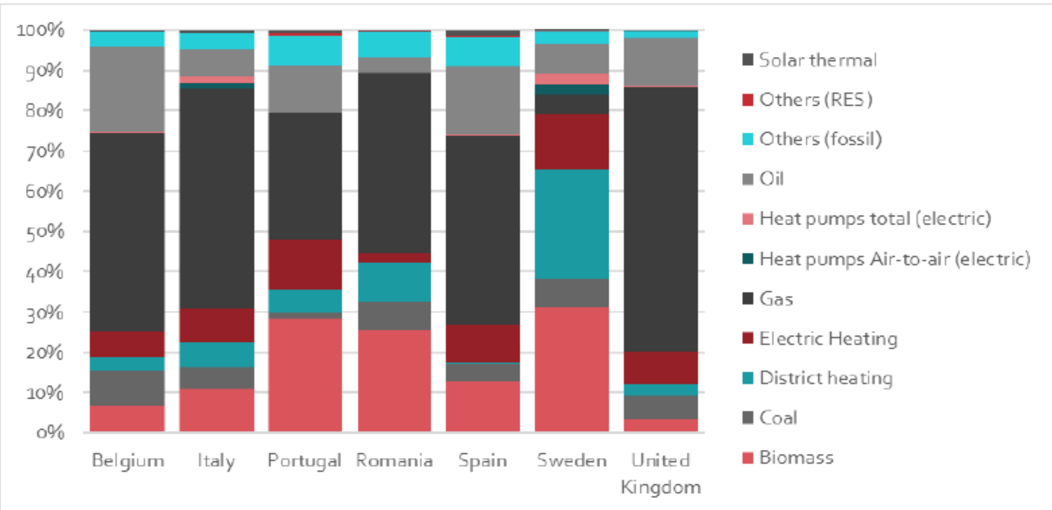

Figure 3 Heating, total final demand by energy carrier 2015 (9)

The heating and cooling demand could be divided into three sectors: residential, industry and tertiary (i.e. the service sector). The share of thermal demand by each sector and country is presented in Figure 4. The residential and industry sector contributes with the largest shares in all seven countries. In Belgium, Portugal, Spain and Sweden the industry has the largest thermal demand, while the residential sector has the largest demand in Italy, Romania and United Kingdom.

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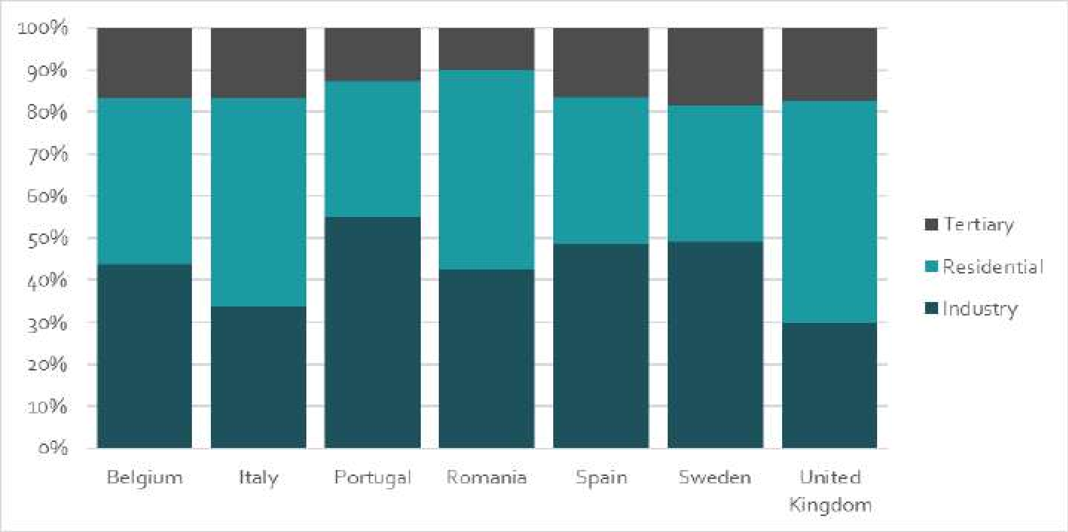

Figure 4 Heating and cooling, total final demand by sector 2015 (9)

The share of different types of heating and cooling demand can be seen in Figure 5. Space heating and process heating are the largest in terms of thermal demand for all countries, but the division between these two types varies. In Portugal process heating has the largest share, while countries such as Italy and United Kingdom have large shares for space heating. Cooling is a small share of the total thermal demand.

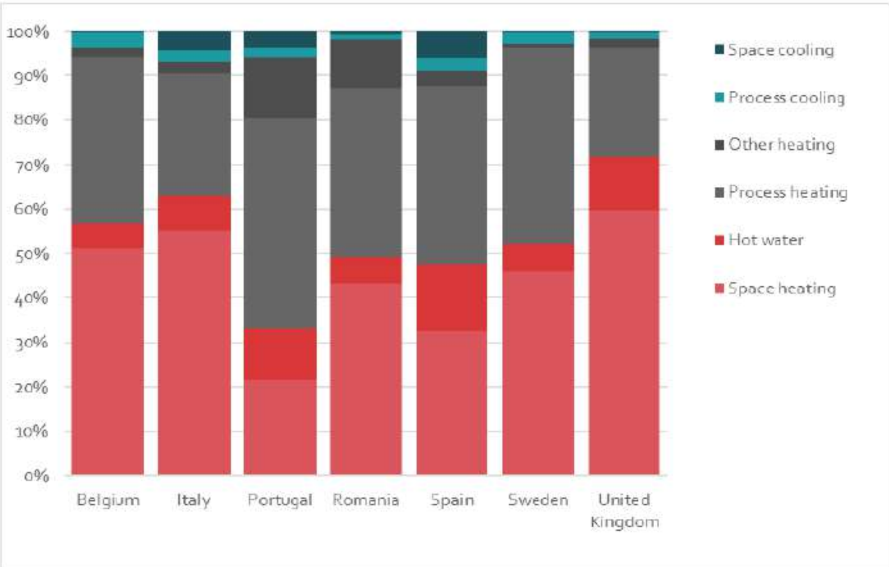

Figure 5 Heating and cooling, share of type of heat in total final demand 2015 (9)

Regarding cooling, both process and space cooling, the most common technique is electric compressor chillers in the studied countries.

4.9 Energy prices in the demo site countries

In Figure 6 the energy prices in the demo site countries are compared. Romania, UK, and Belgium are found to have the lowest natural gas prices for households, while Sweden has the most expensive. Note that in Sweden there is a great difference between the natural gas price for households and non-households due to a high tax. In all countries, electricity is more expensive than natural gas. With

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exception from Sweden, the electricity price is between 2.2 to 4.2 as high as the natural gas for households.

The figures for district heating prices are somewhat older than the figures for electricity and natural gas. The oldest figure is for district heating price in Italy, for year 2009. Hence, the columns in Figure 6 cannot be compared unreserved. However, the figure indicate that the district heating prices are in parity with the natural gas price for households in Italy and UK, while the district heating price in Sweden is lower than the natural gas price for households, and in Romania it is somewhat higher than the natural gas price for households.

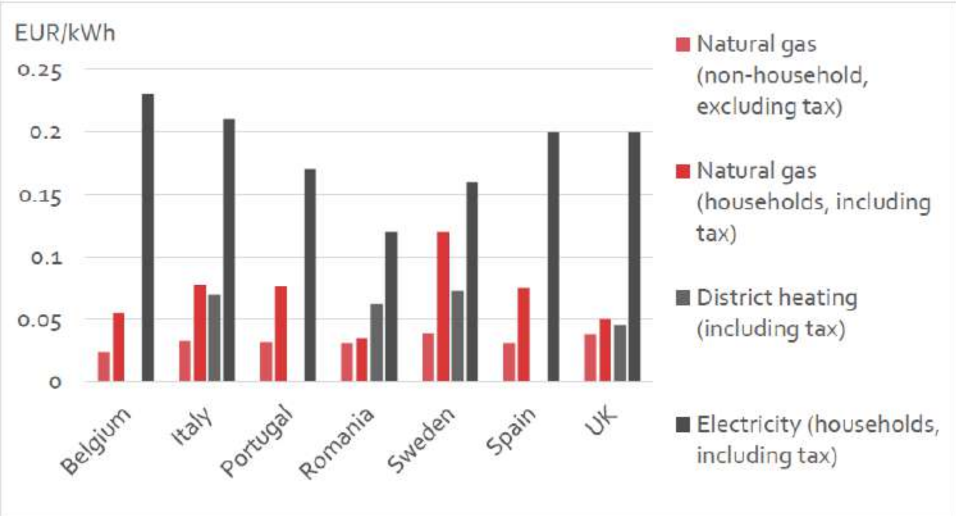

Figure 6 Energy price comparison of the demo site countries. Data sources: Natural gas and electricity prices (year 2019) from Eurostat (10), District heating prices (year 2013 for Romania, Sweden and UK and year 2009 for Italy) from Werner (11).

In the first half of 2021, average household electricity prices in the EU increased slightly compared with the same period of 2020 (€21.3 per 100 kWh), standing at €21.9 per 100 kWh. Average gas prices in the EU registered the inverse path, decreasing slightly to €6.4 per 100 kWh in the first half of 2021. More recently, wholesale prices for electricity and gas are increasing substantially across the EU. Table 1 reports the energy price comparison of the demo site countries in the first half of 2021.

country	Natural gas prices (including taxes) for household consumers, €/kWh	Natural gas prices (including taxes) for non-household consumers, €/kWh	Electricity prices for household consumers (including taxes), €/kWh	Electricity prices for non-household consumers (including taxes), €/kWh
Belgium	0,0468	0,0266	0,27	0,1464
Italy	0,0703	0,0308	0,2259	0,1837
Portugal	0,0762	0,0301	0,2089	0,1294
Romania	0,0317*	0,0288*	0,1536	0,118
Sweden	0,1234*	0,0552*	0,1791*	0,0961*
Spain	0,0691	0,0287	0,2323	0,13
UK	-	-	-	-
*estimated				

Table 1 Energy price comparison of the demo site countries (first half of 2021). Data sources: Natural gas and electricity prices (year 2021) from Eurostat (10).

5 Barriers related to the SO WHAT demo sites

In this chapter, each SO WHAT demo sites are briefly described and their perceived main barriers to DH/C collaboration are presented.

5.1 Antwerp, Belgium (ISVAG) – Waste to energy plant

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Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
ISVAG Incineration (KELVIN)	Antwerp (Belgium)	Waste to Energy	ISVAG superheated stream power plant valorise via incineration local wastes and WH from the boilers.	400 °C	WH/C collaboration

Table 2 Description of site in Antwerp

The perceived main barriers to WH/C collaboration are:

- The **long-term commitment** of the end users to use the heat. The end user companies may feel that they will be too dependent on one supplier. The end users can't guarantee that they are in production in 10 years, or that they will need as much heat in the future.
- **The price of the heat** (CAPEX/OPEX). One main barrier is the competition from natural gas, and the end user's unwillingness to pay for the heat if the price is higher than the natural gas.
- When building DHN in Belgium, there are very **few contractors available**, since these contractors also build the gas grid. The prices of constructing the infrastructure can vary a lot depending on when and where the project is planned.

5.2 Olen, Belgium (UMICORE) – High tech manufacturing

Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
UMICORE Rare material Centre (KELVIN)	Olen (Belgium)	High tech manufacturing	UMICORE's Olen site revolves around recycling and production of high-tech materials based on cobalt and germanium.	50 – 265 °C	Internal heat recovery

Table 3 Description of site in Olen

The perceived main barriers to WH/C collaboration are:

- **DHN is an unknown technology** at the demo site. Umicore is more familiar with the existing steam network, which the company have had for 40-50 years.
- It is not the core business for Umicore, and thereby it is difficult to get capital when **competing with the core business investments**.

5.3 Willebroek, Belgium (IMERYS) – Chemical manufacturing

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Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
IMERYS Carbon black manufacturing (KELVIN)	Willebroek (Belgium)	Chemical manufacturing	IMERYS manufactures Carbon Black producing a mixture of H_2 and CO as by-product which is currently burned in a furnace whose excess heat could be recovered.	600 °C	WH/C collaboration

Table 4 Description of site in Willebroek

The perceived main barriers to WH/C collaboration are:

- **The long-term commitment of the end users** to commit to use the heat. The end users may feel that they will be too dependent on one supplier. The end user companies can't guarantee that they are in production in 10 years, or that they will need as much heat in the future.
- **The price of the heat** (CAPEX/OPEX). One main barrier is the competition from natural gas, and the end user's unwillingness to pay for the heat if the price is higher than the natural gas.
- For Belgium a general, a main barrier is the **long distance from the industry to first large size potential end user.**

5.4 Navia, Spain (ENCE) – Pulp mill

Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
ENCE Pulp Mill (ELEUKON/ CARTIF)	Navia (Spain)	Pulp Mill	This is the mill with the largest production capacity belonging to ENCE Group (535 ktons/year) and the most efficient pulp mill on the eucalyptus market in Europe.	70 - 230 °C	WH/C collaboration

Table 5 Description of site in Navia

The perceived main barriers to WH/C collaboration are:

- **Lack of regulations and economic incentives**. Natural gas is cheaper. Subsidies will be needed to balance the economy.
- **Lack of experience and knowledge about the technology.**
- **Problem to deploy the pipes.** The deployment requires several regulations (river regulations etc) which are handled by regional authorities. The administration related to processes are considered as barriers. In the existing heat networks in Spain, the regional government owns the pipes and distribute to their own uses. In case the private ESCO company will be responsible for the deployment and distance to the administration will thereby be bigger.

5.5 Maia, Portugal (LIPOR) - Waste to energy plant

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Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
LIPOR Maia Waste to Energy Plant (LIPOR)	Maia (Portugal)	Waste to Energy	Two incineration lines in a continuous and almost automatic operation burn and treat 380,000 tons/year of municipal waste.	Outlet Flue gases 150 °C Steam to turbine 395 °C Condensates 55 to 60ºC	WH/C collaboration

Table 6 Description of site in Maia

The perceived main barriers to WH/C collaboration are:

- The **lack of experience of heating/cooling network** systems in Portugal, currently there is only one existing (located in Lisbon). There is not a culture of using these systems. The lack of experience relates not only to construction phase but also operation and maintenance.
- Normally the **demand for heating (mainly) and cooling is low**. There is a low energy demand for heating and cooling, due to the mild climate at the demo site. However, there is need to improve the comfort in the existing building stock, and that would lead to increased demand for heating and cooling.
- **Large investments in infrastructure** will be needed. Due to the lack of investments related to DH/C network in the area of the demo site there will be a need of large and new type of investments to create a new network.
- The cultural aspect, **medium-long term cooperation and commitment** with large investments. To achieve DH/C cooperation new collaborations need to be developed between different actors and companies, and the contract length could be a large barrier between the partners. The waste to energy plant has stable operation the entire year(unless the shut-down periods for overhaul and preventive maintenance, normally two times per year) and will be running for a long time, with the monopoly activity to burn waste in a not competitive sector. The risk of closure is small, and the supply is stable. The barrier with commitment applies more for the potential customers.
- **The price of the heat**. The issues of the price of heat/service and being competitive with natural gas and electrical solutions is important.

5.6 Constanta, Romania (RADET) – DHN, WH from local industries

Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
Constanta DHN (RADET)	Constanta (Romania)	DHN, WH from local industries	RADET aims to renovate this old DHN valorising local industries WH.	70 - 250 °C	WH/C collaboration

Table 7 Description of site in Constanta

The perceived main barriers to WH/C collaboration are:

- **The current organization framework for thermal energy production and supply.** The district heating network in the region has been inherited and was based on the interest of heat producers and to preserve the position of the heat producers. Thereby it is mostly

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beneficial from the perspective of large heat producers. In some cities in Romania the heat production and heat distribution can be in the same company. In Constanta though the heat production and distribution are performed by two different companies.

- **The DH is relying on one single thermal power plant**. The biggest part (93 percent) of the heat comes from the same power plant. The company administrating the power plant is a state-owned company and due to the lack of investment funds, it was not able to upgrade the technology and to reduce the production costs. At some apartment buildings, small natural gas boilers have been installed which covers the other 7 percent in RADET's DHN supply.
- **Obsolete infrastructure of the current district heating network**. If different companies would like to deliver heat to the DHN, the price should be smaller than the price of the power plant. The DHN is prepared for that technical solution, but it has very large losses and requires a huge refurbishment process. At present, the local municipality that owns the DHN is preparing a large project for re-sizing and upgrading it.
- **Regulatory and financial barriers**. The situation of the market. Even though RADET has the principal possibility to buy heat it is still complicated to implement the collaborations. This is due to that the heat producer must be certified etc to be able to sell the heat, and it can be difficult. Newcomers must build up their business plan and need to apply for loans at the bank or to other financing institutions, but there are still many risks and uncertainties. A new specific law that is regulating the district heating sector is at present under debate at the Romanian Parliament.

5.7 Navodari, Romania (Petromidia) – Refinery

Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
Petromidia refinery (GREENMED)	Navodari (Romania)	Refinery	Petromidia is the largest Romanian refinery, and one of the most modern refineries in South East EU.	140 - 450°C	Internal heat recovery

Table 8 Description of site in Nayodari

The plan for the demo site is to perform energy efficiency measures at the refinery. The projects that are aiming the improvement of energy efficiency are considered as development projects and there are internal procedures and rules for promoting and implementing such projects. In principal, there are defined some criteria consisting on threshold values for indicators as IRR, ROI and other similar. In the case of the project defined as demo, due to the energy recovery will be achieved within the same plant and no collaboration with other companies, the questions regarding perceived barriers to DH/C collaboration between a heat supplier and a heat user for this deliverable are not applicable to the demo site.

5.8 Pessione, Italy (M&R) – Distillery, food and beverage

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Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
Pessione Distillery (M&R)	Pessione (Italy)	Distillery, Food and beverage	M&R Pessione plant processes requires heating (distillation, bottle warming etc.) or cooling (product, CO_2 injection, conservation etc.).	-8 - 60 °C	Internal heat recovery

Table 9 Description of site in Pessione

M&R is evaluating different solutions for heat recovery internally. No external solutions and collaborations are under consideration because no factories or public buildings are located nearby. The heat and cold recovery will be used internally and valorised internally only. Due to the energy recovery will be achieved within the same company, the questions regarding perceived barriers to DH/C collaboration between a heat supplier and a heat user for this deliverable are not applicable to the demo site.

5.9 Middlesbrough, UK (MPI) – Steel industry

Name, Partner	Location	Sector	Process	Temperature	WH/C collaboration or internal heat recovery
Innovation in steel industry pilot (MPI)	Middles-brough (UK)	Steel industry	MPI operates pilot steel industry plant including electric arc furnace and continuous casting plant, the former used also for small scale commercial production, beside research activities.	1,600 °C	WH/C collaboration

Table 10 Description of site in Middlesbrough

The main barrier to WH/C cooperation related to steel industries in general in UK are money and uncertainties. In general, the steel industries in UK have small profit margins and thereby are in the knife edge if the can keep running. The industries try to control their cost by savings in the core business. Often the organization is occupied with the core business, not issues regarding energy efficiency. There is a **lack of funding, capital and manpower for non-core investments** even if there is a good business case.

When energy efficiency actions have been performed, the following factors have been keys:

- Investments with shorter payback than 6 months, and few numbers of people to perform it. Example: Change of pumps
- Investments through the energy performance contract (EPC) business model. Example: Change of lightning
- The respondent sees a need for more initiatives like this, requiring a low number of staff to be engaged and performed in stages.

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6 Conclusions

6.1 Identify the win-win collaboration

The first step in the quest to valorise industrial excess heat is to find a profitable business case. However, due to low costs of alternative heating and the high initial investment cost for piping and other technology, that could be a challenge. A major barrier to an efficient business case is that policy promotes other energy alternatives than industrial excess heat.

In comparison with the other demo site countries, Sweden has a high natural gas price. Instead competition comes from low electricity price and heat pumps. Sweden has been engaged in industrial waste heat recovery for decades. For the industries in the SO WHAT collaborations, there is a great value in replacing the cooling equipment by excess heat delivery to a district heating network. Both in Varberg and Gothenburg, the business case of the excess heat collaboration has been considered as a win-win deal between the industry and the district heating company.

In addition, the owners of the district heating systems in Varberg and Gothenburg are the municipalities, and they had a political will to promote the heat collaboration. The municipalities regarded this as both a way to use local resources more efficiently and promote the local industries; an important enabling factor.

6.2 Opportunity to use industrial excess heat for cooling

Generally, in southern Europe where several of the studied countries are situated, the cooling requirements is relatively large. Furthermore, due to the competition with low price natural gas for heating, one alternative business case which potentially could have better profitability is using waste heat to produce district cooling. This could be done with absorption chillers, as it for example is done in Gothenburg. A common competitive way of producing district cooling is with compressor chillers, which use electricity. In all countries the electricity price is higher than the price of natural gas which makes this an interesting option. However, the compressor chillers generate more than three kWh cold per kWh electricity input, which flattens the cooling energy cost for compressor chillers. Hence, to compete with compressor chiller the price of alternative cold needs to be below one third of the electricity price.

6.3 Set the policy and regulatory framework

Policy support, such as financial support or legal requirements, would be needed to reduce natural gas use for heating and by that make the industrial waste heat more competitive. One example related to legal aspects from the PESTLE analysis is Spain where new regulations are expected to boost a shift from gas heating to electric heat pumps. On both national and European level, the use of excess heat should be equally promoted. With policy's promoting district heating and excess heat collaboration, the barrier can decrease. In the countries or regions with no or limited tradition of building DHN, lack of regulations is mentioned as a barrier. Development of the regulatory framework is essential for the exploitation of industrial excess heat, e.g. permission process for piping.

6.4 Technical know-how

Lack of experience of the technology is one major barrier in many of the demo site countries. A barrier to realize the potential, is the limited access to technical knowhow. Knowledge transfer and

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development of tools to evaluate the techno-economic feasibility, through for example similar projects like SO WHAT, can potentially contribute to reduce this barrier in the long run.

6.5 Trust and understanding

Another important enabling factor was trust between the collaborating parties. The experience is that close cooperation relation and openness between the parties are keys to establish a successful collaboration. Trust between the partners makes other barriers easier to overcome. On the other hand, lack of trust would be a barrier which makes other barriers even larger.

One part of building trust is to increase understanding about each other's systems. Lack of this understanding has been highlighted as a major barrier by the interviewed demo sites.

6.6 Remove the barriers with contractual arrangements

To summarise, the demo sites have considered different main barriers depending on the sector, level of earlier experiences and infrastructure of DHN etc. The mentioned barriers cover a wide range of areas and issues, some of them may be managed by contractual arrangements and some of them need to be handled by other measures. The following main barriers are connected to current contractual arrangements for WH/C exploitation:

- Long-term commitment of end users
- Large initial cost
- Not core business
- Financial barriers
- Requirements for a short payback period for investments
- Difficulties to agree on pricing
- Lack of knowledge or understanding of each other's systems, processes etc
- The risk of industries shutting down. All demo sites except for one have ranked this barrier as important.

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MODULE 2.2: DRIVERS AND BARRIERS, CONTRACTS AND BUSINESS RISKS

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Summary

Drivers and barriers

- Efficient resource use, reduced cost and emissions
- High initial cost, difficulty to agree on pricing, ownership and responsibilities

Business risks

- Dependence on external partners
- Lack of know-how and legal framework in some countries

Contractual arrangements

- Win-win collaboration
- Ownership and responsibilities
- Time of commitment
- Exit paragraph

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DRIVERS AND BARRIERS TO UTILISATION OF INDUSTRIAL EXCESS HEAT

Industrial excess heat is a valuable energy resource that can replace fuel and electricity. Why isn't it already made use of?

Drivers

Efficient resource use is a major driver for exploitation of excess heat, since no one likes to see valuable resources being wasted. In addition, there are economic and environmental drivers.

1. Costs may be saved when fuel and electricity use is replaced.
2. Cost saving when active cooling, such as cooling towers, is not needed to discard the heat at large industries.
3. Replacing fossil fuels, e.g. natural gas, will reduce green house gas emissions.

On a regional or national scale, there may be further drivers, such as reduced dependency on imported energy, or job creation.

Industrial excess heat is a resource that often goes up in smoke.

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Barriers

Barriers to utilisation of industrial excess heat can be divided into two categories:

1. Barriers which deteriorate the business case
    - Low cost of current heating, e.g. natural gas.
    - High initial investment cost for piping and other technology.
    - Policy promotes other energy alternatives than industrial excess heat in some countries.

Piping cost is a large part of the investment.

1. Barriers which remain even though the business case is profitable:
    - Lack of regulations is a barrier in some countries, e.g. permission process for piping.
    - Lack of technical know-how is a barrier in some countries.
    - Wish to be independent from external partners.
    - Risk of industry moving or closing.

Many of the barriers may be handled by contractual arrangements.

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BUSINESS RISKS WITH EXCESS HEAT COLLABORATION

All investments involve risks. What risks are largest in the context of heat collaboration? How can the risks be mitigated?

Business risks

There is no such thing as an risk-free investment. Depending on local prerequisites, the risks related to excess heat collaboration will be quite different. One watershed is if there is an existing district heating or cooling network, or if that technology is lacking in the region or even in the country.

Genaral risks

- Dependency on external partner – resources outside of own control.
- The heat source is the only/main one – risk of large disruption for the heat costumers.
- Difficulty to agree on price of heat – implies an increased risk of continued difficulties at renegotiation of the contract.
- Unpredictable heat flow – involves risk for unexpected costs.
- Risk of industrial closure.
- Risk of end-users changing to other energy resource – cost competetive other forms of heat supply.

Additional risks if no existing DH/C network

- Lack of regulations and policy
- Lack of technical know-how

Reduced risk

By adding industrial excess heat to an excisting district heating network, the risk exposure to fuel prices can be reduced.

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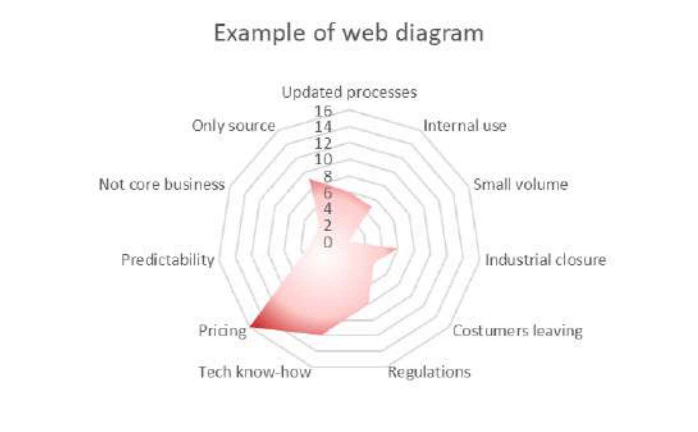
Risk heat mapping

A risk assessment can be made through risk heat mapping of a specific investment. The likelihood and consequence of the major risks are estimated. Then, by multiplying consequence x likelihood, the *heat* of each risk is calculated. This gives an overview of the most important risks to mitigate, and an indication of risk premium that should be applied for investers.

		Consequence				
		Very small (1)	Small (2)	Medium (3)	Large (4)	Very large (5)
Likelihood	**Very large (5)**	Moderate (5)	High (10)	High (15)	Catastrophic (20)	Catastrophic (25)
	Large (4)	Moderate (4)	Moderate (8)	High (12)	Catastrophic (16)	Catastrophic (20)
	Medium (3)	Low (3)	Moderate (6)	Moderate (9)	High (12)	High (15)
	Small (2)	Low (2)	Moderate (4)	Moderate (6)	Moderate (8)	High (10)
	Very small (1)	Low (1)	Low (2)	Low (3)	Moderate (4)	Moderate (5)



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Risk mitigation

The vast part of the risks can be mitigated with well-designed contracts and well-thought-through partner arrangements: facilitating for the parties involved to learn about each other's processes.

Examples of risk mitigation measures

- Issues regarding building DHN and piping could be simplified through involving a third party (ESCO). Such a party can, for example contribute with needed expertise.
- The most important mitigation activity is to have clear contract outlining responsibility and what happens in the case of failure to deliver waste heat at given volumes and temperatures.

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CONTRACTUAL ARRANGEMENTS

How can contract be used to overcome barriers, share the benefits and reduce risks?

Contractual arrangements

What to include in the contract?

- Ownership of different parts of the system.
- Pricing.
- Responsibilities – e.g. what happens in the case of failure to deliver waste heat at given volumes and temperatures?
- Contract period – when and how to renegotiate.
- Exit paragraph – how long in advance a partner needs to announce that it is leaving the collaboration and how costs that occur as a result of that will be divided between the partners.

The contract should ensure that the collaboration will be a win-win.

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MODULE 2.3

LEVELIZED COST OF HEAT, COST-BENEFIT ANALYSIS, FINANCING SCHEMES

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Summary

Levelized Cost of Excess Heat (LCoEH)	• Economic assessments of excess heat • Facilitates the pricing of excess heat and the economic comparision of different heating alternatives
Cost-Benefit Analysis (CBA)	• Socio-economic assesements of the costs and benefits from investments in excess heat and cold recovery technologies • Useful for making decisions on large public sector investments and to attract financial support
Financing schemes	• Different types of financing schemes, with special focus on ESCO models • Facilitates the viability of an investment

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LEVELIZED COST OF EXCESS HEAT (LCOEH)

What is the cost of excess heat relative to other heating alternatives?
How could excess heat be priced?

What is LCOEH calculations?

LCOE (Levelized Cost of Energy) calculation is a standard approach to calculate the average net present cost of the unit of energy (usually KWh) produced by a generation plant over its lifetime. A version of this is LCOEH (Levelized Cost of Excess Heat).

LCOEH facilitates:

- the pricing of excess heat
- the economic comparison with other heating alternatives
- the assessment of the maximum distance from the point of production to generate revenues

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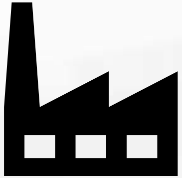
Four approaches to LCOEH calculations

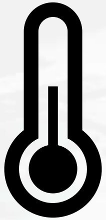
The calculations of LCOEH can be seen from four different perspectives

Industrial facility



Producers of excess heat

District heating and cooling network operator



Distributors of excess heat

End-user

Users of excess heat

Global system

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Calculating LCOEH

Capital cost

Operation and maintenance cost

Excess heat cost
This is zero for the industrial facility and in the global perspective

$$LCOEH\left[\frac{€}{MWh}\right] = \frac{I_{EH}\ CFR\ (1 - T\ D_{pv})}{8760\ i\ (1-T)} + \frac{O_{EH,total}}{8760\ i} + c_{EH}$$

IHE: the investment cost for the equipment [€/MW]

CFR: capital recovery factor which discounts the investment [-]

Dpv: the present value of depreciation [-]

i: the capacity factor, a ratio between the total operative full load hours and the annual hours (8,760 h) [-]

T: tax rate [-]

$OEH,total$: total O&M costs [€/MW]

cEH: the cost of the excess heat [€/MWh], zero for the industrial facility and in the global perspective

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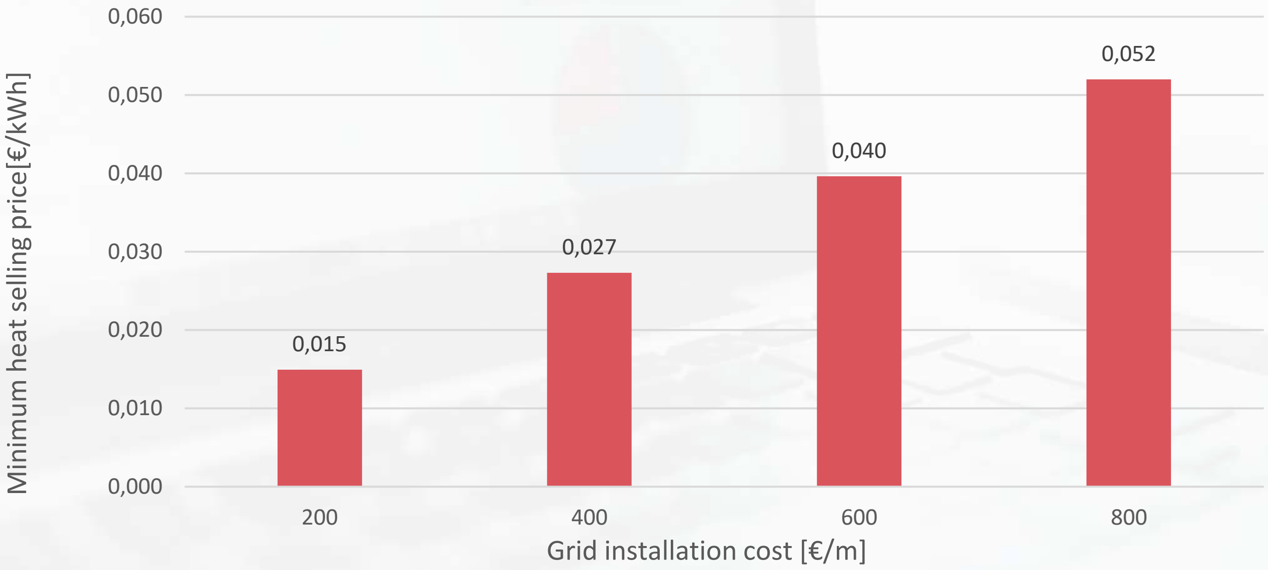
Ex. Heat price with different heat grid costs



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COST-BENEFIT ANALYSIS (CBA)

Is the investment profitable from a socio-economic perspective?

CBA captures socio-economic values

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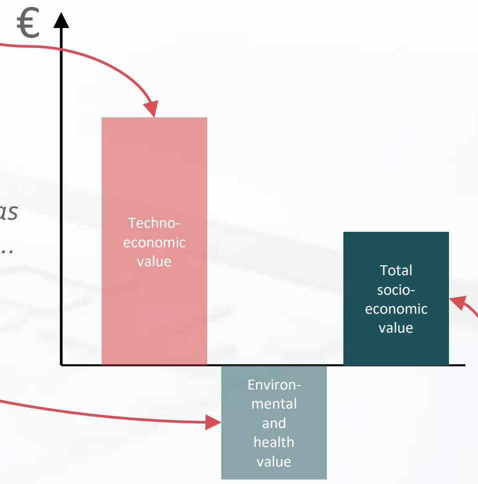
The CBA captures more values than a business economic perspective, such as the cost and benefits for increased or reduced impacts on environment and health.

Why do a CBA?

- Make a socio-economic assessment of the costs and benefits from investments in excess heat and cold recovery technologies
- Useful for making decisions on large public sector investments and to attract financial support

1. An investment can seem profitable from a business economic perspective, but…

2. …could lead to increased emissions which has a negative impact on environment and health…



3. …which in turn decreases the total socio-economic value of the investment

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CBA inputs

Technology investment option

- Type of technology
- Technical life time
- Installation size
- Annual energy production
- Investment and maintenance costs*
- Input demand (water, material, work hours etc.)*
- Fuel and electricity demand*
- Emissions*

Investment scenario

1. a combination of **technology investment options**
2. the investment and reinvestment years of these options and
3. the years during which these options are in operation

A collection of the investment scenarios to be compared, incl. a reference scenario as baseline

***For these four input categories there is also a need for additional national input data**

- Emissions from the electricity production
- External costs of the emissions
- Costs of the variable inputs, fuel and electricity

Example:

Scenario 1: Excess heat to nearby industry

- Technology investment option 1: Heat exchanger
- Technology investment option 2: Absorption chiller

Example:

- Reference Scenario: No excess heat recovery
- Scenario 1: Excess heat to nearby industry
- Scenario 2: Excess heat to district heating grid
- etc.

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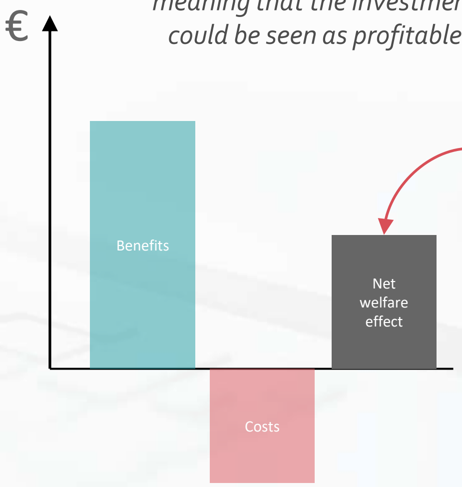
CBA outputs

The investment scenarios are compared to a reference scenario and the following could be calculated:

- **Changes in emissions**
- **Net welfare effect = benefits - costs**
  - The difference between the change in external costs, e.g. decreases in impact on environment and health, and the change in techno-economic costs, e.g. changes in CAPEX and OPEX.
  - Investments where the net welfare is positive could be considered a profitable investment.
- **Benefit/cost (b/c) ratio:**
  - The ratio between the calculated benefits and costs.
  - Investments where the b/c ratio exceeds 1 could be considered a profitable investment.

Example

The net welfare effect is positive and the b/c ratio 2.2, meaning that the investment could be seen as profitable



b/c = 2.2

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FINANCING SCHEMES

What financing schemes could support the viability of an investment?
What type of ESCO contracts could be useful?

Chosing a financing scheme

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Excess heat and cold recover as well as district heating and cooling projects have high upfront costs, but choosing the right financing scheme can support the viability of an investment.

The answers to these questions can provide some guidance:

- What kind of organisations will be involved in the ownership and the operation?
- Will the ownership be divided?
- Will an ESCO (energy service company) be involved?
- What will be the target of the ESCO?

→

- Financing schemes
- ESCO model (if applicable)

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Financing schemes

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The ownership and operation of district heating and cooling networks can be public, private and mixed public private. This affects the possible financing schemes.

Public	Private	Mixed public-private
Investments by a public entity could be finances through: 1. Financial aid from European Union and from different national administration 2. Collaboration with another public organisation 3. Acquisition and/or exploitation of networks of other municipalities	Investments from a 100 % private company can get financial support from a local entity: 1. Repayable loans 2. Non-refundable grants 3. Tax advantages 4. Other benefits	Different financing schemes for public-private collaborations: • **ESCO contracts** • Concession • Leasing • Property Differentiated by Elements • Mixed Society with Selected Minority Private Capital • Mixed Society with Minority Private Capital from Investment Funds • Mixed Society with Majority Private Capital

ESCO is the most common model

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ESCO (Energy Servive Company) contracts

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		Services	Values
Energy Supply Contracting (ESC)	Efficient supply of the energy demand	• Purchasing of fuel • Energy delivery and invoicing • Management of energy distribution • Energy production plants: financing, engineering design, planning, construction, O&M etc.	• Efficiency increase • Clear and optimized operational costs • Supply assurance increase • Application of the most recent safety standards
Energy Performance Contracting (EPC)	Reduction of the energy demand through energy conservation measures	• Design • Installation • (Co)-Financing • Operation & Maintenance • Optimization • Customer specifications	• Guarantee of results • All-inclusive costs of the services • ESCO assumes commercial, technical and operational risks
Integrated Energy Contracting (IEC)	Both efficient supply and reduction of the energy demand	A combination of ESC and EPC models	

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THANK YOU FOR YOUR PARTICIPATION

SOWHAT TEAM

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H2020 Work Programme

D4.8 – SO WHAT MANUAL

Lead Contractor: IESRD

Date: 05/09/2022

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

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25/01/2022	3.0	Nick Purshouse	Updates following review
04/02/2022	4.0	Nick Purshouse	Further updates
21/07/2022	5.0	Olivier Neu	Further updates
27/07/2022	6.0	Olivier Neu	Further updates
25/08/2022	7.0	Nick Purshouse	Final draft for review
31/08/2022	8.0	Arianna Amati	Review
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05/09/2022	11.0	Arianna Amati	Final Review before the submission

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Executive Summary

The overreaching aim of this document is to provide users of the SO WHAT Advanced Tool detailed instructions on how to install, navigate, and utilise the various pieces of software, as well as identifying relevant technologies, buildings, and data to be used within the analysis, for the purposes of waste heat/cooling recovery and reuse.

The document is intended to be used as a step-by-step guideline to enable new users to get started with creating pilot site models, as well as with investigating ways to recover and exploit their waste heat and/or cold (WH/C) resource potential, either by re-using this resource internally (on-site) or by distributing it externally (to local district buildings/sites through a district heating/cooling network).

Also included is a methodology on how individual sites may identify relevant waste energy recovery technologies to investigate and model as well as the relevant building and data that would be best suited to this analysis.

It should also be noted that as well as a formal deliverable, this report will be updated and used as the paper version of the manual for people to use and it will also form the basis for the online version (D4.6 Delivery of self-learning modules). Alongside this, training videos will be produced, as part of D7.6 Training Resources for Relevant Stakeholders.

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Introduction

This document represents the Deliverable 4.8 which contains a manual for the SO WHAT commercial/advanced tool. It is intended to be used as a step-by-step guideline to enable new users to get started with creating pilot site models, as well as with investigating ways to recover and exploit their waste heat and/or cold (WH/C) resource potential, either by re-using this resource internally (on-site) or by distributing it externally (to local district buildings/sites through a district heating/cooling network).

This manual will highlight the relevant IES and RINA-C software to download for this project, how to download it, and how to utilise the tools to develop a model appropriate for waste heat/cooling energy recovery. This includes how to prepare the models, upload data, run simulations, and review and analyses the results.

A methodology on how individual sites may identify relevant waste energy recovery technologies to investigate and model as well as the relevant building and data that would be best suited to this analysis has also been included.

As such, the document has not been written in a standard SO WHAT deliverable format, and differs in the numbering of its different sections. This is to enable the easy production of the SO WHAT Manual to be lifted directly from this document both on paper and online (D4.6 Delivery of self-learning modules).

This document is structured into 3 main Sections.

- Section A details the installation process of the relevant IES software.
- Section B outlines the setting up of models, collecting of relevant data, and initial energy simulations for both baseline and comparative theoretical model.
- Section C discusses how to identify relevant buildings and technologies and mentions the integration of RINA-C's PLANHEAT for analysis of the SO WHAT tool for community models.

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Section A Install the SO WHAT software

Below is a sequence of steps to be followed for installing each of the software for SO WHAT purposes. Prior to these steps, the user should have sent an e-mail to info@SO WHATproject.eu asking for the software licences. The user should then have received an e-mail with instructions to follow. This should occur prior to the next steps.

Please make sure you follow every single step as written in the sequence, as missing one will cause some installation problems.

To begin the process of activation of all the licences, please create an account with www.iesve.com.

- Click on login and then – click on here to register. https://www.iesve.com/register
- Enter all required details and create an account. (use the same email address as that to which this email is sent to create the account)

1. Install IES VE

To activate your keys through our new license management system, you will need to be on a machine that has VE (download here) and pointing to the current keys folder location. Then follow the below steps:

- In VE, select Help → Troubleshooting → Set License Folder
- The file path will be displayed. Navigate to that folder and please delete the keys.txt file therein.
- Once deleted, go back to VE 2019, and select Help → Request License
- Complete the form with the Activation Code:
- Select 'Activate'
- Click 'Send Request' and license will be updated within the hour

Once a code has been used it cannot be used again.

If you get an error upon completing the above, please follow these instructions:

- Open VE → Help → request license key
- In tab Action, select "Request free trial" do not send the request
- In the same tab action, select "Activate/Refresh software again
- Send request

Once you have successfully installed VE, please then follow the iCD steps below.

1.1 Additional free training for IES VE

If you would like more training in this, it is suggested that the user watches the free Getting Started with the VE on-demand series here https://distance-learning.iesve.com/p/getting-started. You will need to enrol and/or login to IES Distance learning to access.

You might also find the series of free on-demand ICL (Intelligent Community Lifecycle) Digital Twin courses from the Upskill with IES series useful https://learn-on-demand.iesve.com/courses/category/icl-digital-twin and there are also live online training options with an instructor available here https://www.iesve.com/training/online-training.

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2. Install IES iCD

- Download Sketch Up – 2018 version and above (and below 2022 version for and iCD 2021 version and below). (iCD is a Sketchup plugin)
- Log into https://www.iesve.com/login – please use the same login and password as created above.
- Download latest installer from website - https://www.iesve.com/support/icd/download
- Once you download and install the plugin, then go to Extension s→ IES iCD → Troubleshooting and License → Request License Keys
- Enter all details below, then enter activation code.
- Activation Code – same as the VE code:
- Send request
- A few videos to get you going: https://www.iesve.com/products/icd/trial and https://youtu.be/PQsOGhz6EnU
- Free Training can be found here https://distance-learning.iesve.com/p/getting-started-with-icd. You will need to enrol and/or login to IES Distance learning to access.
- There is also an online User Guide available in the help section of the tool (last icon in iCD toolbar) and an online support section containing lots of getting started resources here https://www.iesve.com/support/icd

If there is an issue with activation email keys@iesve.com and someone from the IES support team will be able to assist. An automatic email with the following message will be sent and someone will return with assistance in time.

"For iSCAN, iVN & iCIM the keys team has not yet given you access to use the software, but they will do so in the next 24 hours. So please follow these steps tomorrow."

2.1 Additional details regarding SketchUp installation

SketchUp can be downloaded from the SketchUp website (https://www.sketchup.com/plans-and-pricing#for-professional). However, please note it requires subscribing for a plan to purchase your own licence. SketchUp Pro is the version is recommended because a desktop version is required to enable an installation and use of the IES iCD Plugin, whereas additional functionalities offered by SketchUp Studio version is not necessary. For example, at IES we avail of a company plan for SketchUp Pro.

The only way to use SketchUp for free is to first apply for a 30-day free trial, so if this is the option you would like to proceed with, you should wait before installing the IES iCD Plugin until when it is necessary to work on software.

3. Install IES iVN

- Download the latest installer from website - https://www.iesve.com/support/ivn/download
- You will need to log in to the website using the same login and password as created above.
- Use your same iesve.com login to sign in to the iVN and start using it.
- A few videos to get you going: https://www.iesve.com/products/ivn/trial and https://www.youtube.com/watch?v=74bH2OBQCr8&feature=youtu.be
- Free Training can be found here https://distance-learning.iesve.com/p/getting-started-with-ivn. You will need to enrol and/or login to IES Distance learning to access.

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- There is also an online User Guide available on the 'start' page in iVN (accessed by clicking the first icon in iVN toolbar) and an online support section containing lots of getting started resources here https://www.iesve.com/support/ivn

Regarding the installation of multiple iVN builds, when necessary, please create a shortcut on your desktop to where IVN is installed e.g., C:\Program Files\IES. When you install an iVN build, then please rename the build accordingly (see screenshot below). As you can see, a user can have at least 10 versions of iVN on their laptop, e.g., iVN 2021_3_0 - 192897 (FB1 - 10122021), i.e., iVN [Version] - [change list number] (branch - date).

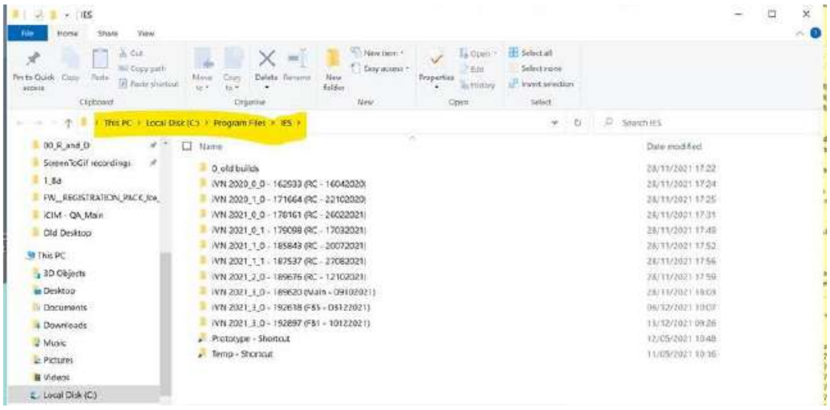

Figure 1 File location for installing IES software.

It is then suggested to save models using the same naming convention, so one can know which build the model was created with, e.g., iVN 2021_3_0 - 192897 (FB1 - 10122021) - [model name] (see screenshot of saved models).

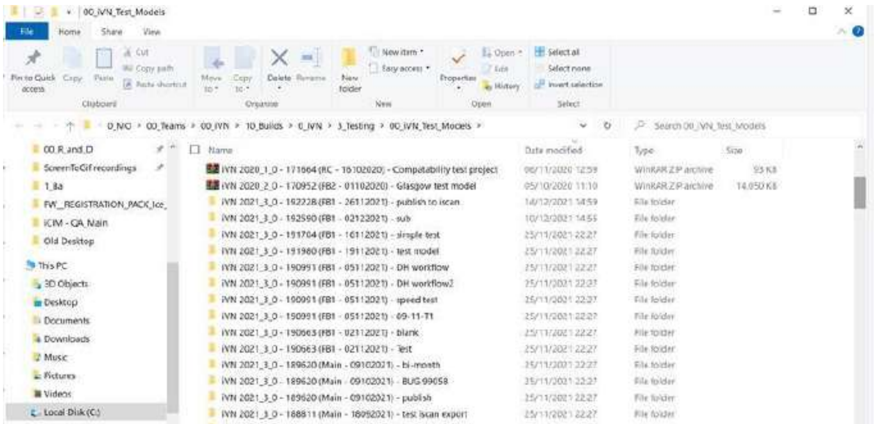

Figure 2 Naming convention advised for model saving.

4. Install IES iSCAN

- Access and sign into iSCAN using your iesve.com username and password (web application https://iscan.iesve.com/).

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- A few videos to get you going: https://www.iesve.com/icl/iscan/trial and https://www.youtube.com/watch?v=34H1dokBlaQ&feature=youtu.be
- Free Training can be found here https://distance-learning.iesve.com/p/iscan. You will need to enrol and/or login to IES Distance learning to access.
- There is also an online support section containing lots of getting started resources here https://www.iesve.com/support/iscan

5. Install IES iCIM

- You can access the trial dashboard through this link - https://icim-trial.iesve.com/icim
- You will need your standard iesve.com login.
- There is also an online support section containing lots of getting started resources here https://www.iesve.com/support/icim

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Section B Waste Heat/Cooling potential for a single industrial/manufacturing site

This section relates to the steps required by the user to collect and organise data that exists for the building(s) and is required to calculate potential waste heat /cooling resources.

1. Identify and collect relevant data

Data is at the basis of an initial identification and assessment of the WH/C resource potential available. To aid the understanding of what data is required and available, the prior completion of a building data checklist should be conducted (see Annex A).

The areas for which information is required are:

- Industrial site information;
- Waste heat/cold recovery & Renewable heat/cold and electricity;
- Industrial site processes information;
- Industrial site services information;
- Automated Meter Reading (AMR) data and energy costs information;
- General building information.

Once the data available has been established, and collected, there are different routes the user should take in order to get to the answer of waste heat/cooling potential, depending on what data they have.

These routes (also known as Data Use Cases) are identified and depending on the type of operational data that can be shared from each facility (i.e. utility bill, partial or detailed sub-metering data, or a combination of these) a generic stepped modelling path is followed towards an initial identification and assessment of their respective WH/C resource potential, as further detailed below, including a brief explanation for each step of the generic modelling path.

For each of the 5 use cases, an associated set of minimum additional information required is defined, as can be seen in Figure 3. Following on from an analysis of completed demo-site data checklists, one of the use cases listed in Figure 3 is identified for each demo site, which allows for assessing whether minimum data requirements are met for an assessment of WH/C resource potential through existing modelling tools, and which provides further details on the subsequent modelling path steps.

Use case no.	Data available	Minimum additional information required
1	Utility bill data only	• Description of processes & services via diagrams or otherwise • Description of inputs & outputs, product flows / temperatures, production calendar • High-level information on daily profiles to inform rough-cut profiles
2	Partial sub-metering only	• Description of processes & services via diagrams or otherwise • Description of inputs & outputs, product flows / temperatures, production calendar • High-level information on daily profiles to inform rough-cut profiles, where required

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Use case no.	Data available	Minimum additional information required
		• Information on what inputs/outputs the sub-metering relates to
3	Utility bill & partial sub-metering	• Description of processes & services via diagrams or otherwise • Description of inputs & outputs, product flows / temperatures, production calendar • High-level information on daily profiles to inform rough-cut profiles • Information on what inputs/outputs the sub-metering relates to
4	Detailed sub-metering time series	• Description of processes & services via diagrams or otherwise • Description of inputs & outputs • Information on what inputs/outputs the sub-metering relates to
5	Utility bill & detailed sub-metering time series	• Description of processes & services via diagrams or otherwise • Description of inputs & outputs • Information on what inputs/outputs the sub-metering relates to

Figure 3 Recommended use case identification matrix.

2. Data formatting, upload to iSCAN, mapping and/or pre-processing

Relevant data is extracted from collected data sources (e.g. energy audit report) and/or data format is adjusted so that it can be integrated into existing SO WHAT modelling tools, in particular for time-series operational data (from utility bills or sub-metering systems).

The data processing platform (iSCAN) requires time series data, but with various formats (e.g., csv) available and a broad range of time resolutions (e.g. from 1 year to 1 minute).

Start Date	End date	Me0	M0	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
2018-01-01	2018-01-31	953221	953221	16827	1618	162773	1387	19926	407	43591	102055	3871	9192	39846
2018-02-01	2018-02-28	829232	829232	11484	1412	111569	1461	18933	465	30035	95017	3704	8642	37513
2018-03-01	2018-03-31	972635	972635	19134	1679	136300	1400	20024	471	50042	105283	4418	11174	30658
2018-04-01	2018-04-30	772062	772062	13254	1419	103981	682	16826	487	34664	84573	4471	9027	16884
2018-05-01	2018-05-31	996217	996217	16449	1516	150913	942	18077	2039	43020	122720	5307	9445	19820
2018-06-01	2018-06-30	1120758	879753	13448	1488	169929	377	18403	4127	35117	101046	4748	7881	20414
2018-07-01	2018-07-31	1426135	996840	41927	1395	208195	436	19986	6832	41927	131632	5328	8646	22210
2018-08-01	2018-08-31	1037283	792013	24347	858	33910	275	18393	6294	24347	115491	3581	7713	19073
2018-09-01	2018-09-30	1462522	1084302	38597	1399	322229	1204	18158	1703	38597	148401	5064	11374	22657
2018-10-01	2018-10-31	1178994	758244	37671	1134	126304	1709	17487	542	37671	121879	4961	13196	26911
2018-11-01	2018-11-30	1126943	773393	44176	1167	189186	742	16908	491	44176	86368	5610	12955	26607
2018-12-01	2018-12-31	881014	595384	32850	809	86017	1154	18388	417	32850	97471	272	12054	24416

Figure 4 Example of time series data in CSV which can be imported into iSCAN.

Formatted time-series operational data is then uploaded to online data visualisation and processing platform (iSCAN).

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To begin go the iSCAN webpage, add your project, and then add buildings within the site. It is important to keep the building names consistent between IES platforms to allow effective data communication and modelling.

After this, project building can have relevant time series data imported and linked to them.

Figure 5 How to begin importing data into iSCAN.

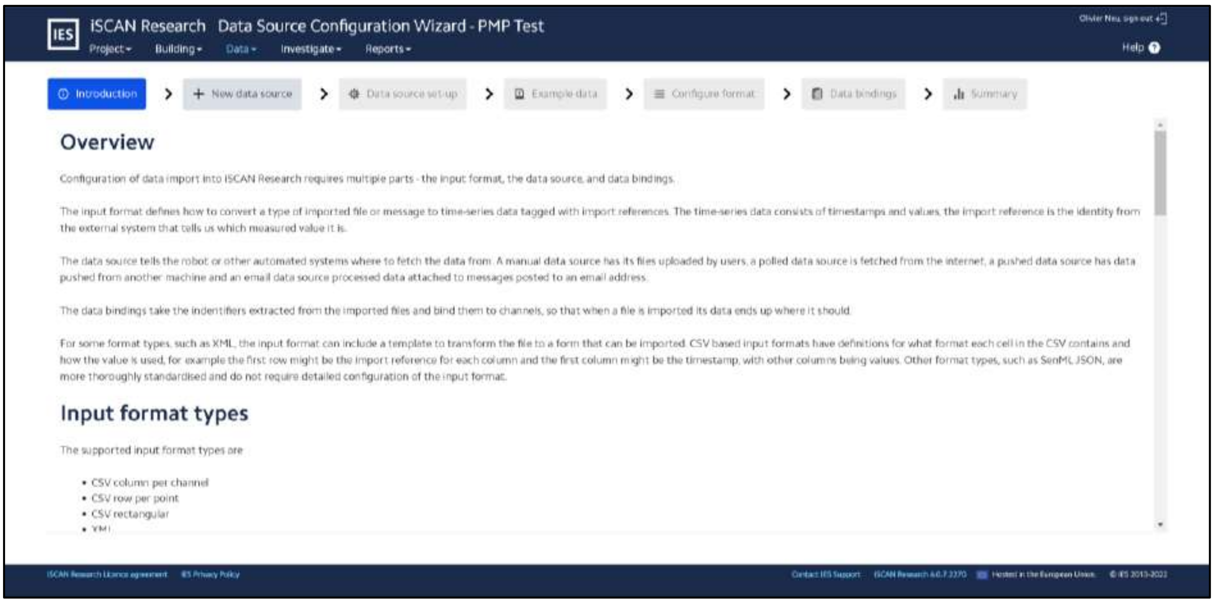

Figure 6 iSCAN data import configuration wizard.

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Uploaded time-series operational data channels are then tagged and mapped across diverse types of energy (e.g., electricity, natural gas, etc.), process, end-use, etc.

Go through the steps of the data source configuration wizard to upload the relevant data profile.

1. Introduction: explains some points such as input format types and how this may relate to the data that is available to upload. Refer back to this page if required.
2. New data source: give the data import a relevant and useful reference name. Select the type of data that is to be uploaded (most BMS and time series data will be CSV – column per channel).
3. Data source set-up: Ensure Keep uploads, Timestamp in input files use local time, and Timestamps use daylight savings (if necessary) are checked while Use time of upload as timestamp for data should remain unchecked.
4. Example Data: Select the data file to be uploaded and click Process file format (this may take some time if the file is large).
5. Configure format: Headers in grey and red, timestamp data is represented in blue, value data in yellow. This shows an example of the data imported where it can be viewed that the example data import was successful and in the correct format. If this needs to be amended it can be done so by selecting the relevant cell and selecting from the drop down list the relevant type. The setting button also gives more insight to different details although this should not need to be used. Click the blue continue button to move to the next page.
6. Data Binding: As this is a new project the data will not have been bound to any previous uploaded data. As shown in the image below simply select the check box by the bindings column header to select all data points and click the Create channel button to assign the default name for each data point (the same name as in the import file header) and click the Save Changes button on the pop up.
7. Summary: Click the Upload files button and from the pop up select the data file for upload then click import data.

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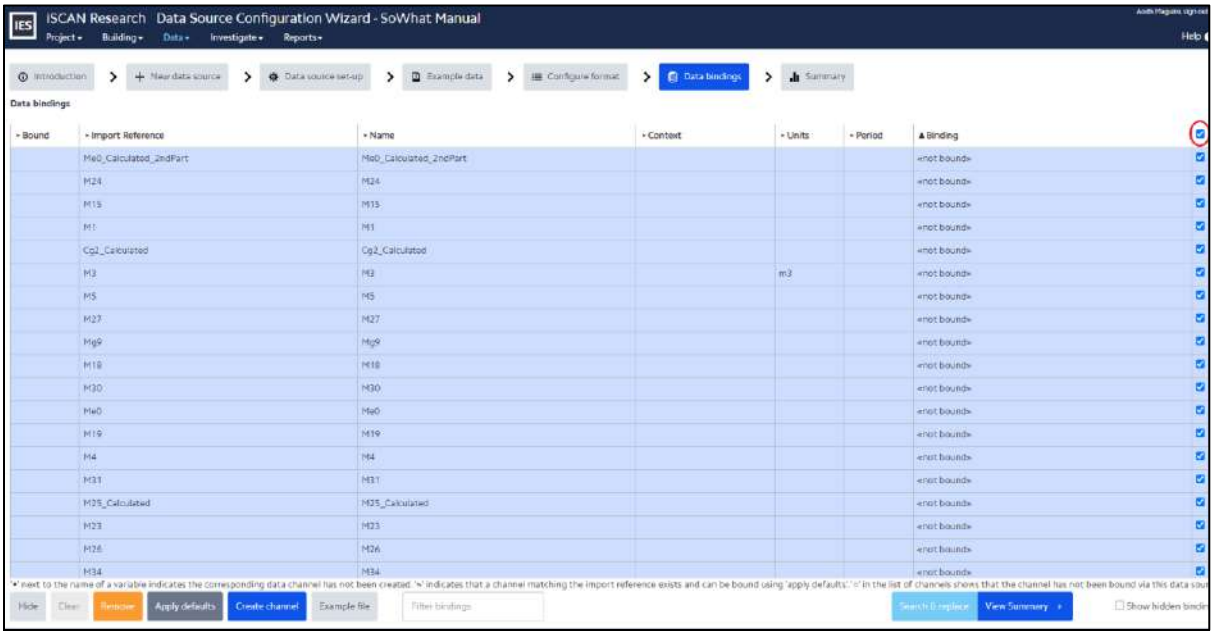

Figure 7 Data binding page within the iSCAN data import wizard.

After these steps your data set should be uploaded successfully. It is best to give a quick review to the data that has been uploaded. Select the investigate drop down and select Visualise where all the data points can be seen under Channels.

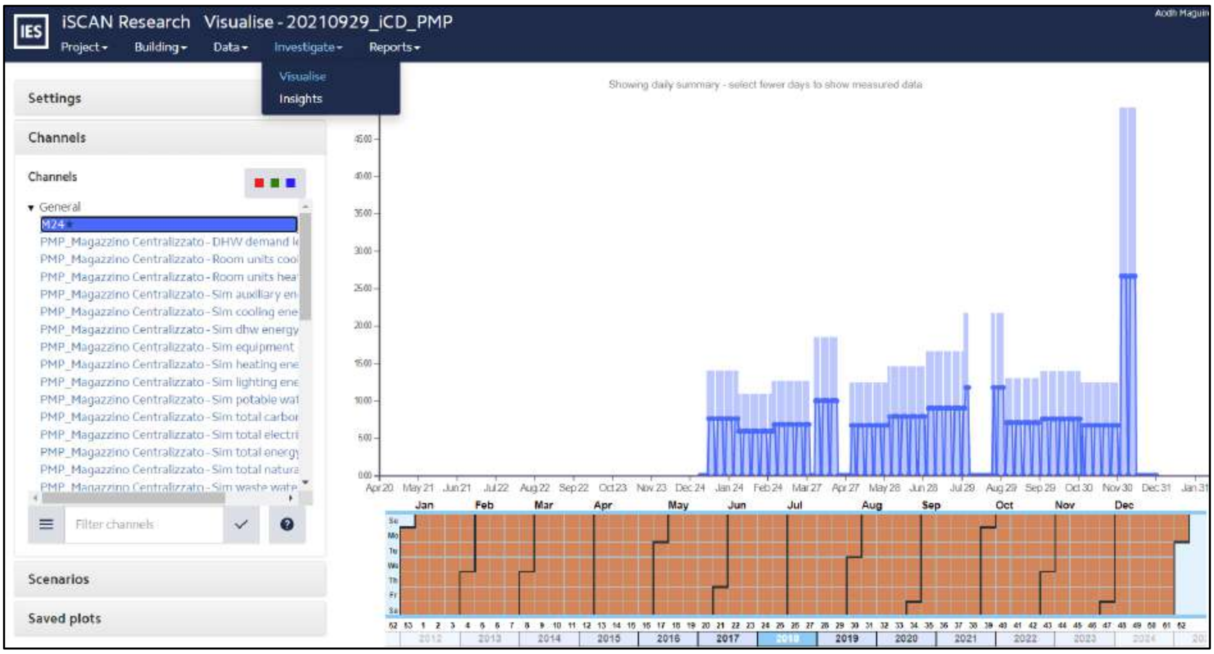

Figure 8 Visualising the data imported to iSCAN.

A small star next to the channel name notes that the units have not been defined for this data point. Select the Data drop down and go to the Channel list to review all the channels (data points) and

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assign relevant information and details to them. It is advised that the Name be changed to a custom name to make this easily recognisable and better describe the channel. Also, the Level and Units boxes should have the relevant information put into them. Once the Units box is filled the star by the channel name will be removed.

The Expression box at the bottom allows mathematical expressions to be written for custom data points (such as adding all electrical meter data to have a singular total electrical usage for the building), the Syntax button will detail various expression that can be written and provide examples of these.

Sample type represents the type of data that has been imported for this specific data channel. For metered data the Metered Value is best suited although the Average type is often appropriate and most flexible for imported data, there is a help ("?") icon which can be clicked and describes the other sample types in detail to allow the most appropriate to be selected. For more information on this the [IES Learning] video under iSCAN → Data Import will provide guidance on the various types and these steps.

In the example below, submeter "Co" logs lighting kW usage in the example building. The name is changed to reflect this and the level is noted as Energy while Power kW has been assigned as the Units. As this is sub-metered data the Metered Value option has been selected as the sample type with an Expected Period of 60 minutes as this is the time samples the metered data has been recorded in (energy readings are recorded hourly for this example data). Sample type of Metered Value will allow iSCAN to calculate the rate of change over the expected period (60 mins).

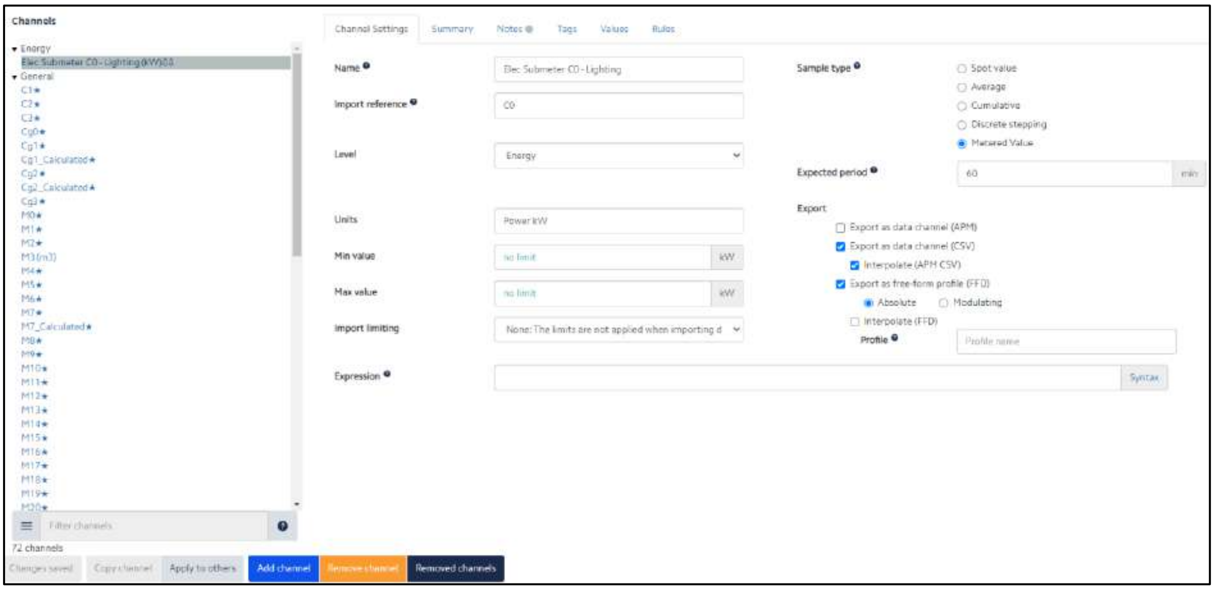

Figure 9 Channel list setting to define specific detials to imported data (meter data in this example).

3. Rough-cut profiling and/or data processing and/or upload to iSCAN

This is applicable for use cases 1, 2 and 3, see Figure 3. Where necessary, rough-cut profiling technique (available through the existing "Utility Bills" module from the IES iSCAN online data collection and processing platform) is used to develop more detailed facility's energy consumption and generation

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profiles (preferably at hourly intervals) from available low-resolution data such as monthly or annual utility bills.

An example of the rough-cut profile creation process is shown below:

Monthly energy consumption or generation data (kWh, as exemplified for sub-meter "M3") converted into energy demand or supply (kW, as exemplified for sub-meter "M3") profiles, with a 1-hour time resolution, for each of the 68 meters and sub-meters available from the demo site data sources. This is achieved by distributing the metered / sub-metered monthly energy consumption / generation (kWh) into their associated load operational schedule, and constrained by their respective rated power (kW), as exemplified for sub-meter "M3" in the figure below.

Figure 10 Rough-cut profiling for the demo-site, energy consumption on a monthly basis.

Figure 11 Rough-cut profiling for the demo-site, energy consumption on an hourly basis.

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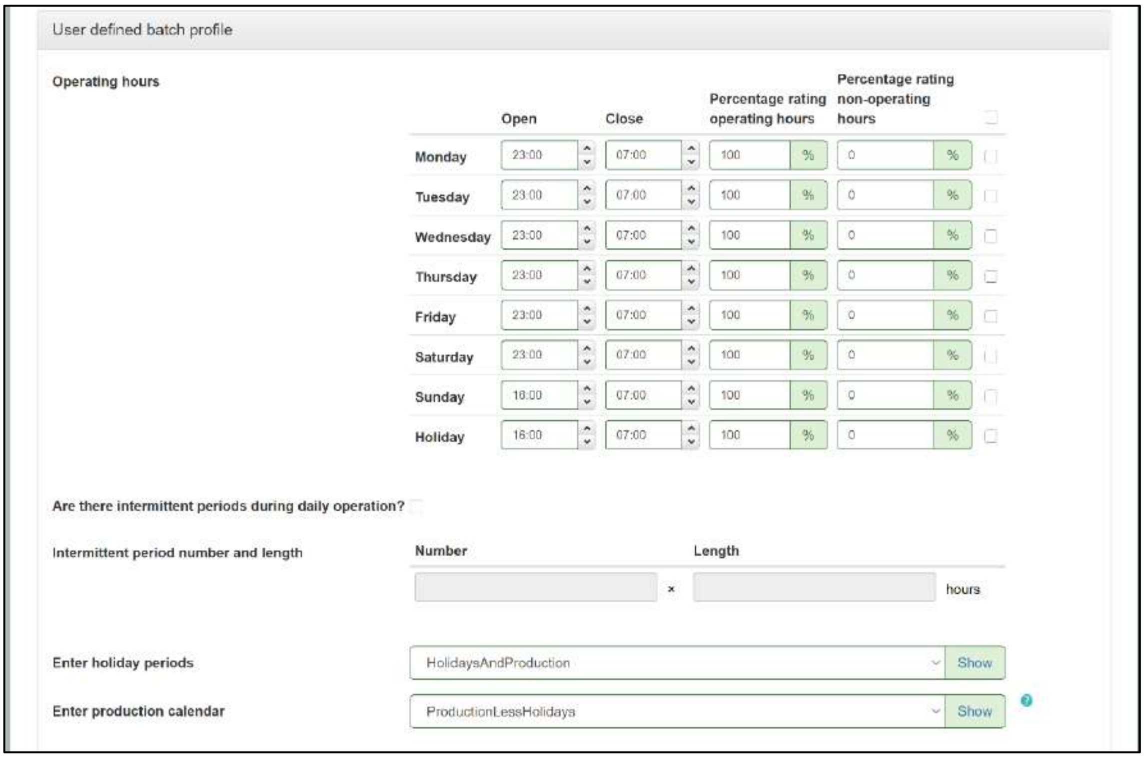

Figure 12 Rough-cut profiling for the demo-site, operational schedule questionnaire.

Subsequent data processing is applicable for all demo sites, but less resource-intensive and more accurate for use cases 4 and 5, Figure 3. Collected and uploaded time series operational data are further processed in to generate energy input and heat output profiles, including waste heat and cold, for industrial processes and process components of interest. This can be achieved offline or directly through the IES iSCAN online data processing platform, by implementing mathematical "Expressions" (i.e., formulas) on the collected data. Such mathematical "Expressions" vary in terms of complexity and are specific to each demo-site, depending on the collected data types and depending on whether "rough-cut" profiling was necessary or not. It should be noted that such a step might even be bypassed in cases where collected data already include all the process energy input and output profiles, including waste heat and cold, which are necessary for the development of an Energy Sankey diagram. On the opposite, such a step might be quite resource-intensive by requiring the use of external databases, in addition to the data available from a demo site, such as thermophysical properties of common energy conveyor mediums (e.g., air, steam, water, gases, etc.).

4. Produce results and visualisation for potential Waste Heat/Cooling

This is relevant to the 5 use cases that are detailed in Figure 3. Subsequent to data rough-cut profiling and processing that enabled to generate energy input and output profiles for industrial processes and process components of interest, including waste heat and cold, there are two ways to visualise an overall industrial site waste heat and cold resource.

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On the one hand, this can be achieved directly through the IES iSCAN online data processing platform, by implementing mathematical "Expressions" (i.e., formulas) in order to aggregate the pre-processed energy input and heat output profiles, including waste heat and cold, for industrial processes and process components of interest, at a whole site level and with a 1-hour time resolution. An example of such a waste heat/cold resource profile visualisation can be seen in Figure 13 below.

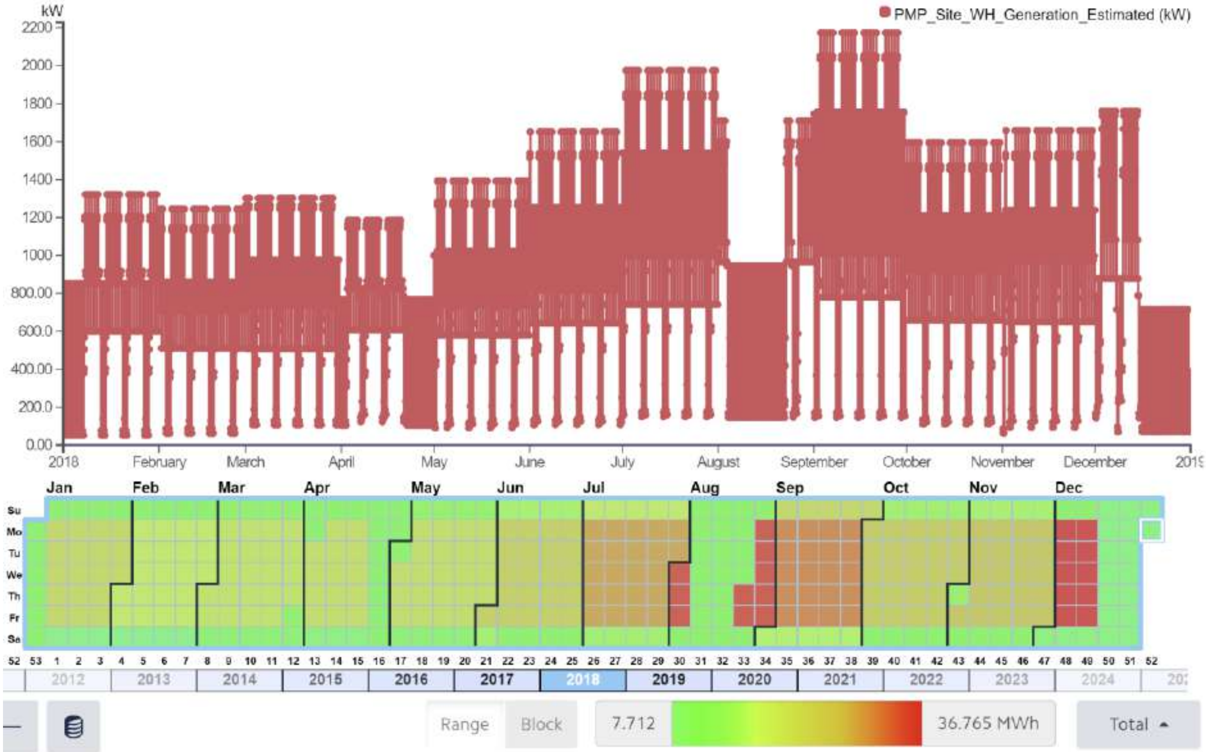

Figure 13 Example of demo-site aggregated waste heat resource profile, with a 1-hour time resolution (iSCAN)

On the other hand, this can be achieved through the development of an Energy Sankey diagram. To do so, a building energy simulation model of the facility (construction and HVAC systems, if necessary) needs to be created first through the IES VE detailed building energy modelling and simulation platform, where a sufficient level of general building information was previously collected from industrial demo sites, as based upon the prior completion of a building data checklist (see Annex A). Alternatively, a simplified standard building model can be used instead, with adjustments possible, in particular for weather conditions, as illustrated in the Figure 14 below. Then, process models of the internal manufacturing lines of interest, at a process or component scale, can be created. However it should be noted that processes are not modelled as physics-based models, but rather as data-based models represented by a single or a series of components. Furthermore, the visual representation of these components can be adjusted or designed from scratch, but here simply represented by a box for each process considered, as exemplified in Figure 15 below. Subsequently, Creation and population of process databases, in particular energy inputs and heat outputs (including waste heat) time series operational data. Once processes are modelled by one or a series of components, energy input and output profiles that were previously processed in iSCAN can be associated with relevant components, as well energy inputs from building model HVAC systems

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(including RES systems), if these are modelled, as exemplified in Figure 16 for a SO WHAT project demo site. Annual building energy simulation is then performed through the VE and existing tool scripts are used for visualisation of process energy flows through an Energy Sankey diagram, as illustrated in Figure 17 below for a SO WHAT project demo site. In particular, the Energy Sankey diagram considers the energy and heat/cooling flows in the factory and is created around several column headings. Each heading represents a column of nodes which are built up from the model data the user has entered in the manufacturing view. Each heading relates to the following elements within the manufacturing view: Source (i.e. Fuels), HVAC Plant Convertors (i.e. IES VE Apache Systems), System Load (i.e. Load developed on the systems), Use/Demand Sinks (i.e. Component variables), Process Converters (i.e. Components), Sinks (i.e. Products & Waste heat removal).

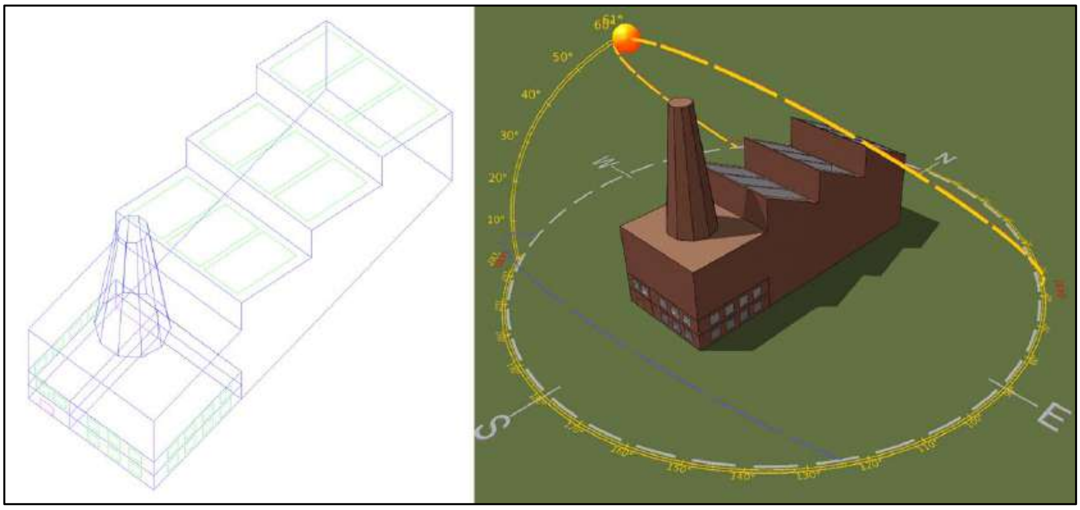

Figure 14 Simplified standard demo-site building model

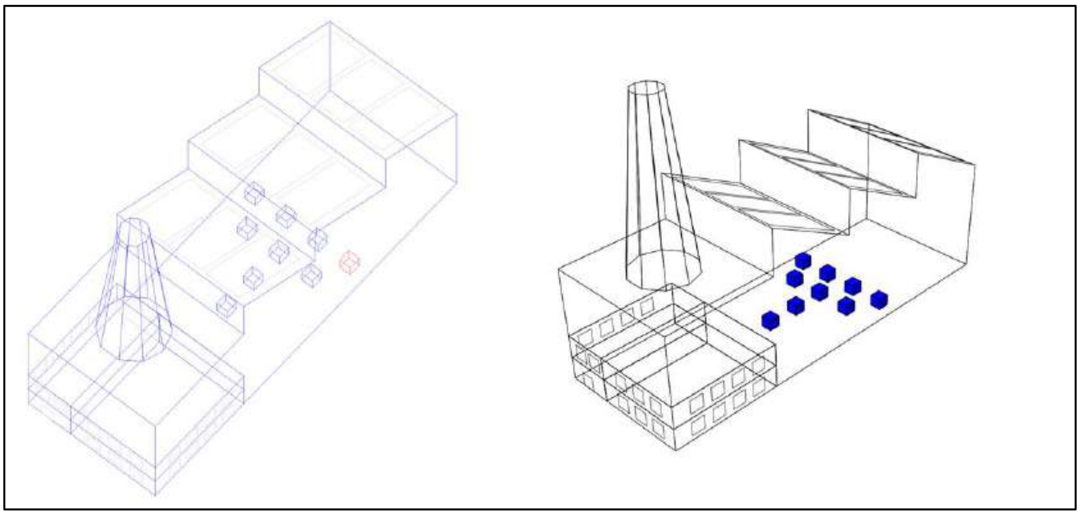

Figure 15 Example of demo-site process component model

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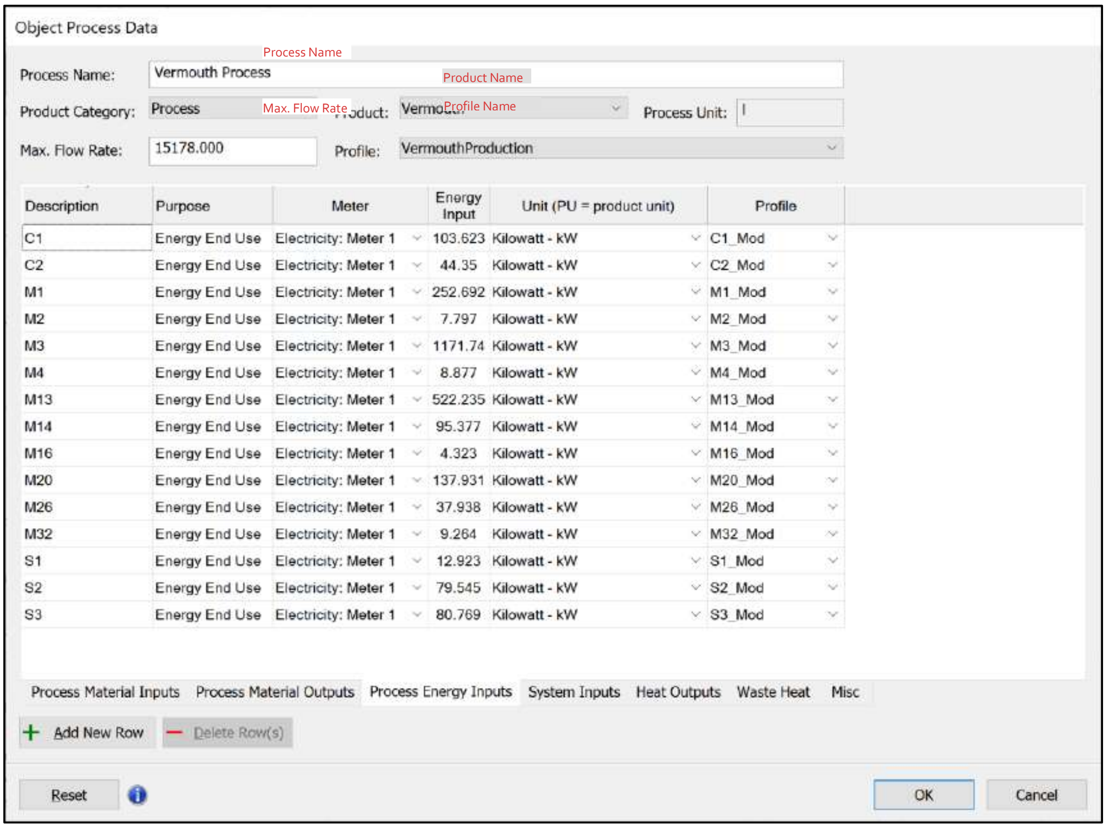
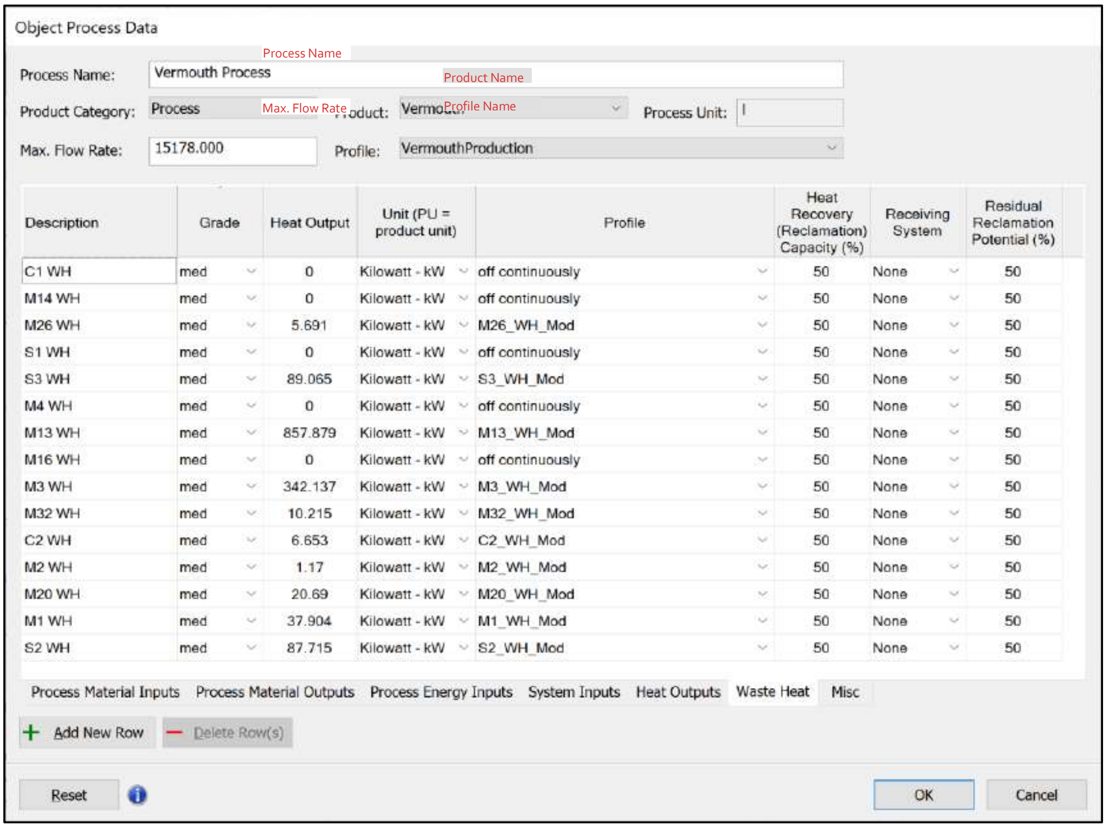


Object Process Data

Process Name: Vermouth Process
Product Category: Process   Product: Vermo...   Process Unit: l
Max. Flow Rate: 15178.000   Profile: VermouthProduction

Description	Purpose	Meter	Energy Input	Unit (PU = product unit)	Profile
C1	Energy End Use	Electricity: Meter 1	103.623	Kilowatt - kW	C1_Mod
C2	Energy End Use	Electricity: Meter 1	44.35	Kilowatt - kW	C2_Mod
M1	Energy End Use	Electricity: Meter 1	252.692	Kilowatt - kW	M1_Mod
M2	Energy End Use	Electricity: Meter 1	7.797	Kilowatt - kW	M2_Mod
M3	Energy End Use	Electricity: Meter 1	1171.74	Kilowatt - kW	M3_Mod
M4	Energy End Use	Electricity: Meter 1	8.877	Kilowatt - kW	M4_Mod
M13	Energy End Use	Electricity: Meter 1	522.235	Kilowatt - kW	M13_Mod
M14	Energy End Use	Electricity: Meter 1	95.377	Kilowatt - kW	M14_Mod
M16	Energy End Use	Electricity: Meter 1	4.323	Kilowatt - kW	M16_Mod
M20	Energy End Use	Electricity: Meter 1	137.931	Kilowatt - kW	M20_Mod
M26	Energy End Use	Electricity: Meter 1	37.938	Kilowatt - kW	M26_Mod
M32	Energy End Use	Electricity: Meter 1	9.264	Kilowatt - kW	M32_Mod
S1	Energy End Use	Electricity: Meter 1	12.923	Kilowatt - kW	S1_Mod
S2	Energy End Use	Electricity: Meter 1	79.545	Kilowatt - kW	S2_Mod
S3	Energy End Use	Electricity: Meter 1	80.769	Kilowatt - kW	S3_Mod



Object Process Data

Process Name: Vermouth Process
Product Category: Process   Product: Vermo...   Process Unit: l
Max. Flow Rate: 15178.000   Profile: VermouthProduction

Description	Grade	Heat Output	Unit (PU = product unit)	Profile	Heat Recovery (Reclamation) Capacity (%)	Receiving System	Residual Reclamation Potential (%)
C1 WH	med	0	Kilowatt - kW	off continuously	50	None	50
M14 WH	med	0	Kilowatt - kW	off continuously	50	None	50
M26 WH	med	5.691	Kilowatt - kW	M26_WH_Mod	50	None	50
S1 WH	med	0	Kilowatt - kW	off continuously	50	None	50
S3 WH	med	89.065	Kilowatt - kW	S3_WH_Mod	50	None	50
M4 WH	med	0	Kilowatt - kW	off continuously	50	None	50
M13 WH	med	857.879	Kilowatt - kW	M13_WH_Mod	50	None	50
M16 WH	med	0	Kilowatt - kW	off continuously	50	None	50
M3 WH	med	342.137	Kilowatt - kW	M3_WH_Mod	50	None	50
M32 WH	med	10.215	Kilowatt - kW	M32_WH_Mod	50	None	50
C2 WH	med	6.653	Kilowatt - kW	C2_WH_Mod	50	None	50
M2 WH	med	1.17	Kilowatt - kW	M2_WH_Mod	50	None	50
M20 WH	med	20.69	Kilowatt - kW	M20_WH_Mod	50	None	50
M1 WH	med	37.904	Kilowatt - kW	M1_WH_Mod	50	None	50
S2 WH	med	87.715	Kilowatt - kW	S2_WH_Mod	50	None	50

Figure 16 Data syncing of process energy inputs (on top) and process waste heat energy output (at the bottom)

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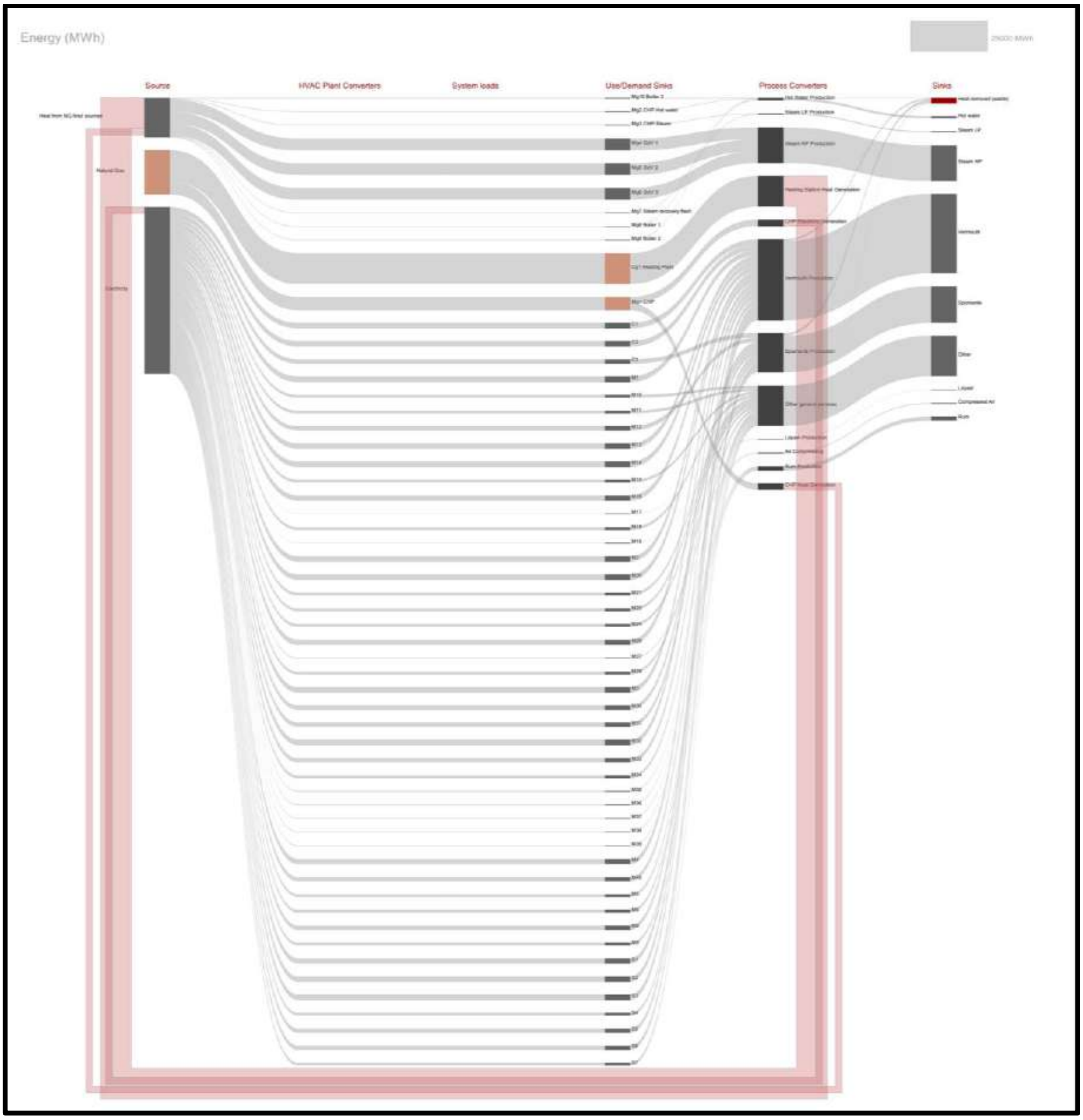

Figure 17 Example Energy Sankey diagram for a SO WHAT project demo site

5. Set up and simulation of Waste Heat/Cooling recovery and exploitation technologies for use in industrial facility

Once the potential waste heat in the industrial facility is known, and the user has a good idea of which technology they wish to simulate, a baseline model of the site's energy demand and carbon emissions is required in order to allow the simulation to give valid results.

5.1 Set up baseline model of industrial site

A baseline model is fundamental to understand the current energy demand and carbon emissions of the block under assessment and to assist in the potential for any waste heat or cooling recovery for use internally and within the community.

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First, a 3D model of the block under assessment needs to be created. The iCD tool allows several file formats to be imported, including Shapefiles and GeoJSON files. If the geometries of the buildings in the block are available into any of those formats, you can import them as shown below.

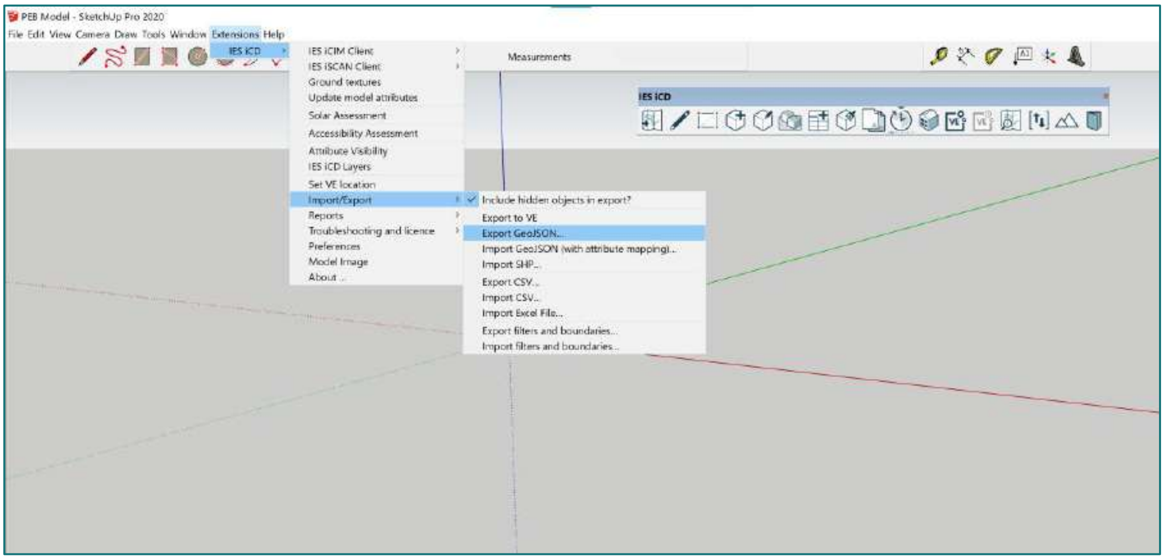

Figure 18 Shapefile and GeoJSON file import.

If those formats are not available, which is often the case, the iCD gives the user the possibility to import buildings from Open Street Map (OSM). The OSM database can contain higher or lower level of detail depending on the site location, but it normally gives a good basis upon which building the initial model. Click on the *OSM import* button and import the area needed for the project.

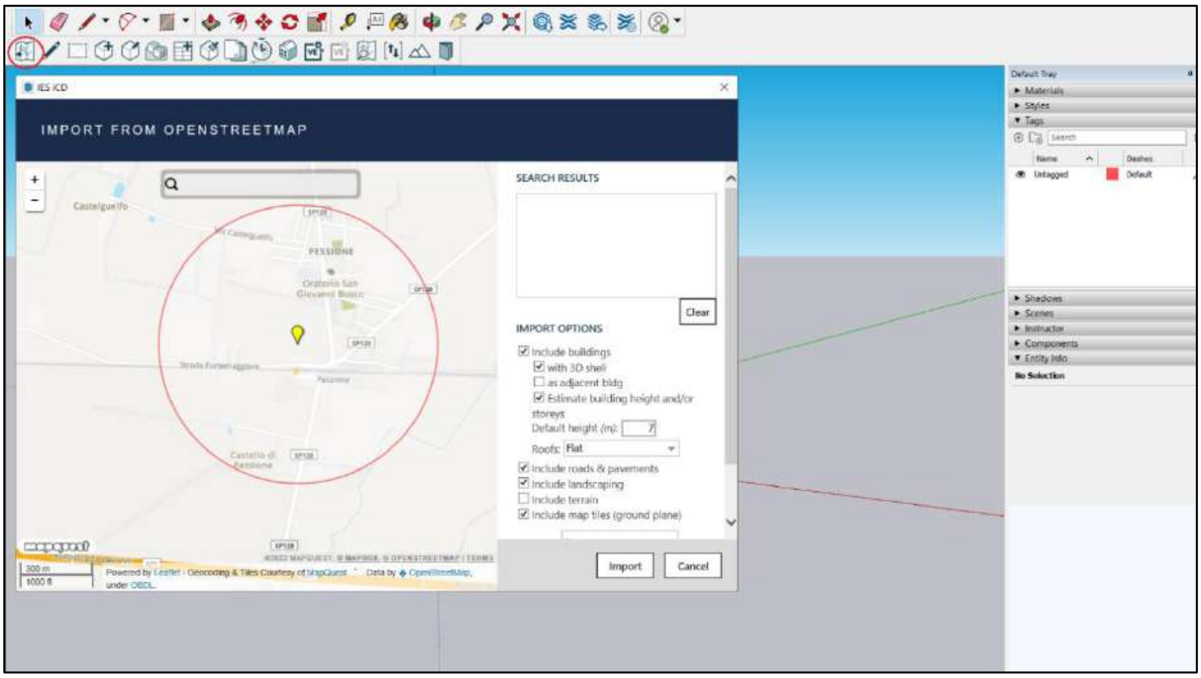

Figure 19 Importing from OSM to iCD.

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Once the import from OSM is complete, the buildings will appear within the model as well as the map tiles and roads, if selected during the import process. At this point, the user needs to start addressing the building geometries within SketchUp/iCD model. Where OSM does not have a certain info (e.g. number of storeys of a building), a default building height will be assigned instead. The same for glazing ratios, roof types and more. For such reason, it is fundamental that the user addresses each building and manually modifies each parameter that seems to be inaccurate, based on the information they are able to collect.

With a baseline model in place the user needs to ensure the building geometries are correct. Where there hasn't been certain info provided (e.g. number of storeys of a building), a default building height will be assigned instead. The same for glazing ratios, roof types and more. For such reason, it is fundamental that the user addresses each building and manually modifies each parameter that seems to be inaccurate, based on the information they are able to collect.

In order to do so, click on a building and open the object parameters. Every attribute of the building can be changed manually. You should aim to reach the most accurate level of detail you can possibly reach, in order for your baseline to be a realistic representation of the actual block.

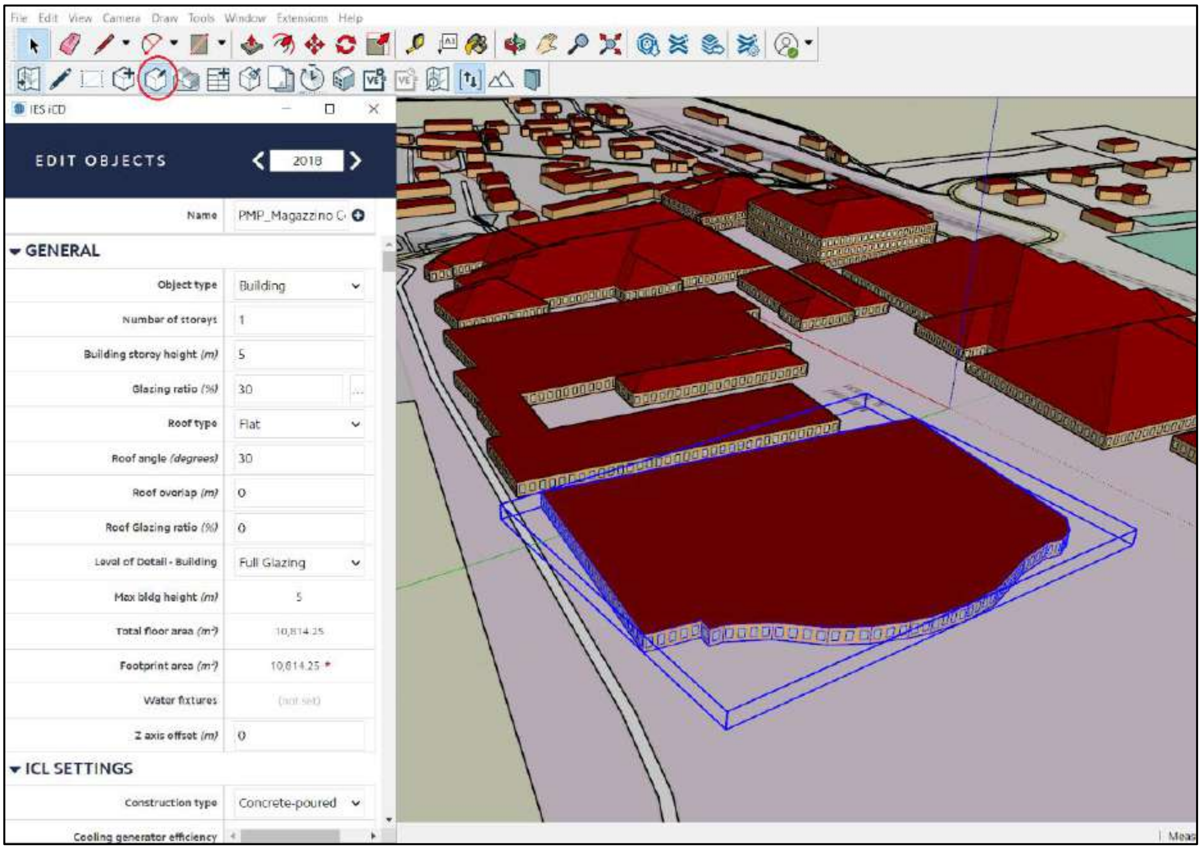

Figure 20 Editing building details in iCD.

Once enough input data has been assigned to the model to represent as close as possible the real set of buildings, it is time to run energy simulations in order to get demand profiles of the buildings and have an estimation on their energy and carbon footprints.

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Before simulating, it is important to link the iCD to a project in iSCAN. This will allow the user to export simulated data into the iSCAN platform for each building straight after an energy simulation has been carried out. To link the iCD to iSCAN, first login into iSCAN and create a new project. Give it a name, and add any additional user that might need to collaborate on the same project from the 'Project users' page.

The newly created project now needs to be connected to the iCD in order for data to be streaming from one tool to the other. To do so, from the iCD go into Extensions → IES iCD → IES iSCAN Client → Setup Endpoints and Token. Here, add the scan project url and token, then click on Save. Note that the url and token can be retrieved from iSCAN within the 'API tokens' page of your new project. If there are no tokens created yet, you can create a new one by clicking on 'Create token', and then copy that into the iCD. Make sure to select the 'maintainer role' when creating the token.

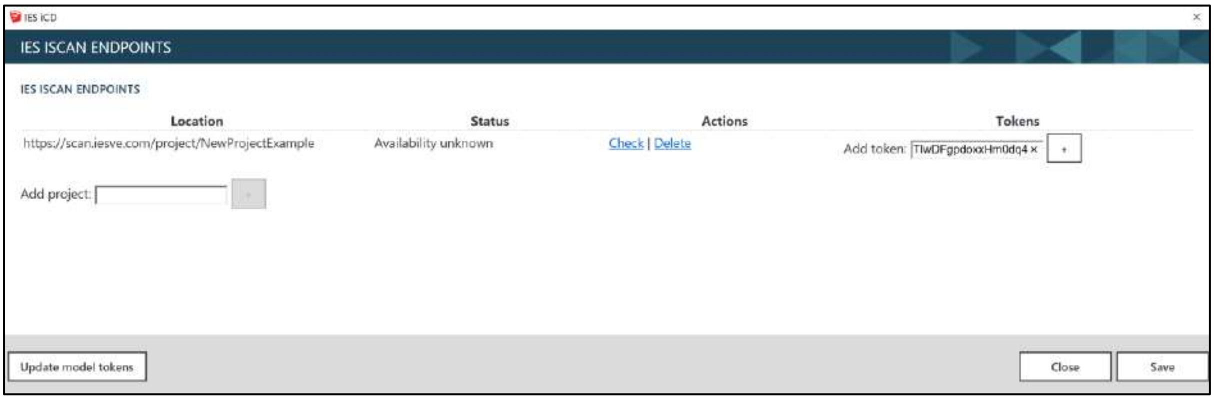

Figure 21 iCD connection to iSCAN.

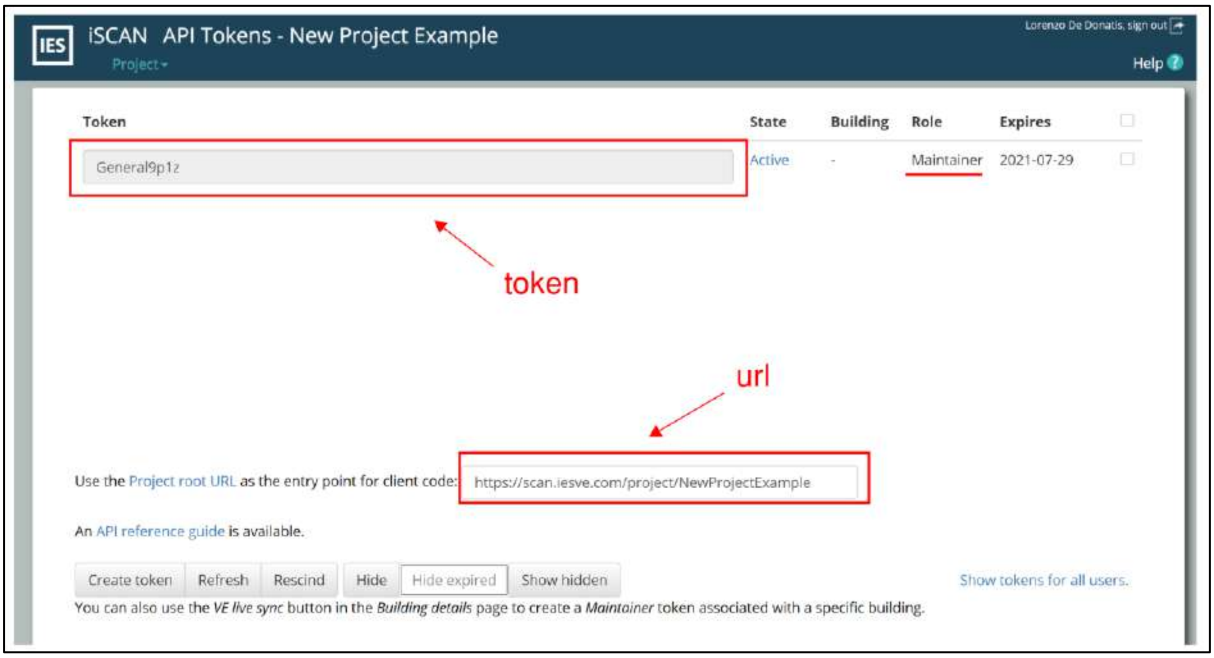

Figure 22 iSCAN Project token and url.

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Before running energy simulations, give a specific name to the buildings in the block. As noted previously it is important to keep the same building names across platforms and models to allow for seamless integration of the models and data. This will help recognising the demand profiles of each building once they will be exported into iSCAN.

Also, it is important to set the CO2 emission factors and costs according to the specific country in which your model is located. To do so, go into Extensions → IES iCD → Preferences and set tariffs and emissions according to your knowledge. If not known, you can leave them by default as per UK dataset.

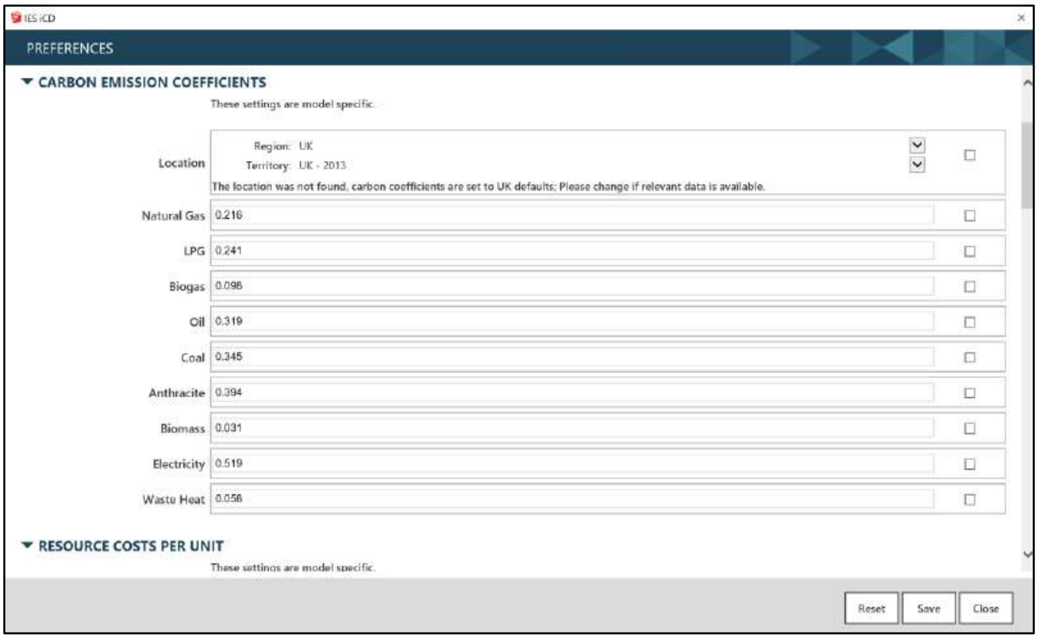

Figure 23 Carbon emission factors and Tariffs.

It is now all set to start running energy simulations from the iCD tool. In order to do so, select one or multiple buildings and click on the VE simulation button within the iCD toolbar, select your simulation preferences, hit 'update' then 'Launch'. Remember to tick the 'Export' button if you wish to push the time series demands into iSCAN. You will also need to select the iSCAN project to which you want to send results to, from the dropdown menu.

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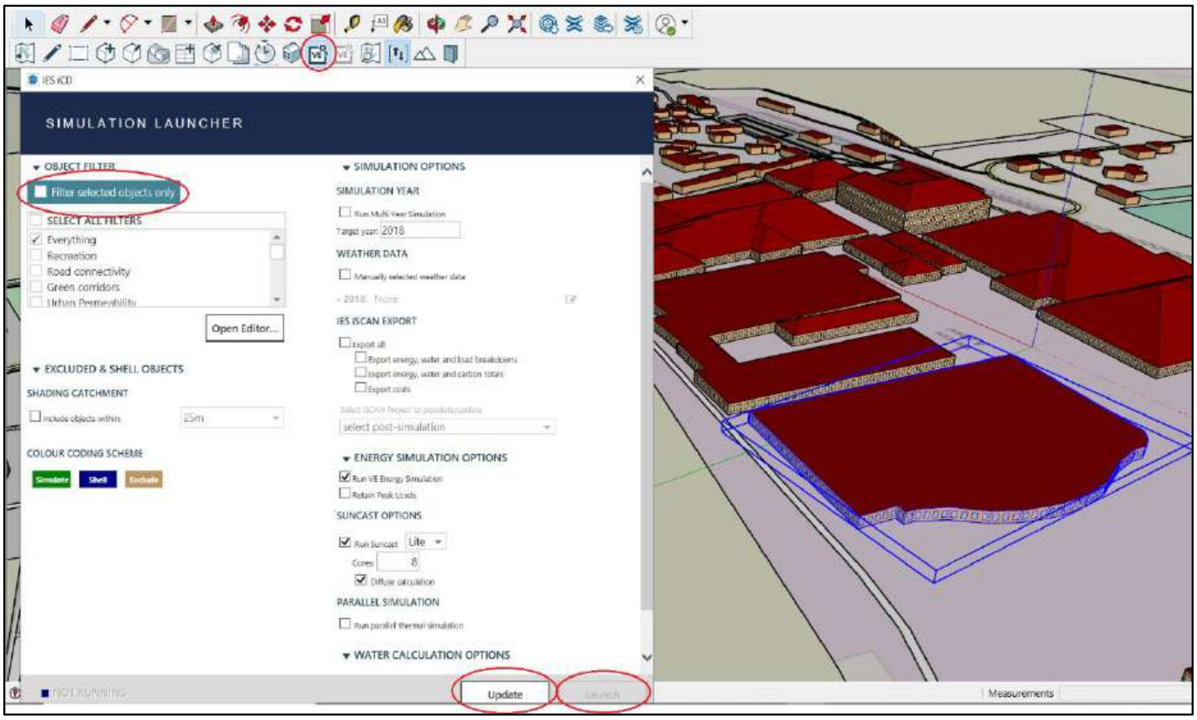

Figure 24 Running basic energy simulations in iCD.

If the simulation has not already exported the results to iSCAN the below option should appear after the simulation and the project and endpoints can be selected if an error has occurred.

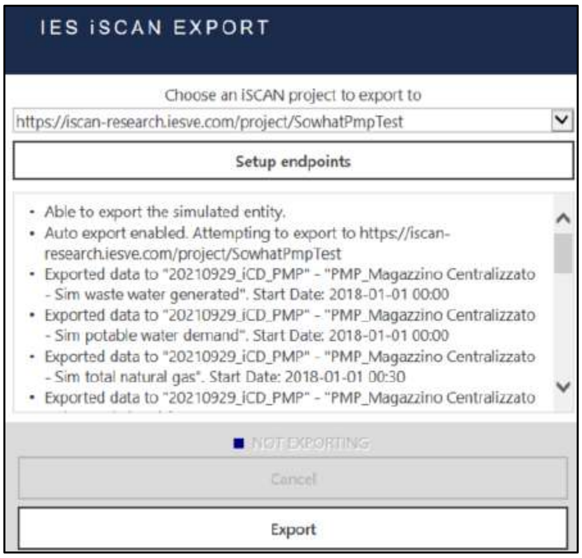

Figure 25 Exporting iCD simulated results to iSCAN.

Once the energy simulation has finished running for your building (or set of buildings), you will see results being exported into iSCAN. At the end of the process, a new building will be created into the iSCAN project, with the same name of your iCD project, as seen in Figure 26. Within that building, all

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relevant time series channels will be created, with a clear naming formed by the name of the specific building and the name of the variable. Summary values of energy demand data will also be shown within the iCD, into the building properties.

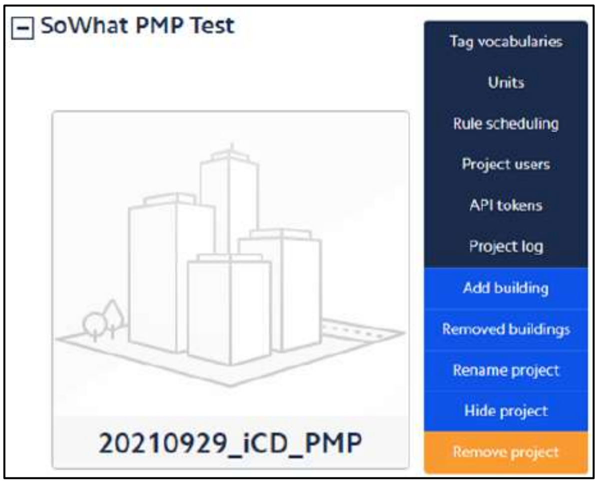

Figure 26 iSCAN project homepage.

In iSCAN, use the "Investigate" tab to review the data over a time series that has been simulated for this building.

Figure 27 Visualising exported iCD simulation results in iSCAN

Basic energy simulation results can also be reviewed in iCD after the energy simulation has been completed. While the desired building is selected click the Room/Building Query button and scroll to the Simulation Results section.

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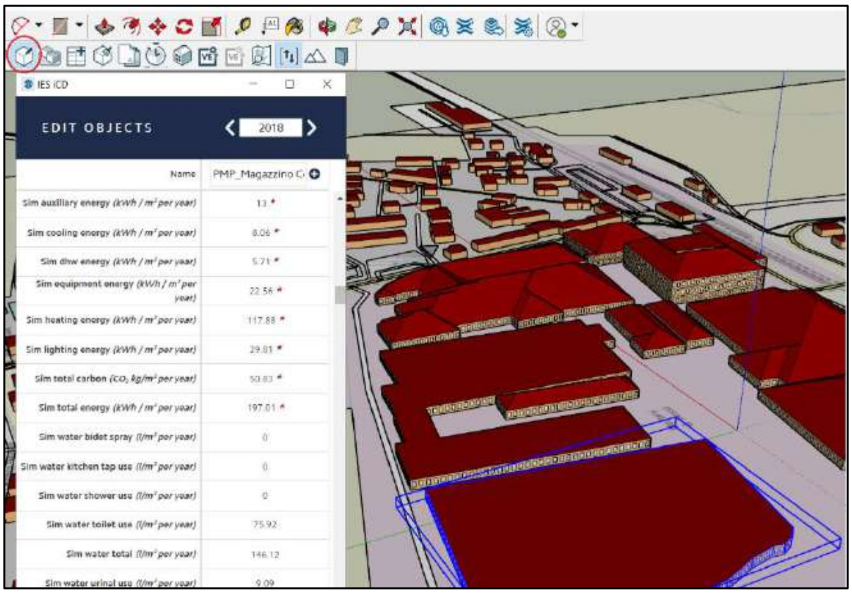

Figure 28 Reviewing the simulated energy totals within the iCD building viewer.

A report for all the buildings that have been simulated can also be reviewed by going into Extensions → Reports → Energy Reports → Full Energy Reports. To note this is a model level report rather than a building level report. Other reports can also be reviewed in this section that may be of interest.

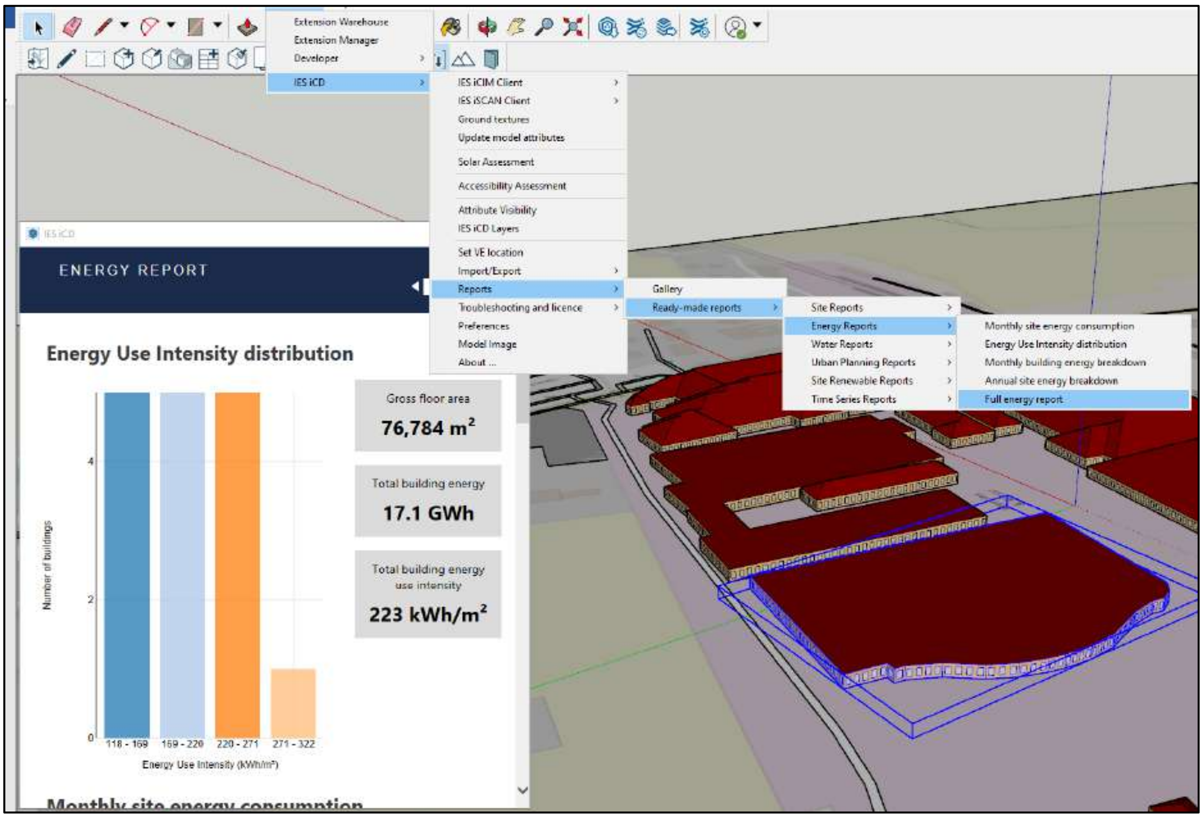

Figure 29 Full energy report from the iCD simulation.

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5.2 Export data from iSCAN to iCD

Section B.2 details how meter data can be uploaded to iSCAN. After meter data has been uploaded and connected to iSCAN the exporting of this data to the iCD model will allow for analysis in iCD and greater model accuracy and detail.

Tags made in iSCAN for relevant buildings in iCD must have the same name between the 2 platforms. Ensure that either the iCD model has the same buildings name as detailed in iSCAN or the reverse of this.

In iSCAN select the Tag vocabularies option in the project menu page. On the next page click the Create Tag Vocabulary at the bottom left of the page.

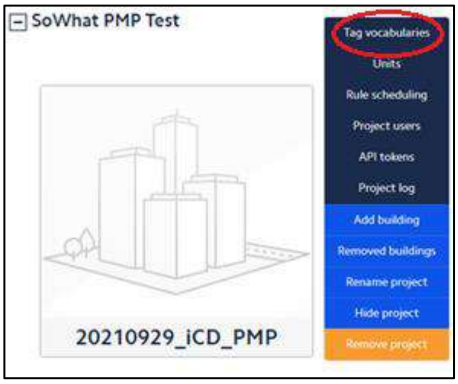

Figure 30 Setting up tag vocabularies in iSCAN to link data to relevant buildings.

Two Tag Vocabularies will need to be made. The first under Building Names and the second under Variables. Building Names will contain a list of the building names for this project. The Variables will contain the metered data for the buildings and site. Using both of these identifiers it will be possible to assign metered data to the relevant building in the iCD model. To note, the tags in the Building Names Vocabulary must be the same as the building names in the iCD model.

Select the Buildings tag you have created and select Create Tag in the bottom left of the page. Now enter a building name for one that is in your project site. Repeat this step for all building you intend to model in your project. Once done this will similarly be repeated in the Variables Tag Vocabulary you have created. For this example, Metered Lighting will be imported (as shown in section TO1.2), although this will need to be repeated for other data that is to be exported.

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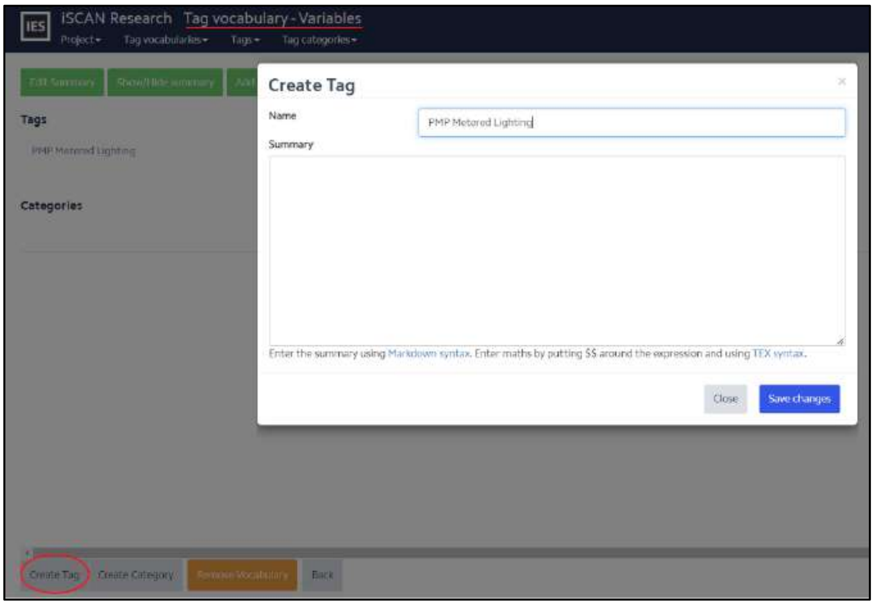

Figure 31 iSCAN tag creation.

It is now necessary to return to the project list page, select the project, and then the Channels List under the Data drop down to return to our metered data that has been imported to iSCAN. Select the data point within the Channel List (in this example it is the Electrical Submeter Co – Lighting) and select the Tags option. Within this page select Add Tag and add the building and then variable that were previously created in Tag Vocabularies.

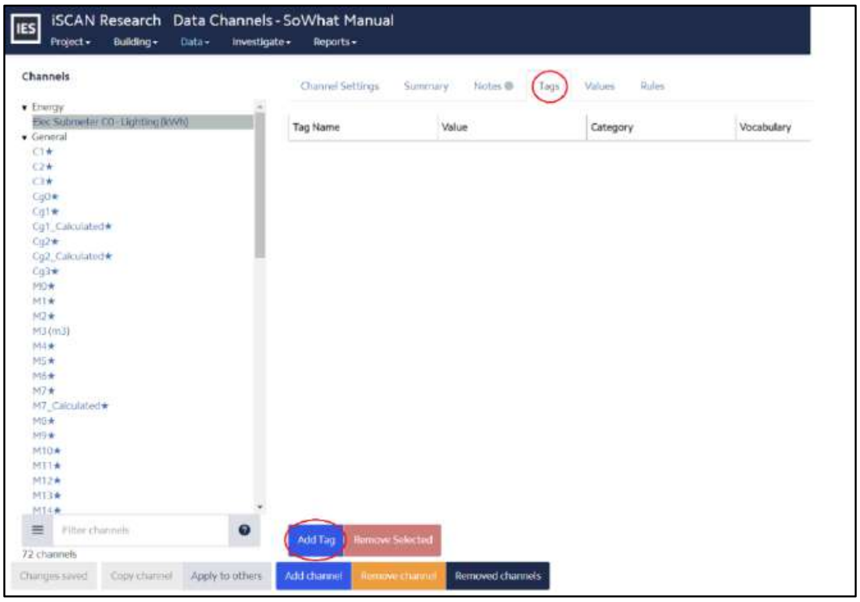

Figure 32 Assigning variable and building tags to relevant data in the iSACN channel list.

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The iCD model building and the iSCAN data now need to be linked if this has not already been done. Return to the Projects List page and select the API Tokens button. Here a token should be created under the Maintainer role.

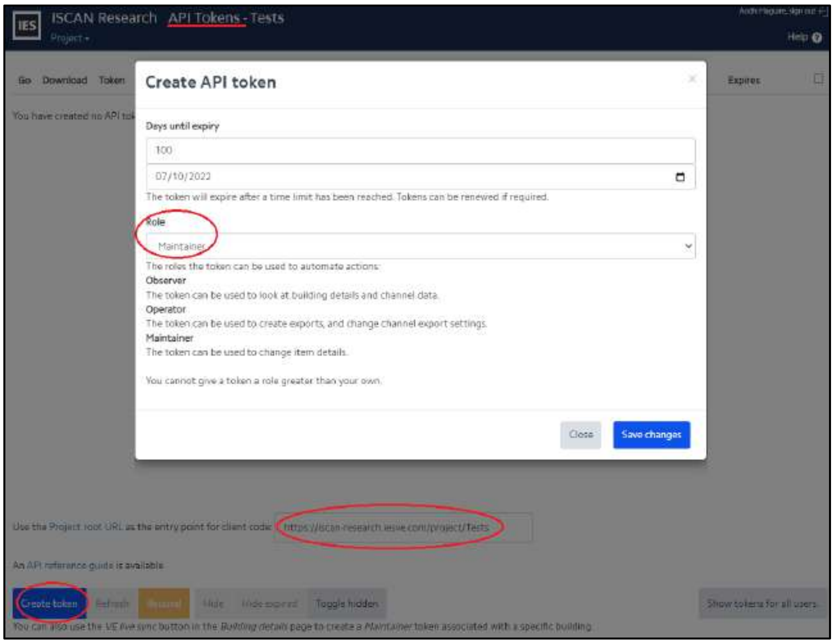

Figure 33 Creating tokens in iSCAN to link the iSCAN data to the iCD model.

Return to the iCD model and select Extensions→IES iSCAN Client→ Setupn Endpoints and Tokens. Paste the URL from iSCAN into the Add project box and copy the iSCAN token into the Add token box.

Now it is possible to link the tags made in iSCAN to the iCD model. Click Extensions→IES iSCAN Client→Channel Associations. The IES iSCAN Channels box will pop up, select the Match button and then select Save. To view the results and that the import has been done correctly, in iCD select the relevant building, click the Room/Building Query button and scroll to the User Defined section and find the relevant meter data variable that has been imported.

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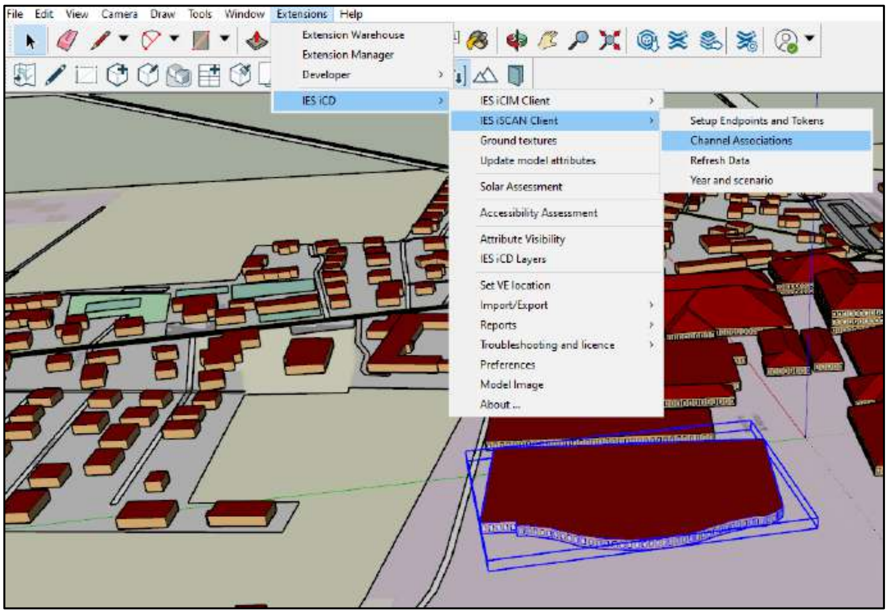

Figure 34 Linking the iCD model to iSCAN.

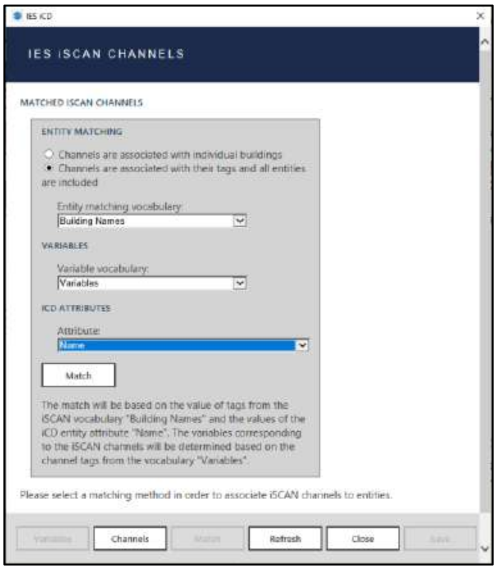

Figure 35 Matching the correct iSCAN channels to iCD.

5.3 Synchronisation of iCD data with iCIM model

In order to use the Network tool, we need to bring a copy of our iCD model onto the iVN model. This cannot be done through a simple export/import but needs to be done by first exporting the iCD model onto the cloud.

To do so, from the iCD toolbar, click on the 'Synchronise' button, add the iCIM url as a new endpoint, and then add a new project, as seen in Figure 36 and Figure 37 below. Enter a project name and description (optional), and click on 'Create' to synchronise your model to the cloud. This will create a

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new project on the iCIM, permanently linked to your desktop version of the model. From this point on, any change made to the iCD model can be sent to the cloud model by simply clicking again on the synchronise button and send the changes. This is also useful when multiple users are working on a single model, so that they can send/download changes to the cloud to always work on the most updated model.

In order to enable a successful iCD/iCIM synchronisation, all the landscaping objects (Water bodies, Soft Landscape, Hard Landscape), in particular the largest water body object, should be removed from the iCD model. Although these objects can be included into an iCD model prior to be synchronised with an iCIM model, the large size of some of these objects (e.g. water body objects) may create a size issue when synchronising with iCIM.

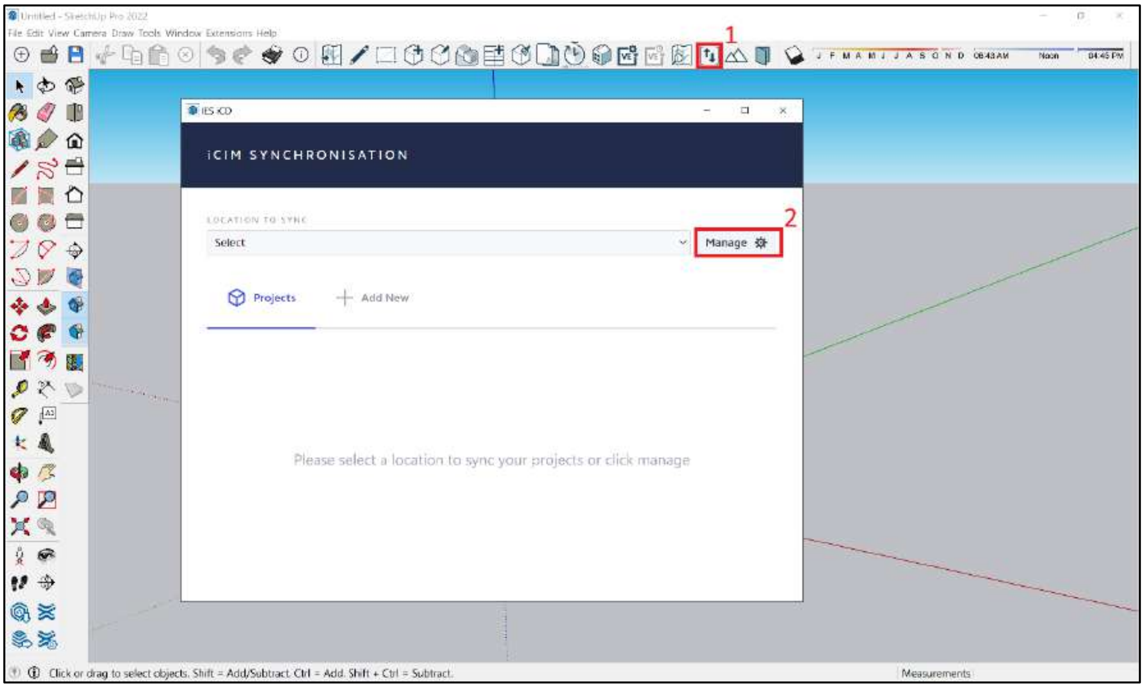

Figure 36 Synching the iCD model to iCIM.

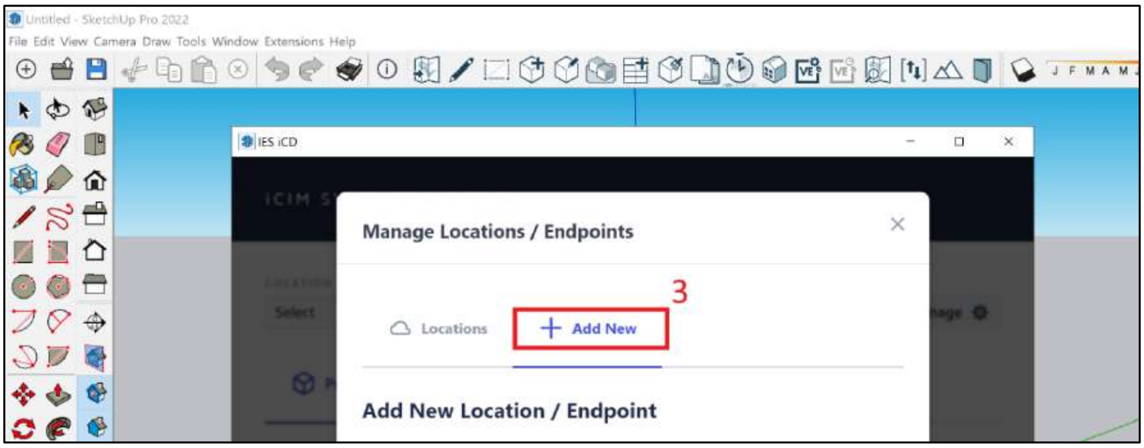

Figure 37 Setting up the endpoints between iCIM and iCD to link them.

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With regards the iCIM url endpoint, it should be noted that enabling of dangerous operations is not necessary, and the following iCIM Trial endpoint should be setup (https://icim.iesve.com/trial/cim or https://icim.iesve.com/trial/gfc), as per Figure 38 below.

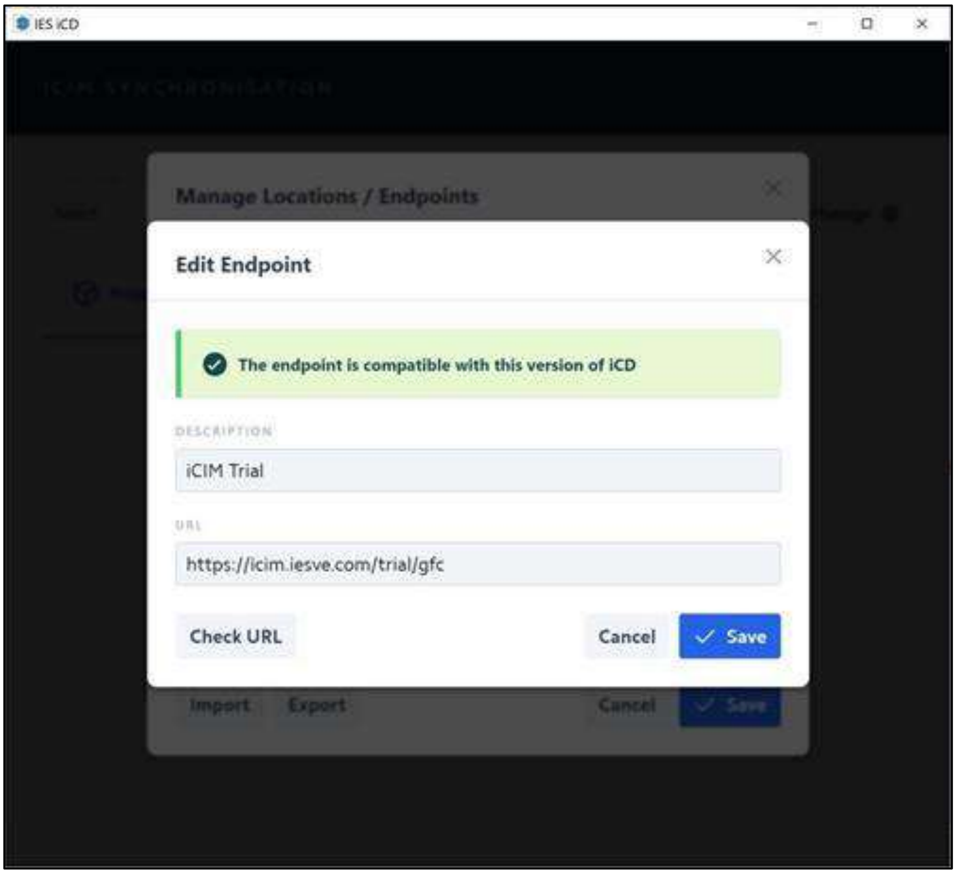

Figure 38 Final step in linking iCD and iCIM models.

In this way, iCIM models that are synchronised with iCD models can be accessed in iCIM Trial here https://icim.iesve.com/trial/#/.

6. Identify and select technologies to recover and reuse waste heat/cooling

A wide range of waste heat and cold (WH/C) recovery technologies in industry are presently available in the software. They greatly differ in terms of operating principle and operating conditions, target applications, development stage, costs and benefits.

These technologies were assigned to five main categories:

1. Heat-to-heat technologies.
2. Thermal energy storage technologies.
3. Waste heat to cold technologies.
4. Heat to power technologies.
5. Heat upgrade technologies.

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The image below details the findings from research conducted to identify technologies with potential use in the various SO WHAT project sites for waste heat/cooling recycling.

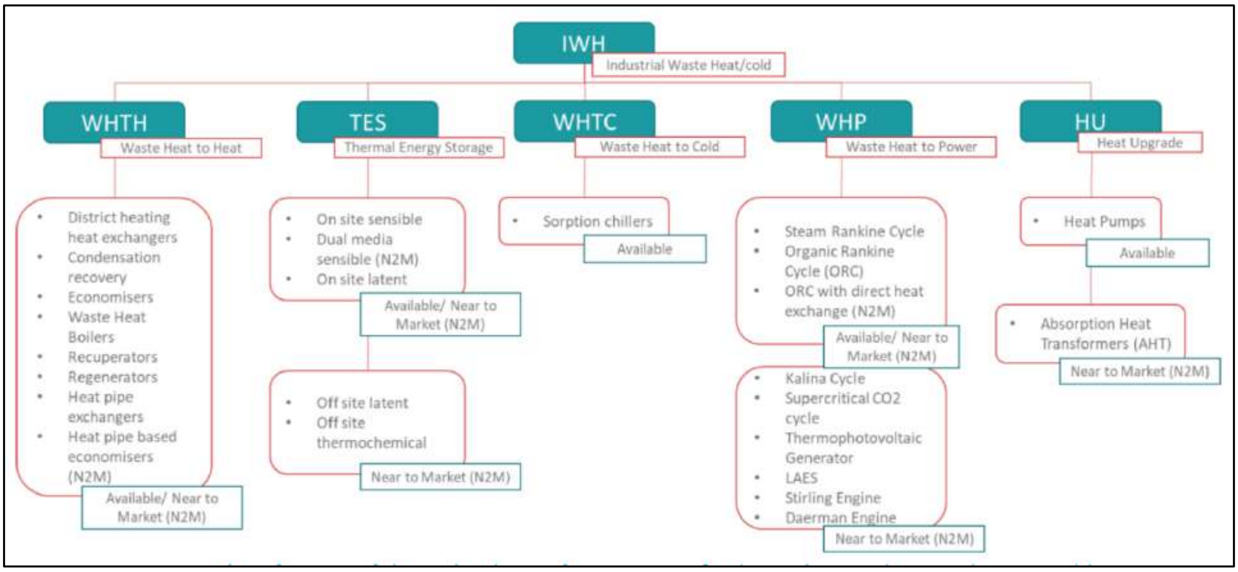

Figure 39 Waste energy technologies identified for the SO WHAT project.

Discussion should occur internally within the user's organisation to select which technologies are most suitable to the use's context. To aid this, the SO WHAT project has produced number of documents as follows:

D2.6 - Scenarios to be covered by the SO WHAT tool

D1.6 - WH/C recovery and thermal storage technologies

Within the D2.6 document, the project produced a methodology and scenarios to help guide the users on their selection. The following sub sections are an overview of this.

6.1 SO WHAT methodology for selecting technologies

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 will be 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 the following 6 stages (Figure 40), which are described in further detail below, whereas the full lists of scenarios for each of these 6 stages can be found in Table 2 of the previously submitted deliverable report D2.6 - Scenarios to be covered by the SO WHAT tool.

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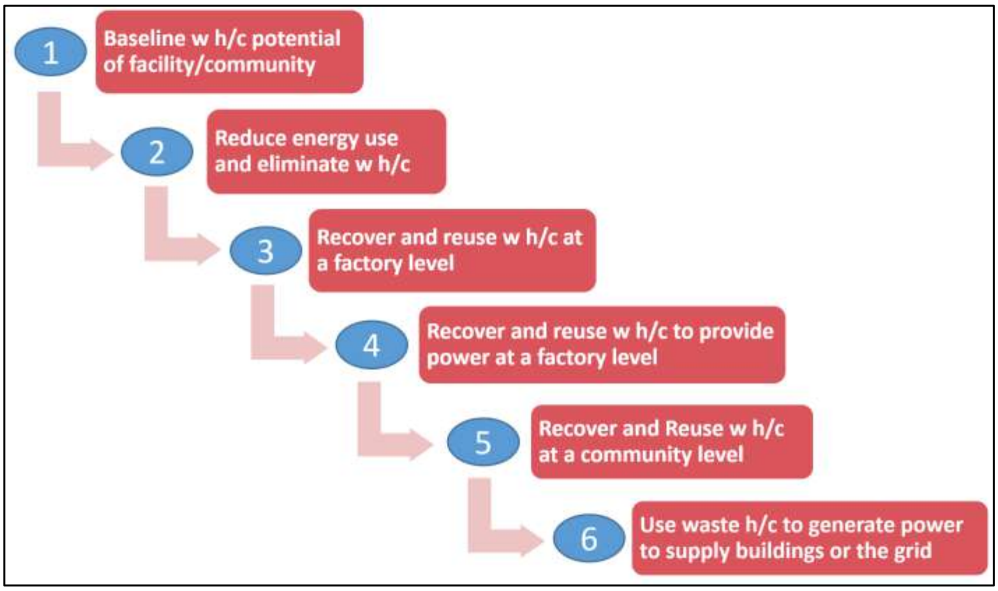

Figure 40 Scenario Selection Hierarchy

Stage 1: Baseline waste heat/cooling potential of facility/community

Although a 'scenario' is defined as a potential future state, the user must first have conducted a baseline simulation of the current state of waste heat/cooling potential and so this is considered as the top in the hierarchy and first scenario to consider. In both the free and commercial versions of the SO WHAT tool, this step will be done before the user is able to go through the other future scenarios. There are 3 Scenarios associated with this stage (see Table 2 of the previously submitted deliverable report D2.6 - Scenarios to be covered by the SO WHAT tool).

Stage 2: Reduce energy use and eliminate waste heat/cooling

This stage of the scenario hierarchy is not directly the focus of SO WHAT, nonetheless it is a logical and necessary step that the user should consider and decide whether to conduct before moving to explore waste heat/cooling recovery and distribution. As the overall aim of reusing waste heat or cooling is to reduce the amount of resources utilised and cut down on carbon emissions, the industrial user of one facility should therefore try to improve the overall energy efficiency of their building before looking specifically at waste heat/cooling. In the software (as explained in D2.3), there will be a link in the commercial tool into IES VE to enable the user to conduct detailed energy performance simulations of their facility and analyse the best energy efficiency strategies for the whole building.

Similarly, the user of that facility should also look to completely eliminate waste heat/cooling from their process before trying to understand recovery potential. This is explained using Kaizen techniques. It should be noted this analysis is not part of SO WHAT, but was a key focus of a prior EU FP7-NMP funded project REEMAIN.

Stage 3: Recover and reuse waste heat/cooling at a factory level

This relates to the recovery of waste heat/cooling to be re-used in the factory. Firstly, the user should look at whether they can re-use the waste within the same process as this will be the most efficient

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way to initially utilise resources, before analysing further on how utilise it in a different process in the facility. There are 16 Scenarios associated to this stage which describe the different technologies to recover waste heat, and how it can be reused as heat in the factory processes (see Table 2 of the previously submitted deliverable report D2.6 - Scenarios to be covered by the SO WHAT tool).

Stage 4: Recover and reuse waste heat/cooling to provide power at a factory level

Stage 4 continues within the factory, albeit this time to generate power rather than solely thermal energy. There are a further 4 Scenarios associated with this Stage (see Table 2 of the previously submitted deliverable report D2.6 - Scenarios to be covered by the SO WHAT tool) relating to general guidance on how to generate power and how to add solar panels/solar collectors, as well as more specific guidance on maximising the use of renewable energy and the optimal mix of different installations.

Stage 5: Recover and reuse waste heat/cooling at a community level

Stage 5 moves to the scenarios at a community level in terms of the recovery of waste heat/cooling from industry. After analysing the previous stages, if the user wishes to move to this stage, they should move to Section C for details on how to conduct this simulation. The first scenario concerns the overall matching of supply and demand, and then other scenarios look at how either a district heating network, or another means of transport, could be used to distribute the waste heat to the consumer. There is also a scenario related to the storage of waste heat so that it can be used at a later date, as well as two other scenarios that allow the user to conduct a cost benefit analysis of expanding a district h/c network, or constructing a new one, to connect to newly identified waste heat sources and users.

Stage 6: Recover and reuse waste heat/cooling to provide power at a community level.

The final Stage relates to recovering waste heat/cooling from an industry and then converting this to produce electricity to be used either by other local buildings as part of a micro grid, or to be sold and used by the national grid. After analysing the previous stages, if the user wishes to move to this stage, they should move to Section C for details on how to conduct this simulation

6.2 Simulation of Waste Heat/Cooling recovery for industrial site

The IES iVN (Intelligent Virtual Network) is designed to perform "as-is" and future scenario simulations of a community's energy demand and supply distribution network. In the SO WHAT project, the ability of the iVN to model and simulate heat flows and networks can be created, allowing for the ability to simulate different waste heat and cooling technologies.

The iVN can provide for the following capabilities:

- Modelling a range of technologies for recovering and reusing waste heat and waste cooling.
- Model the District heating and cooling infrastructure network and run simulations.
- Reporting improvements and analysis to show where opportunities exist to supply a community with excess WH/C and integrate with renewables.
- Potential demand response flexibility - identify what times demand response could be used to reduce the load-mismatch between available WH/RES and demand.
- Allow user to export iVN data to the iSCAN e.g. for access by the SO WHAT dashboard.

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6.2.1 Setup iVN project parameters

Now that a copy of the model is stored in the iCIM cloud platform, it is possible to bring that directly into the iVN Network tool. To do so, open the iVN and go into Import > iCIM Link. In the iCIM Endpoint box enter the following link: https://icim.iesve.com/trial/gfc/ and press the Load Projects button. After this you will need to enter your access credentials where it will allow you to view a list of projects that you have access to on iCIM. Select the relevant iCIM project and ensure the 'Sync building results' box is ticked and that the date range includes data from the dates for which you wish to simulate, then click the import button on the bottom right of the page.

Figure 41 Importing iCIM model to iVN.

Once the process is completed, the 3D model will appear, representing an exact copy of the project crated within the iCD. The buildings that have been simulated will also contain time-series demand data, according to the dynamic energy simulation run into the iCD.

As an iCD model (including building geometry from OSM and custom adjustment made by the user) and iSCAN data should already be linked to the iCIM model, this information should be automatically imported to the iVN model from the iCIM model. The image below shows the successful importing of data from the iCIM model as used as an example previously in this project. Note how this building geometry matches that from the iCD and iCIM models.

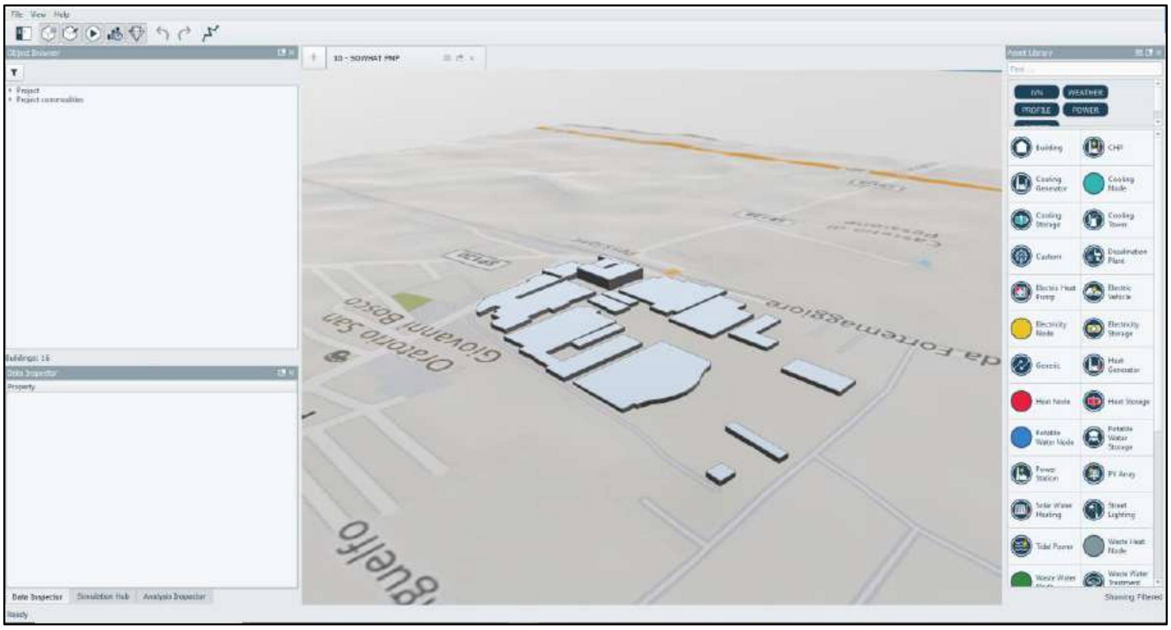

Figure 42 3D visual of iVN model once iCD model has been imported.

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If some of the information with regards to building geometry needs to be corrected or updated it can be edited in the Data Inspector tab of the selected building. Click the Analysis Inspector tab to review that the data from iSCAN and simulated results have been correctly imported to the iVN model. Charts and tables with the iSCAN data should be visible and populated accordingly.

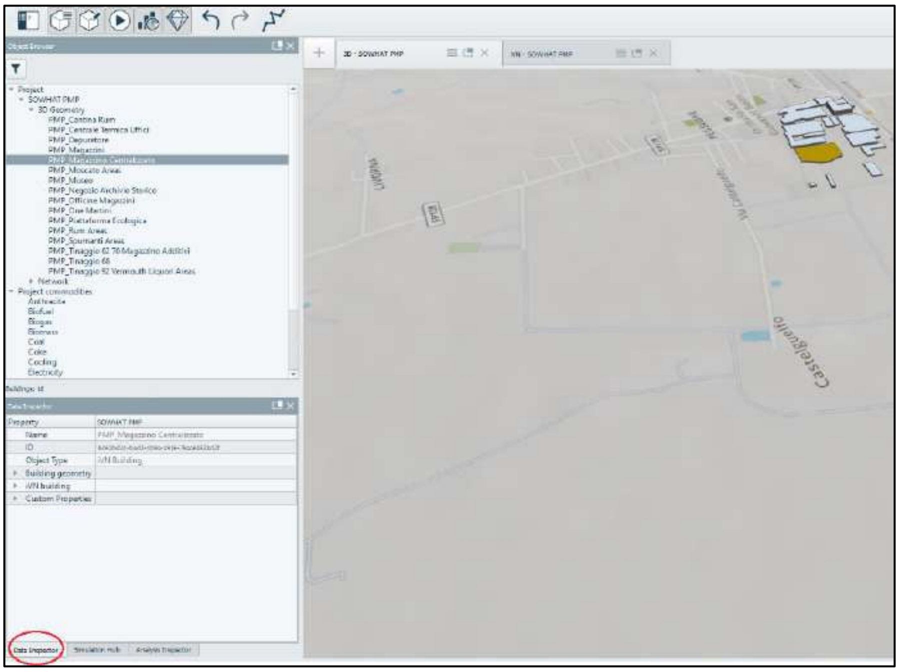

Figure 43 Data inspector tab where building details can be amended.

If additional iSCAN data needs to be connected to the iVN model due to either more recent data being collected or the import has not been done effectively it is possible to connect the iVN directly to the current iSCAN profiles. To do this click the Homepages button as circled below.

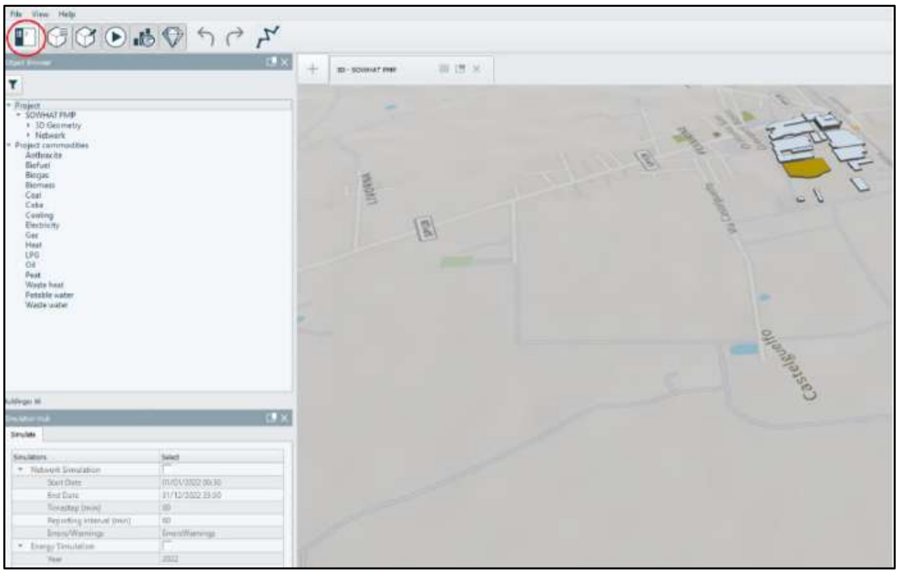

Figure 44 iVN homepage button.

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Click the Import button and the iSCAN link option. Similarly, in Section B.5.2 regarding creating iSCAN API tokens for linking data between iSCAN and iCD an API token with a reference link must be entered here. Add the iSCAN token and link URL and a list of the channels from iSCAN in the relevant boxes in the iVN Homepage Import section and select the building(s) and channel(s) as required. Multiple buildings and channels can be selected to import. Ensure the date range is correct to include all the data that is required from iSCAN.

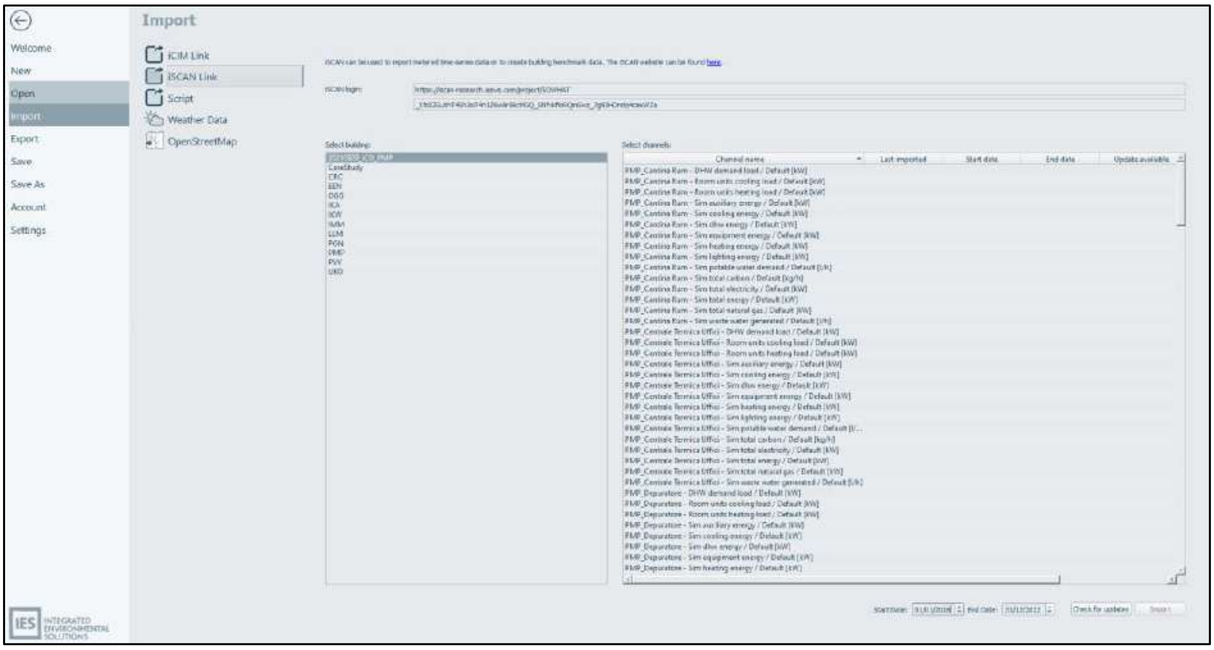

Figure 45 How to import iSCAN data (if required and updated iSCAN data is available).

Other key parameters to set up in iVN at a model project level, prior to progressing with the modelling of iVN baseline and scenario network models, include the following:

- Weather File: In order to visualise the current weather file in use, from the object browser, left click on the imported model project name, and expand the Model Location section in the Data Inspector. By default, the "heathrowewy.fwt" weather file should be the only one available, which is relevant to weather data for the UK London Heathrow airport weather station. In order to adjust the weather file for a more appropriate location than the UK London Heathrow airport, weather file(s) of interest first needs to be imported into the iVN model. To do so, click the Homepages button (Figure 44), then the Import button and the Weather Data link option (Figure 45), prior to selecting the browse button that will automatically open the iVN software installation folder where the list of Weather Files installed by default can be browsed. Select one or multiple weather files of interest and complete import by clicking on the import button. Once import is complete, from the object browser, left click on the imported model project name, and expand the Model Location section in the Data Inspector in order to select the weather file to use. More details on simulation Weather Files can be found here https://www.iesve.com/support/weatherfiles.
- Project commodities (fuels) carbon dioxide emission factors: In order to visualise and amend the imported model project carbon dioxide emission factors for each of the project

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commodities (fuels), from the object browser, expand the list of Project commodities and left click on the fuel of interest, for which the CO2 factor for consumption (kg/kWh) can be seen in the Data Inspector. By default, values relevant to the UK are set. These can be amended by left clicking on the CO2 factor for consumption (kg/kWh) value cell and by entering a more appropriate value for the country and year of interest.

It is strongly advised to set the same Weather File and Project commodities (fuels) carbon dioxide emission factors in iVN as the parameters previously set up in iCD, in order to ensure consistency in energy and carbon emission results, as simulated through both the iCD and the iVN platforms.

6.2.2 iVN baseline network model

The modelling of the electricity, heating and cooling networks is split into two methods, the virtual and physical networks:

- The virtual network modelling provides simple Hierarchical Demand Aggregation and Supply Allocation (HDASA) whereby waste heat network nodes represent the points in the network where the demand for commodities is aggregated at a node and the allocation of load is made to generators connected to this node. Thus, network nodes define the hierarchical tree structure and act as anchor points for Installations and Buildings. For example, waste heat tree nodes are tree nodes that deal specifically with the aggregation of waste heat and prompt to attach waste heat and cold (WH/C) recovery technologies in order to process the waste heat. Processing waste heat is the act of rejecting waste heat to the atmosphere. Consequently, "Demand" can be considered as the amount of waste heat processing which occurs, whereas "Generation" is considered as the production of waste heat by, e.g., chillers. In the virtual model, waste heat nodes involve calculations based on power only; they do not involve water flow rates, supply temperature, return temperature or other thermophysical properties of water.
- The physical network modelling is a more complex modelling approach, whereby hydraulic and thermal calculations are performed alongside water flow rates and supply and return temperatures which allow the heat network model to include distribution losses, and a more accurate picture of how to network operates. The development of a physical network model is more relevant to an external exploitation of a site waste heat/cold resource potential, by recovering and distributing such a waste heat/cold resource potential to the community (i.e. site surrounding buildings) through a district heating or cooling network. The physical network modelling approach is detailed in Section C.

To begin developing a baseline network model, a new 2D virtual network view should be created and opened. To do so, click the "+" button and select 2D virtual network view. Note this 2D virtual network view can be visualised in various ways: geographical view (i.e. buildings are geolocated on a map), schematic view (i.e. hierarchical tree structure), custom view. Then select the building you wish to start developing a relationship between and drag them into the workspace. The selected buildings will appear into the 2D virtual network geographical view in the exact geolocation at which they belong to. The example in the image below show the 3 highlighted buildings which were selected and dragged into the workspace (2D virtual network schematic view).

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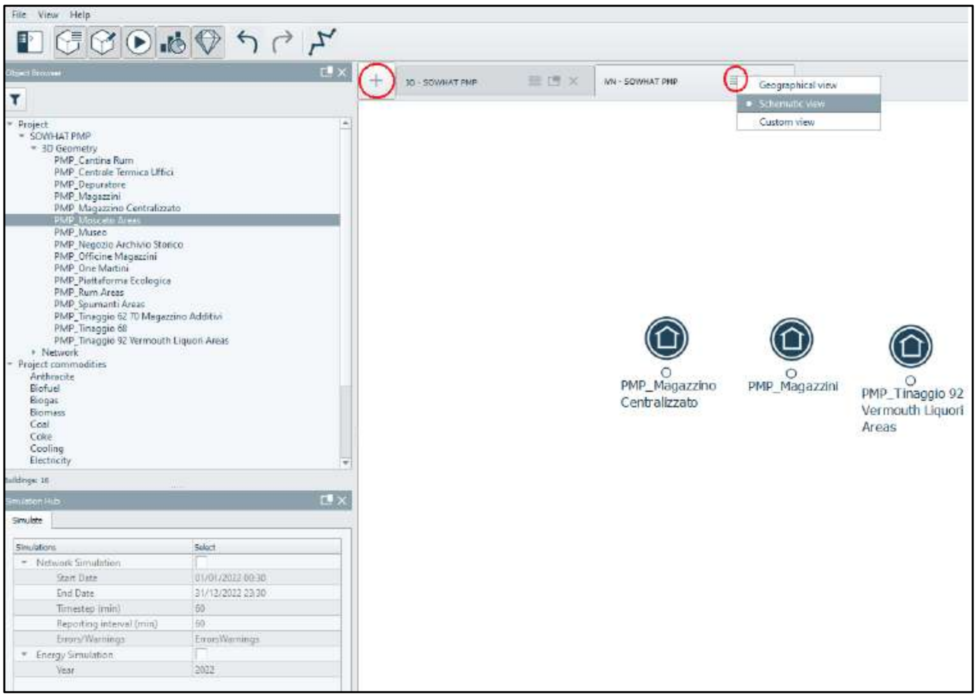

Figure 46 Adding a 2D virtual network schematic view in iVN for network configuration.

Now it is possible to create the relationship model. It should be noted that this model is a hierarchal model where links are drawn from "parent nodes" down to "child nodes".

Assets can be connected to nodes. The connections represent the flow of energy in the network. The nodes represent decision points where supply and demand meet.

Nodes must be selected and connected as a source (i.e. provides heating, cooling, electricity etc.) or sink (i.e. consumes heating, cooling, electricity etc.). Firstly, right click on a node and select "select iVN item for connection". Secondly right click the connection node and select "connect iVN item" and choose either "As Sink" or "As Source" depending on what is relevant in this network connection. In the below example the cooling node was selected first and the building selected second as the sink for cooling (as it will consume cooling energy from this cooling node for air conditioning). To note, multiple nodes/buildings/assets can be selected at any one time for connection if required and connecting to the same item, also, if you click away from these items during the process it will deselect them.

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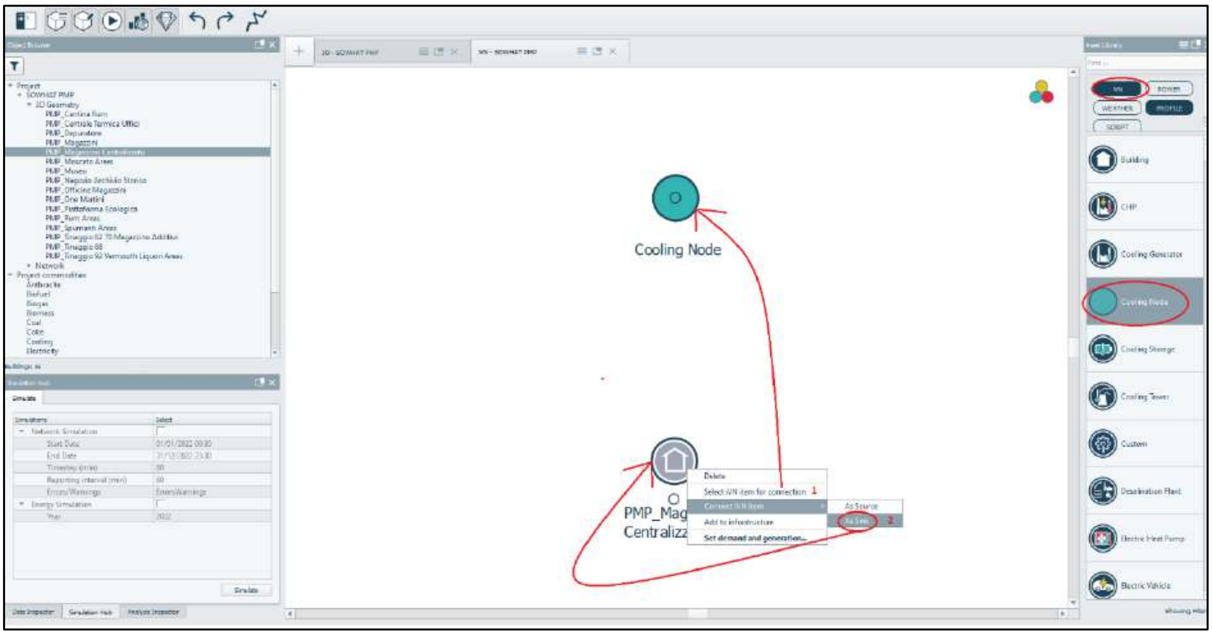

Figure 47 How to link buildings and nodes within an iCD network.

For the following example we will have two buildings that have 2 separate cooling load/nodes as sources which then ultimately sends the waste heat from this process to one waste heat sink node, as well as another separate building which is heated by a heat source node.

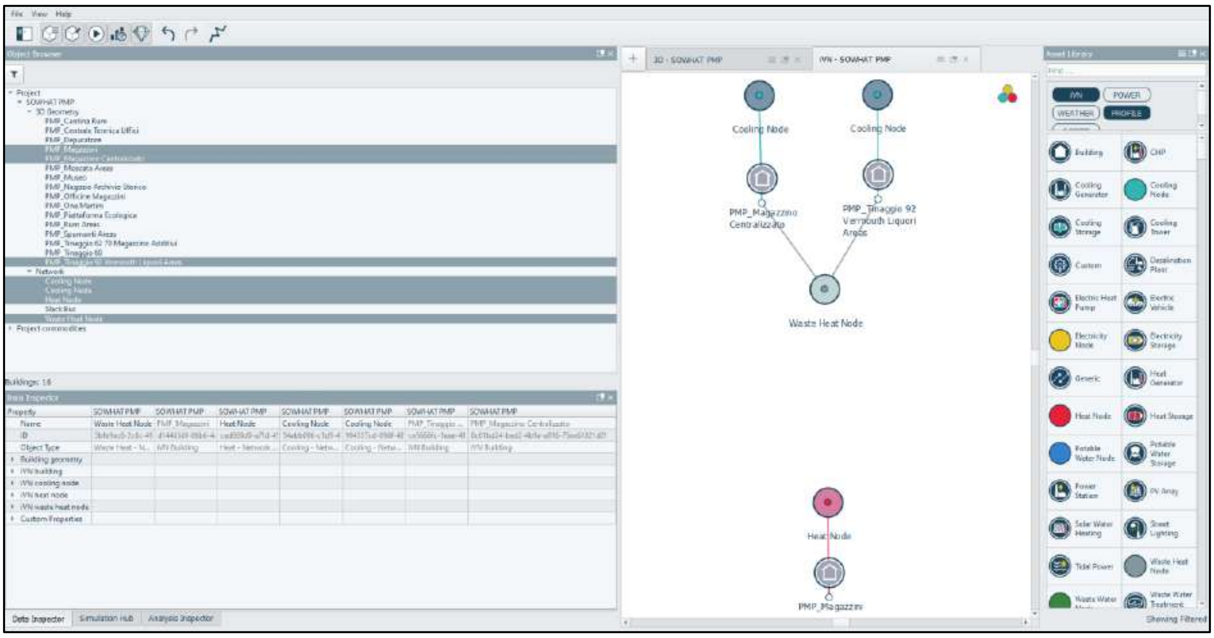

Figure 48 A multi-building and node network within a baseline structure.

By double-clicking on one building we can see the demand profiles already imported and add as required. Associate the channels to each building as required.

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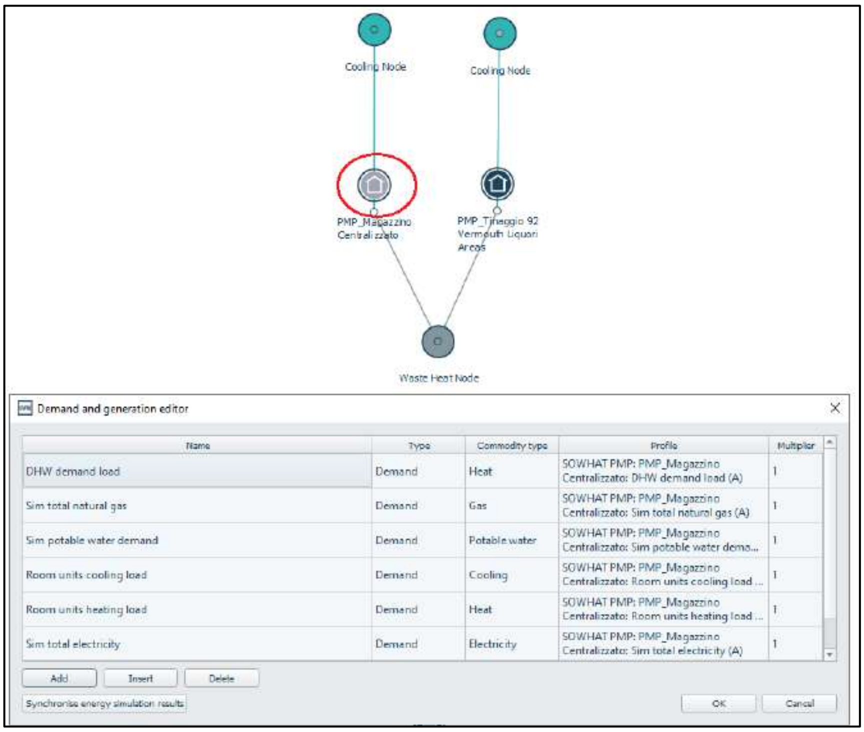

Figure 49 The demand and generation editor for buildings where data can be edited as required.

It is possible to amend the associated loads if required in this box. The Multiplier column can be used to turn off certain loads if non-applicable or to increase the contribution of certain loads (for example if a system is added but there is a multiple of these and the factor needs to be increased). As simulated data can be imported (from iSCAN/iCD) along with metered data it is preferable to turn off the simulated data as real-world metered data is available. If simulated data is present while there is also metered data simply set the multiplier for the simulated data to 0. The commodity types and whether the load is a source (generation) or demand (sink) for the building can be amended by double clicking the relevant box and new demands or generators can be added as required. Ensure these are correct and add/amend as required.

When the network has been fully developed and the associated building and node details are inputted a simulation for the baseline model should be undertaken. This baseline network model will allow for the performance of the building(s) to be viewed and compared to a later scenario network model, which will include potential waste heat and cold (WH/C) recovery technologies, as well as potential renewable energy sources to be added, as discussed in the next section.

Select the network to be simulated from the object browser, then open the simulation hub, tick the 'Network Simulation' button and hit 'Simulate'. Make sure the start and end dates for the simulation corresponds to the dates for which you have simulated your buildings, so that the timestamps of the imported demand profiles will match the ones of the added assets.

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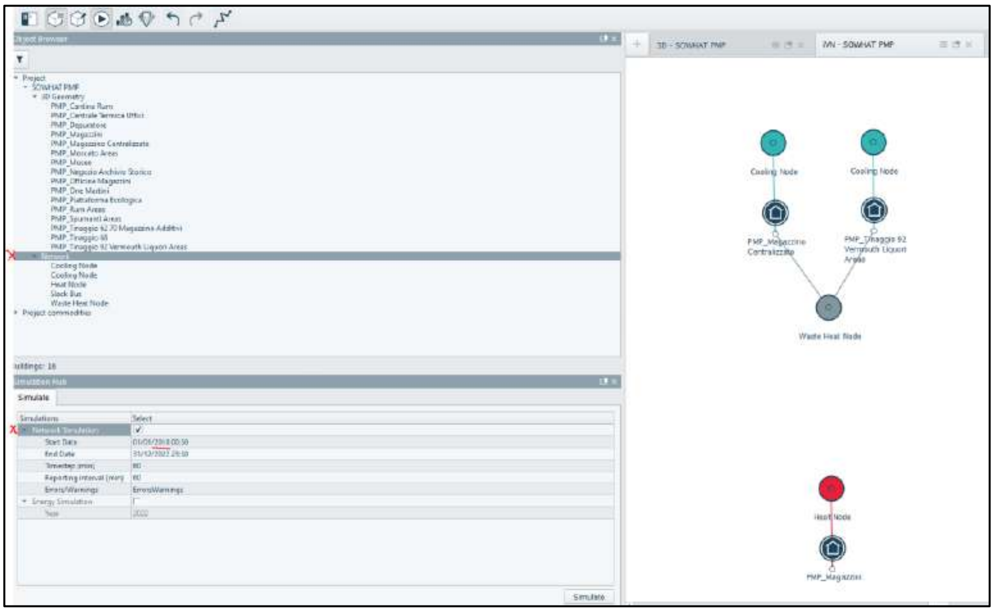

Figure 50 Running a network simulation within the simulation tab for the baseline model.

During this simulation, the iVN will make calculation at each timestep (60 mins by default) on the energy generation, total and residual energy demand, CO2 emissions and more. Once the simulation is finished, we can check the results by opening the analysis inspector, clicking on a node or asset in the network and plotting any of the variables available in either table results, line charts or bar charts. Hold control and left click on various assets to select them together and be able to plot different variables on a single chart. Click then on one of the 3 chart types to plot results.

Date/time	Total waste heat production (SOWHAT F (kW)	Total heat demand (SOWHAT PMP, B (kW)	Total electricity demand (SOWHAT P (kW)
05/11/2018 00:00	2071.97700	3446.02300	2092.14700
05/11/2018 01:00	2127.64800	3446.02300	2586.38300
05/11/2018 02:00	2127.64800	3446.02300	2619.20200
05/11/2018 03:00	2127.64800	3446.02300	2619.20200
05/11/2018 04:00	2127.64800	3446.02300	2619.20200
05/11/2018 05:00	2166.92900	3446.02300	2840.46400
05/11/2018 06:00	2166.92900	3446.02300	2840.46400
05/11/2018 07:00	429.90100	4393.20700	1633.78000
05/11/2018 08:00	429.90100	4393.20700	1590.32800
05/11/2018 09:00	429.90100	4393.20700	1590.32800
05/11/2018 10:00	429.90100	4393.20700	1590.32800
05/11/2018 11:00	429.90100	4393.20700	1590.32800
05/11/2018 12:00	429.90100	4393.20700	1590.32800
05/11/2018 13:00	429.90100	4393.20700	1590.32800
05/11/2018 14:00	429.90100	4393.20700	1590.32800
05/11/2018 15:00	429.90100	4393.20700	1590.32800

Figure 51 Analyse network results table.

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Figure 52 Analyse network results line chart.

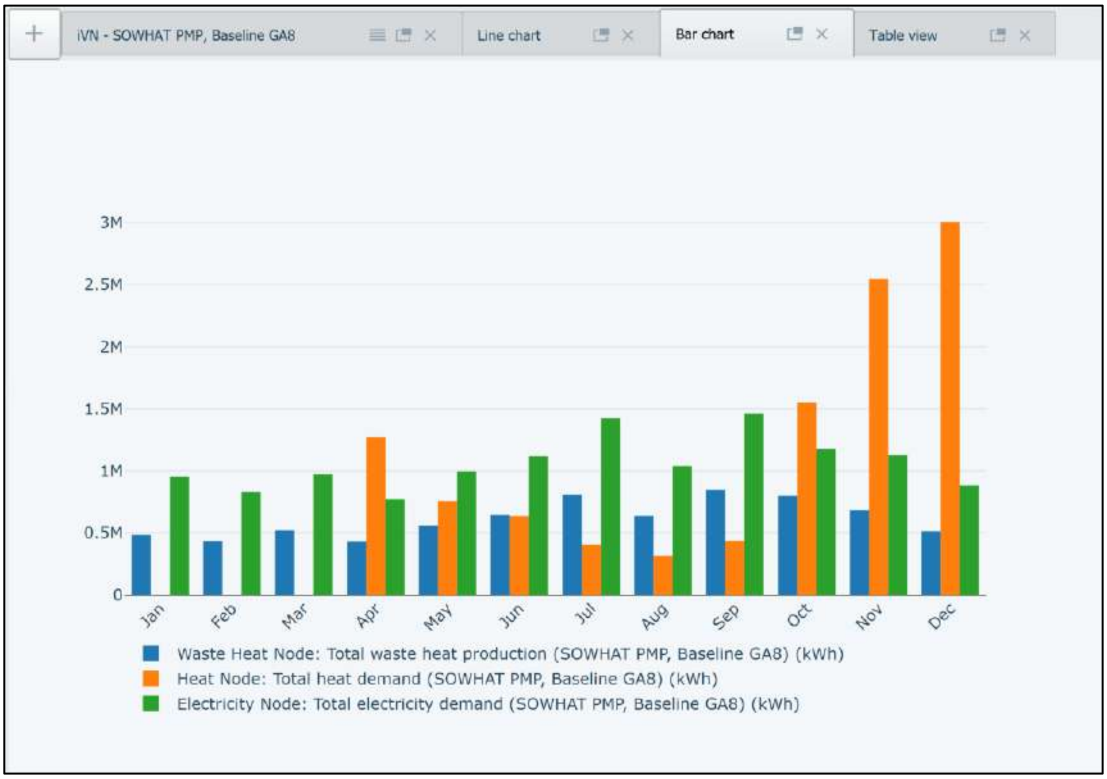

Figure 53 Analyse network results bar chart.

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6.2.3 iVN network model scenario

As explained in the previous section, the virtual and physical network models can be seen as two different aspects of the iVN network modelling platform:

- The virtual network modelling provides simple Hierarchical Demand Aggregation and Supply Allocation (HDASA) whereby waste heat network nodes represent the points in the network where the demand for commodities is aggregated at a node and the allocation of load is generators connected to this node.
- The physical network modelling is a more complex modelling approach that considers the real-world infrastructure that connects the building (e.g. electric cables and water pipes) within the model and site., which allow the network model to include distribution losses, and a more accurate picture of how to network operates.

For both modelling approaches, virtual and physical, it is possible to address different scenarios without affecting the existing baseline network model. To do so, from the object browser, right click on the project name and select 'Copy to new scenario'. This will make an exact copy of the model, including both the 2D virtual network and the 2D physical network views, which you can then rename as you wish.

For the following example the scenario that is being shown below is one where the 2 buildings have independent cooling systems (i.e. cooling required in a manufacturing building). The waste heat is then transformed though a heat exchanger to supply heat for another building. At this time the physical network will not be modelled so physical infrastructure will not be included (details on the physical network modelling approach are introduced in Section C).

As it can be seen cooling source nodes are connected to buildings, which are then source buildings for a waste heat node. This waste heat node is the source for the custom installation asset which would have to be configured and have relevant technical details associated to it as per the heat exchanger system that does or could theoretically exist. This heat exchanger custom installation asset is then the source of the heat node, which in turn is the source of heat to meet the final building heat demand.

The custom installation asset, which has been classified as a heat exchanger in this example, has no innate properties, unlike the other standard assets that have preconfigured operations and input variables, which can be edited directly in the iVN Data inspector. As such this custom installation asset allows the user to define the function and operation through Python scripting which can be assigned to this custom installation asset through. To do so, a custom installation asset can be dragged from the iVN Asset Library into the 2d virtual network view, then connected to the waste heat and heat nodes of the network model scenario, and the relevant Python script is imported to the iVN, as illustrated in Figure 56 and Figure 57.

One of the main activities carried out in the SO WHAT project has been to develop Python scripts, which can be associated to an iVN custom installation asset, for each of the waste heat/cold recovery and exploitation technologies introduced in previous Section B.6. Note these Python scripts are commercially sensitive, so the user should contact the SO WHAT project partners at info@sowhatproject.eu for more information needed in relation to these scripts.

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For this example network, we have some of industrial waste heat resource potential which is then being recovered through a waste heat-to-heat (WHTH) system, in particular a district heating heat exchanger (DHHEX) is being used, as detailed in D1.9 report (modelling algorithms) and in D4.3 (integration into the detailed version of the SO WHAT tool. This DHHEX has been pre-coded for modelling use, although specific inputs are required. The image below highlights the variables that require user input into the Python script for the DHHEX technology, which can be performed either before after importing the Python script into the iVN. These are specific technology inputs and must be found and assigned for the technology/equipment that is to be implemented in the system. This table below is an excerpt from a larger table which includes other waste heat/cold recovery and exploitation technologies and the variables that are to be input by the user, as further detailed in D1.9 report.

#	Category	Technology	Acronym	List of result variables (custom installation-to-iVN)	iVN-to-custom installation input parameters
1a	WHTH	District heating heat exchangers (simulation)	DHHEX	Hot fluid heat capacity rate (C_h) [kW/K] Cold fluid heat capacity rate (C_c) [kW/K] Capacity rate ratio (C*) [/] Maximum heat transfer rate (Q_max) [kW] Number of heat transfer units (NTU) [/] Exchanger heat transfer effectiveness (epsilon) [/] Heat transfer rate (Q) [kW] Heat source outlet temperature (Ths_out) [°C] Cold stream outlet temperature (Tc_out) [°C]	Mass flow rate of the heat source (m_hs) [kg/s] Specific heat of the heat source (cp_hs) [kJ/kg-K] Mass flow rate of the cold fluid (m_c) [kg/s] Specific heat of the cold fluid (cp_c) [kJ/kg-K] Inlet temperature of the heat source (Ths_in) [°C] Inlet temperature of the cold fluid (Tc) [°C]
1b	WHTH	District heating heat exchangers (design)	DHHEX	Heat transfer rate (Q) [kW] Cold fluid outlet temperature (Tc_out) [°C] LMTD counterflow [°C] LMTD parallel flow [°C] Correction factor F [/] Mean temperature difference (DTm) [°C] Heat transfer area (A) [m2]	Mass flow rate of the heat source (m_hs) [kg/s] Specific heat of the heat source (cp_hs) [kJ/kg-K] Inlet temperature of the heat source (Ths_in) [°C] Outlet temperature of the heat source (Ths_out) [°C] Mass flow rate of the cold fluid (m_c) [kg/s] Specific heat of the cold fluid (cp_c) [kJ/kg-K] Inlet temperature of the cold fluid (Tc_in) [°C]
1c	WHTH	District heating heat exchangers (costing)	DHHEX	Purchased cost of the heat exchanger at base conditions (Cpo) [€] Pressure factor (FP) [/] Material factor (FM) [/] Bare module cost factor (FBM) [/] Purchased cost of the heat exchnager at real conditions (Cp) [€] Bare module cost (CBM) [€]	/

Figure 54 Variable input data required for DHHEX systems.

Below shows an extract from the DHHEX Python script which requires user variable input as noted in the image above.

```
import numpy as np  #  is required for mathermatical functions e.g. log()
def DHHEX(INPUTS):
    if INPUTS == []:
        MODE=2    # 1: Simulation, 2:Sizing
        ########################################################
        # parameters
        m_hs=1.0                    # Mass Flow rate of the heat source         [kg/s]
        Cp_hs=5.200                 # Specific heat of the heat source          [KJ/(kg.K)]
        T_hsin=110                  # Inlet temperature of the heat source      [°C]
        ########################################################
        m_c=.4                      # Mass Flow rate of the cold fluid          [kg/s]
        Cp_c=4.200                  # Specific heat of the cold fluid           [KJ/(kg.K)]
        T_cin=10                    # Inlet temperature of the cold fluid       [°C]
        ########################################################
```

Figure 55 Extract of Python code for DHHEX system and some of the variables requiring user input.

To note, this code extract does have more variable inputs required within the script. This is one of the many scripts for the various technologies identified and all require different variables to be input.

As it can be seen in Figure 50, when all the nodes are selected in the workspace 2d virtual network model view, they are also highlighted in the Object Browser and their details (which can be edited as required) are shown in the Data Inspector section.

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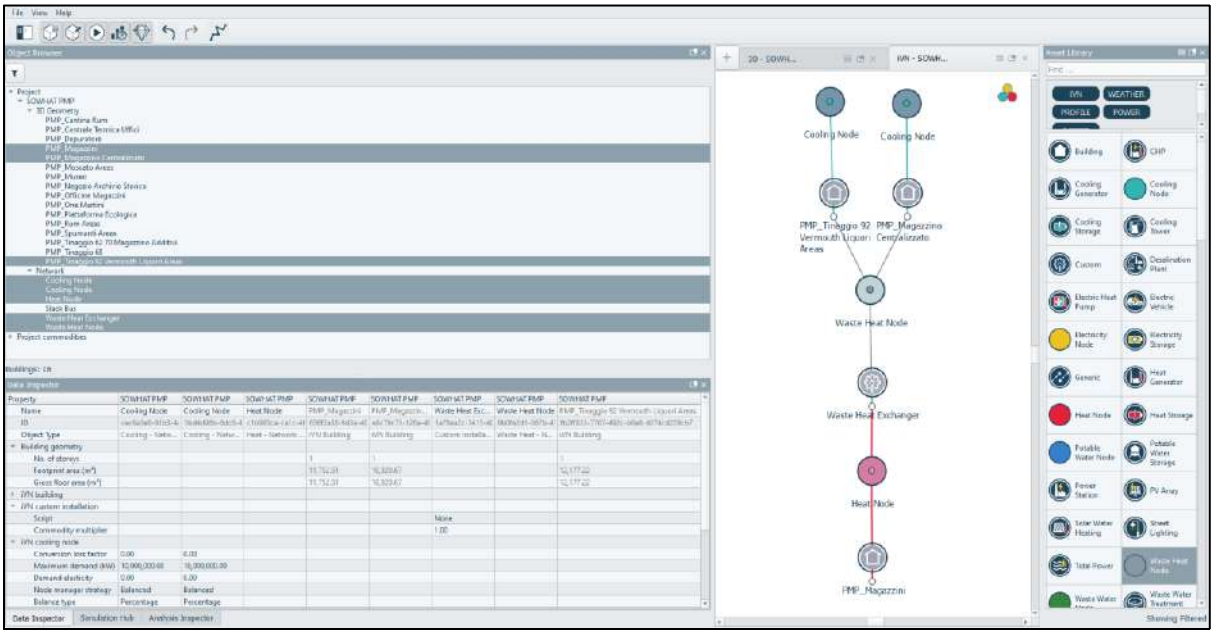

Figure 56 Simple heat recovery network in schematic view in iVN.

The Python script to be associated with the custom installation asset called "Waste Heat Exchanger" must be imported and assigned to this custom installation asset. For this example, it is the DHHEX scrip as noted previously.

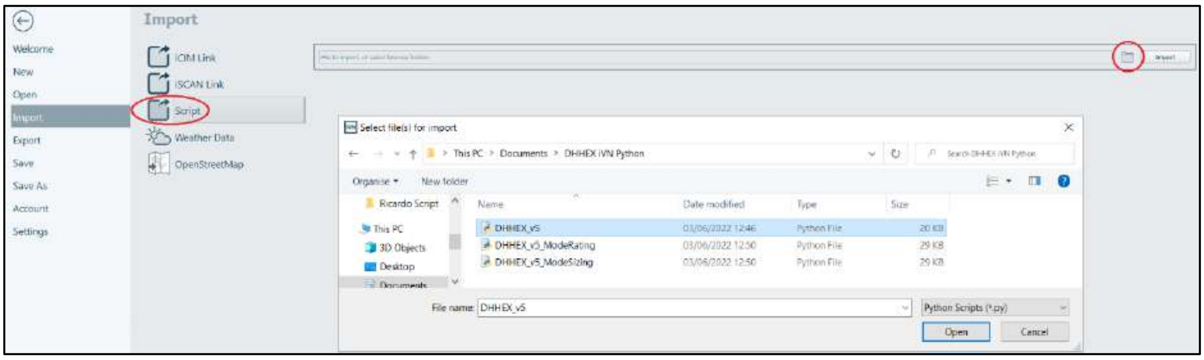

Figure 57 Importing Python script for custom nodes such DHHEX.

Then within the model select the custom node and assign the relevant scrip to it.

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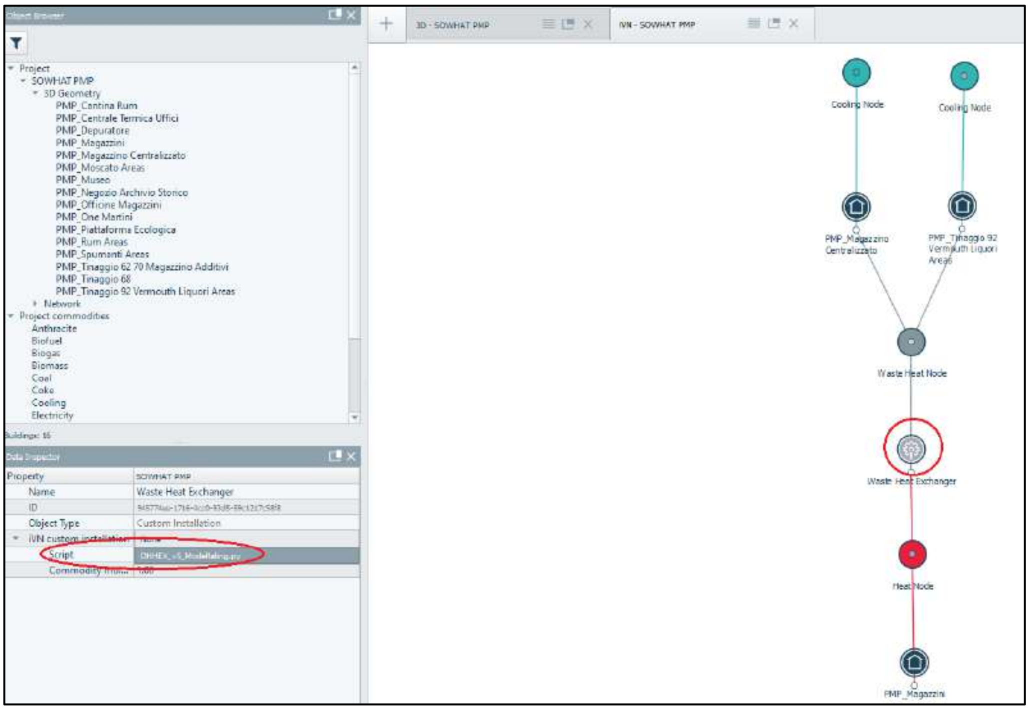

Figure 58 Attaching imported script to the custom node in the iVN.

Now that the parameters are set up, the network model scenario can be simulated, prior to compare these simulated results against these of the baseline network model that was simulated in the previous section. To do so, select the network and run a simulation. You should then review the results in the Analysis Inspector tab and be able to compare them to the baseline (real life) model allowing for the impact of this technology on the network/site/building to be analysed. Multiple theoretical/analysis simulations can be conducted where the network configuration and the variables assigned to the nodes and Python script (for the custom node for the waste energy technology) can be amended and changed to suit various scenarios and compared to the baseline model.

To note, this is a simple example. A real-life building network model will likely be more complex than this and it should be expanded to be as detailed as possible to include all relevant nodes and building systems that produce and consume energy.

6.2.4 Comparison against baseline results (inc. export of simulated results for baseline and scenario network models)

As mentioned in previous section, in iVN, it is possible to compare results from two or more different scenarios. Let's try to compare an example baseline network model to a scenario of this baseline model in which renewable sources have been added, namely solar-PV panels in this case.

To do so, open both models into the 2D view, select the main electricity node in each network holding the control button, and then plot the residual electricity demand as a bar chart for the whole year. Remember you need to simulate both network models before being able to plot results.

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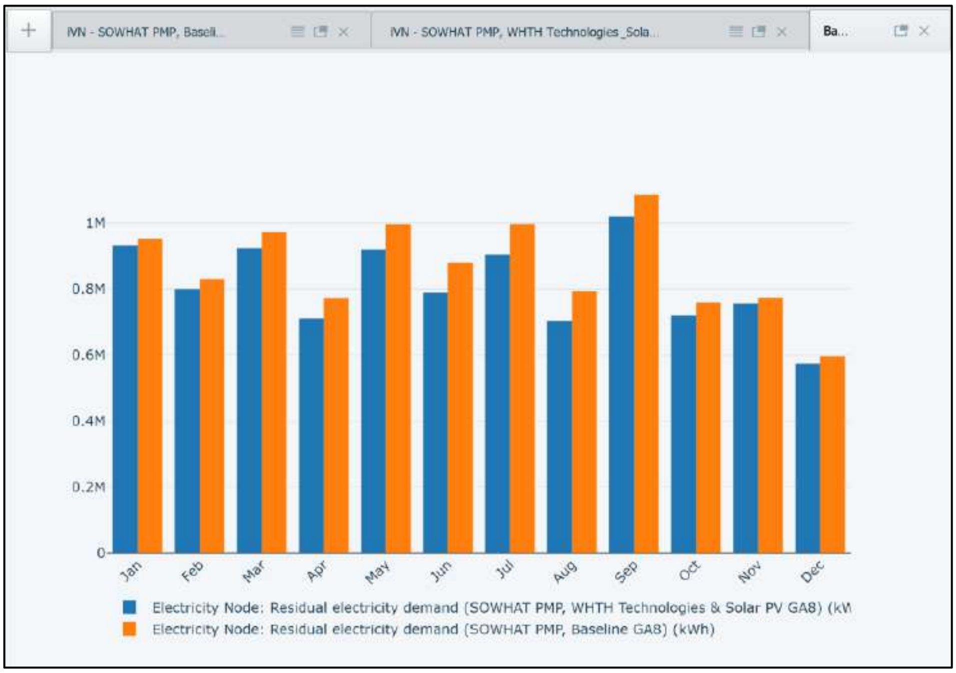

Figure 59 Comparison between scenarios - energy use reduction

In this example, we can see how the demand has decreased across the whole year thanks to the use of solar energy, especially during summer months when the radiation is higher. However, in this example, there still is quite high energy demand to be offset to reach a positive balance, and new scenarios could be created in order to analyse the impact of additional or other sources of renewable energy such as wind, tidal and more.

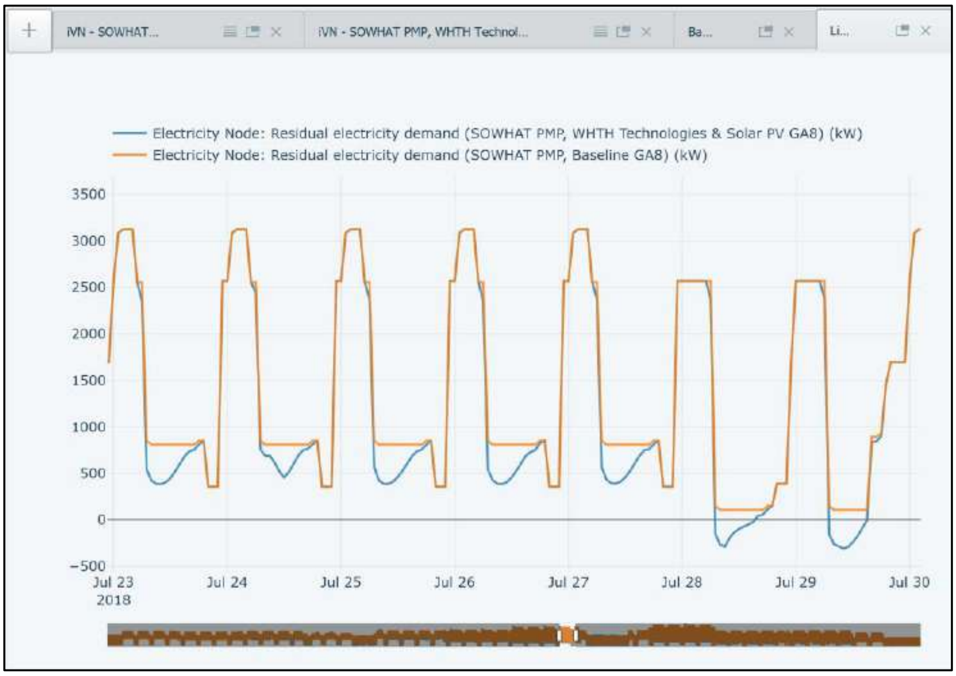

Figure 60 Comparison between scenarios – Surplus generation insight

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During the weekends, the residual electricity demand even reaches a negative value, which means there is surplus of generation compared to the site electricity demand. This could lead to either a local energy market, where feasible, or it could be used to eventually charge an electricity storage to then re-use the stored energy when most needed. A line chart could be plotted to better understand when the peak generation/demand happens, to address the best strategy to exploit the renewable generation, as seen in Figure 60 above.

6.2.5 Export from iVN to iSCAN of simulated results

The "Export results to iSCAN" feature enables users to export iVN result variables to iSCAN to form iSCAN data channels for use by other ICL and 3rd party tools.

The heading 'Export' is a new addition to the Homepage navigator bar. The 'Publish to iSCAN' section is where users setup and manage iSCAN endpoints and iVN object results variables for export.

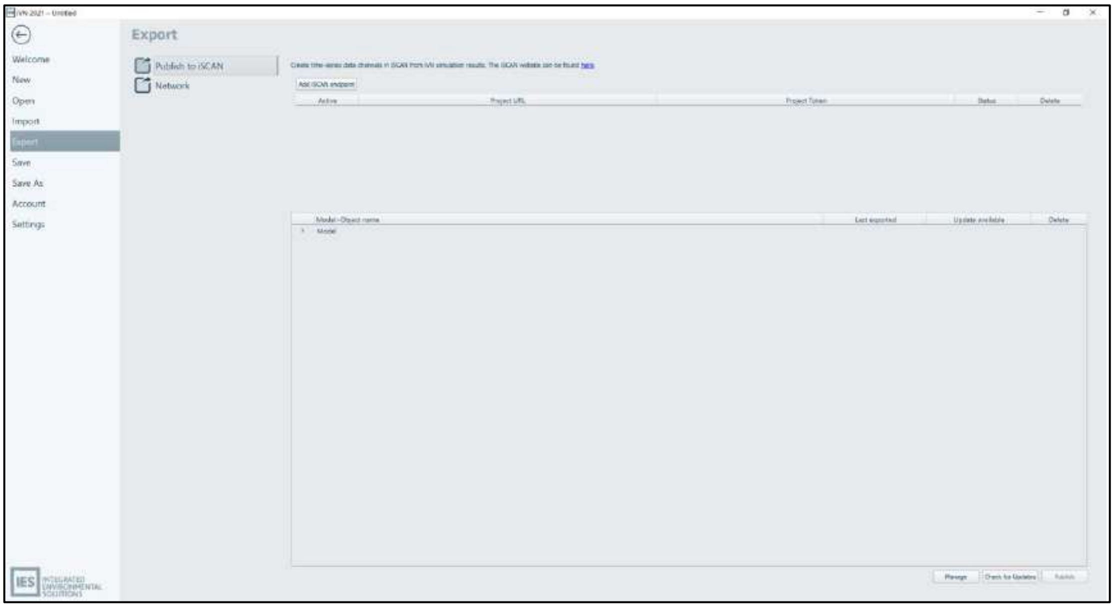

Figure 61 iVN export 'Publish to iSCAN' section

To create an iSCAN endpoint the user selects the 'Add iSCAN endpoint' button. This adds a new row to the iSCAN endpoint management table. The 'Status' indicator informs the user whether the iSCAN endpoint URL and token is valid e.g. Ok = green status, Failed = Red status.

There is no limit on the number of iSCAN endpoints that can be added to the table. Selections and settings within the 'Model > Object name' table are persisted at the project level against the activate iSCAN endpoint.

To avoid sharing sensitive iSCAN endpoint project token data, shared projects do not display the iSCAN endpoint project token data and instead **** are displayed. Only users that have added the iSCAN endpoint can manage and edit the iSCAN endpoint row.

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Figure 62 iVN export 'Publish to iSCAN' URL and token.

The 'Model > Object name' table lists each model/scenario(s) within the loaded project.

Commodity level result variables per model/scenario are added to 'Model > Object name' table by right-clicking the Network heading within the Object browser and selecting the 'Add to Publish to iSCAN' option.

Figure 63 Object browser 'Add to Publish to iSCAN' option for commodity level result variables.

Commodity level result variables for the selected model/scenario are displayed under the relevant model/scenario heading in the 'Model > Object name' table.

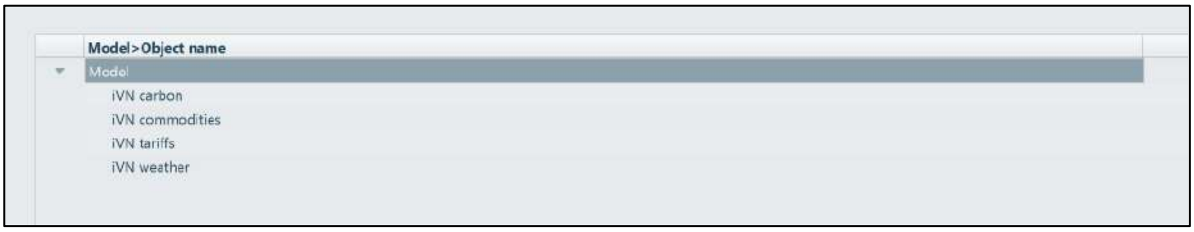

Figure 64 Display of commodity level result variables

'2D Virtual' related objects, except network nodes, can be added to the 'Model > Object name' table by right-clicking the relevant object within the Object browser or via the '2D Virtual viewer' and selecting the 'Add to Publish to iSCAN' option.

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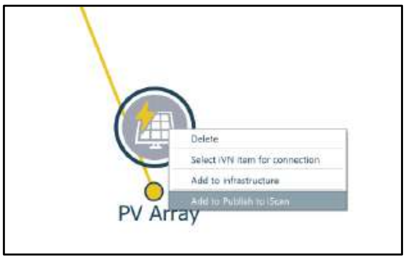

Figure 65 Object browser 'Add to Publish to iSCAN' option for '2D Virtual' related objects.

The selected object(s) (e.g. PV array) are displayed under the relevant model/scenario heading in the 'Model > Object name' table.

Figure 66 Display of '2D Virtual' related objects.

By selecting the 'Manage' button a user can manage the results variables that are to be exported on an object by object type basis. The 'Object result variable' dialog includes a number of default selections and can be edited by the user.

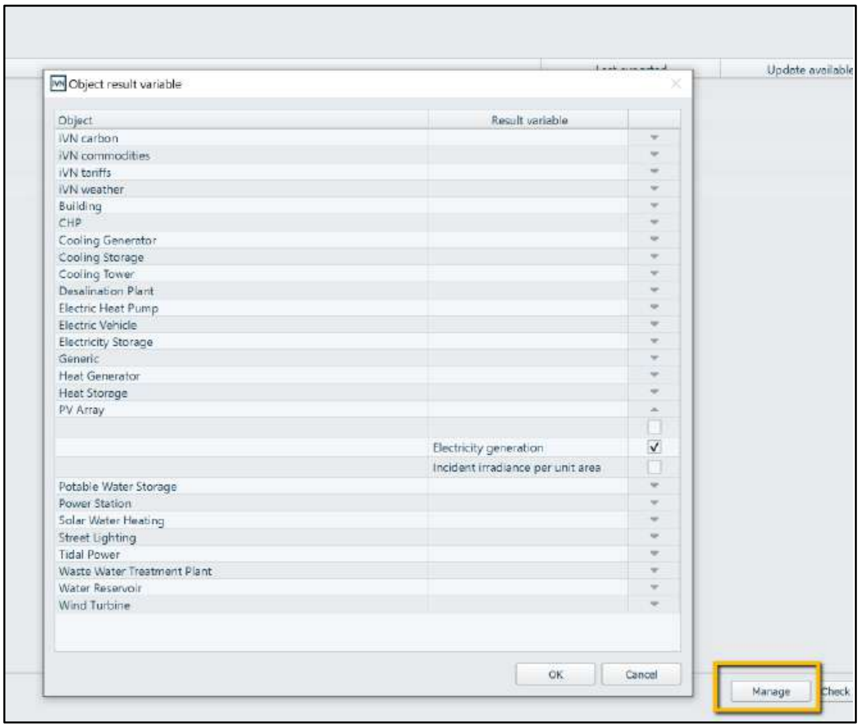

Figure 67 'Object result variable' dialog to manage the results variables to be exported to iSCAN.

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Once setup is complete. The user is required to select a valid iSCAN endpoint (i.e. active) and at least 1 model/scenario (row) within the 'Model > Object name' table. Selection of the 'Publish' button enacts the publish and creation of iSCAN data channels in iSCAN based on iVN result variables.

A progress bar informs the user on the Publish to iSCAN progress.

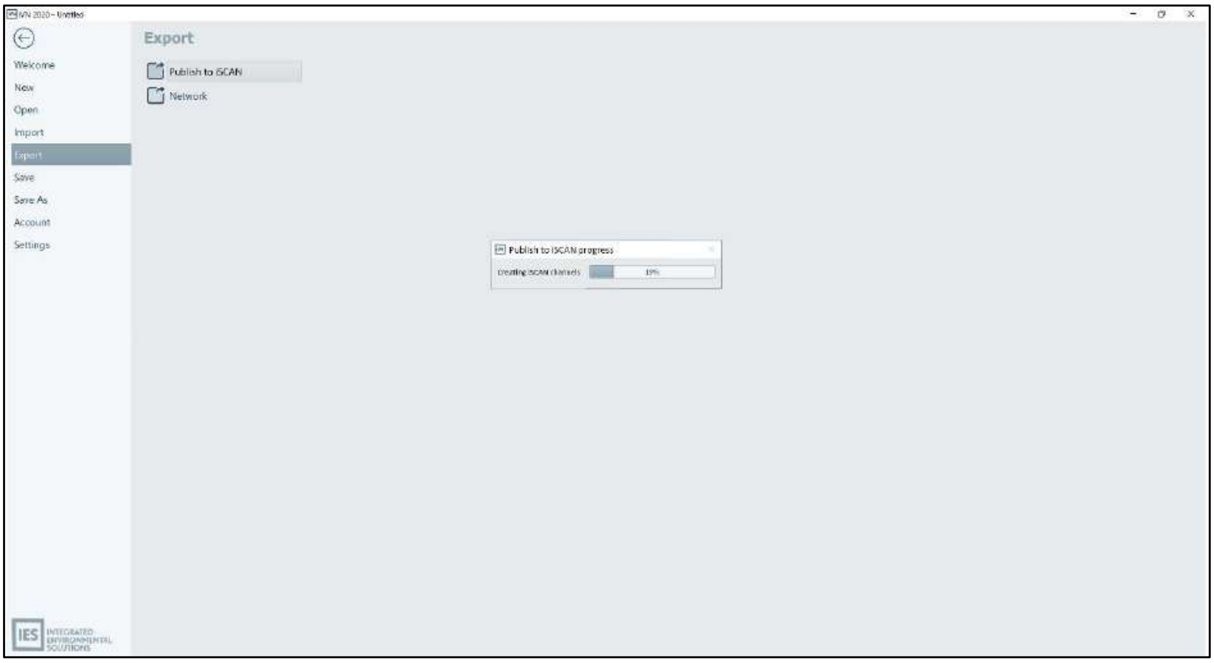

Figure 68 Progress bar to inform the user on the Publish to iSCAN progress.

Upon completion, the 'Last exported' and 'Update available' columns are populated in the 'Model > Object name' table.

The following format for exported iVN results variables in iSCAN is as follows:

- iSCAN building = iVN project name - iVN Model name
- iSCAN data channel = Object type name – result variable name

Once completed, the user can either use iSCAN features to post-process the exported results and/or visualise these exported results directly for analysis purposes, or the user can contact directly the SO WHAT project partners at info@sowhatproject.eu in order to collaborate on the development and setup of ad-hoc online Dashboards, whereby specific widgets and pages can be created and tailored for an appropriate visualisation and sharing of specific KPIs.

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Section C Waste Heat/Cooling potential for the community

There are several elements to this Section depending on what the user wishes to achieve. Whichever aspects the user wants to analyse, the first two sub sections – namely (1) identifying an area of interest and (2) assigning data - need to be completed. From here, the user may set up and perform analysis on the following:

- Heat and Cooling Demand of buildings
- District Heating Network to supply buildings
- Potential Renewable Energy Sources

How to perform each of the above is explained further in the sub sections below.

1. Identify and select area of interest

The area of interest should be imported into iCD via OSM (Open Street Map). If an industrial/manufacturing analysis has been done (Section B), then this may have already been completed, but if not, Section B 5.1 shows how to perform this action. This will allow for base information for the site and surrounding buildings to be present and for additional information to be added.

Boundaries for the area may also be imported using an imported shapefile (.shp) which could be sourced from QGIS (https://www.qgis.org/en/site/) and imported as shown in the figure below:

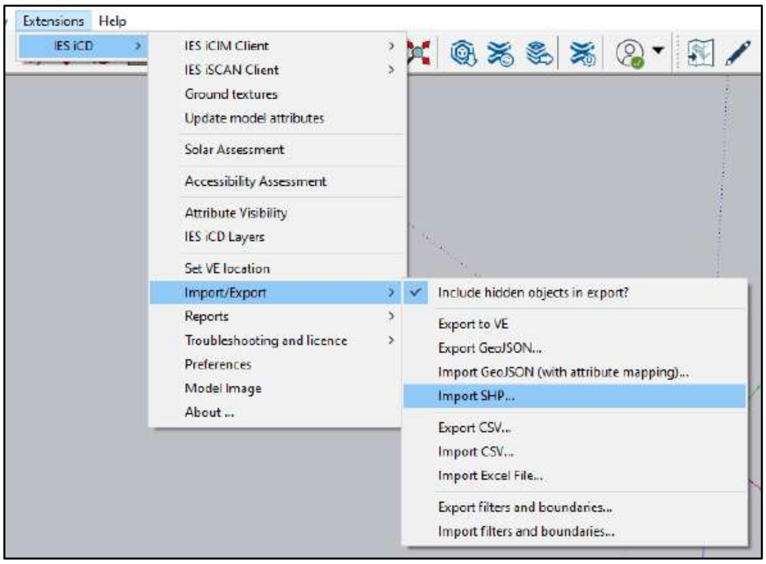

Figure 69 Import shapefile

Final manual tweaks can then be made where building geometry has changed or is not correct in the model / file.

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2. Data assignment

Each building can be assigned various attributes within iCD, which can be edited manually, or imported from other files (.geojson,.shp, .csv). For SO WHAT, the attributes can be related to:

- Geometry Characteristics
- Building type
- Building General information (if known)

Most building data can be added in in the area of the iCD software as shown below:

Figure 70 Building attributes available in iCD.

However, for SO WHAT, the following custom attributes can also be applied to the all buildings regarding their type:

- Commerce
- Education
- Health care
- Hotel
- Office
- Public administration
- Residential
- Restaurant
- Sport

If the user already knows the buildings energy and heat demand, it can be either imported from iSCAN and exported to iCD (see Section B5.2), or created from the use of PLANHEAT software which is specific to SO WHAT (see next Section).

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3. Model the heat demand of buildings in the area using PLANHEAT

It should be noted that the functions performed in the Section are to be completed by a SO WHAT Consultant using PLANHEAT software. If the user wishes to model the heat/cooling demand of buildings in their area, then please contact info@sowhatproject.eu.

PLANHEAT is developed by RINA Consulting for the SO WHAT project and integration between the main SO WHAT software and PLANHEAT has been developed so that current thermal energy (heating, cooling and DHW) demand per each building at district scale can be modelled.

Reference to the PLANHEAT instruction manual (provided by RINA Consulting, will detail how to operate it in conjunction with IES analytical software and models while also explaining its functionality in greater detail.

4. Set up district heating network

To perform this function, the user will need to have iVN software open. The Object Browser displays objects in the 3D or 2D workspace views. The ability to draw, display and edit parameters (i.e. pipes, connections, supply/return temperatures, flow rates, etc) for district heating networks in the iVN has been added for SO WHAT.

In order for there to be a District Heating Network, the following should be present:

- Large, centralised, heat generator facilities heat a circulating fluid (usually water or steam) to a relativity high temperature.
- Potentially smaller decentralized heat generators that operate with medium temperature;
- Pumping facilities pressurize the circulating fluid so it can flow to the end-points (i.e. the consumers of heat).
- Ducts and pipelines carry the circulating fluid directly to the end-points or to heating substations, that act as intermediate facilities with additional pumps or heat exchanges.
- The circulating fluid is exchanged at the end-points using configurable heat exchangers.
- The warm water, which has been cooled at end-points, is returned back to the heat generators parallel return pipes.

For district heating to be successful, it must consider the availability and cost of fuels (or other exploitable heat sources), the topology of the landscape (important for the pressurized hydraulics system) the demand for heat at end-points and the local climate, which heavily influences demand and operating characteristics of the network.

4.1 Configure assets & draw and configure a district heating network

The 2D virtual network is configured by connecting all iVN assets to the nodes for the types of network which are to be simulated. The role of the network nodes is to act as decision points in a network where energy demand are aggregated and loads are allocated (to dispatchable assets), using a control strategy, in order for the providers to meet the demand. Linked nodes create a hierarchy of aggregation through parent-child relationships.

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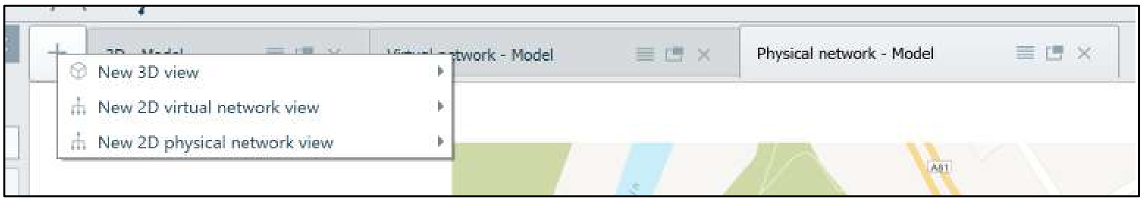

Figure 71 iVN 2D virtual and physical network views.

Users can add 3D building objects to the 2D virtual network by right-clicking the 3D building object in the Object browser or 3D viewer and selecting the 'Add to virtual network' option.

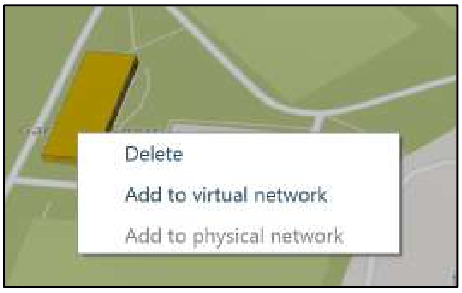

Figure 72 3D viewer and selecting the 'Add to virtual network' option.

A user can also drag/drop assets from the Asset library onto the 'Virtual viewer' and form connections.

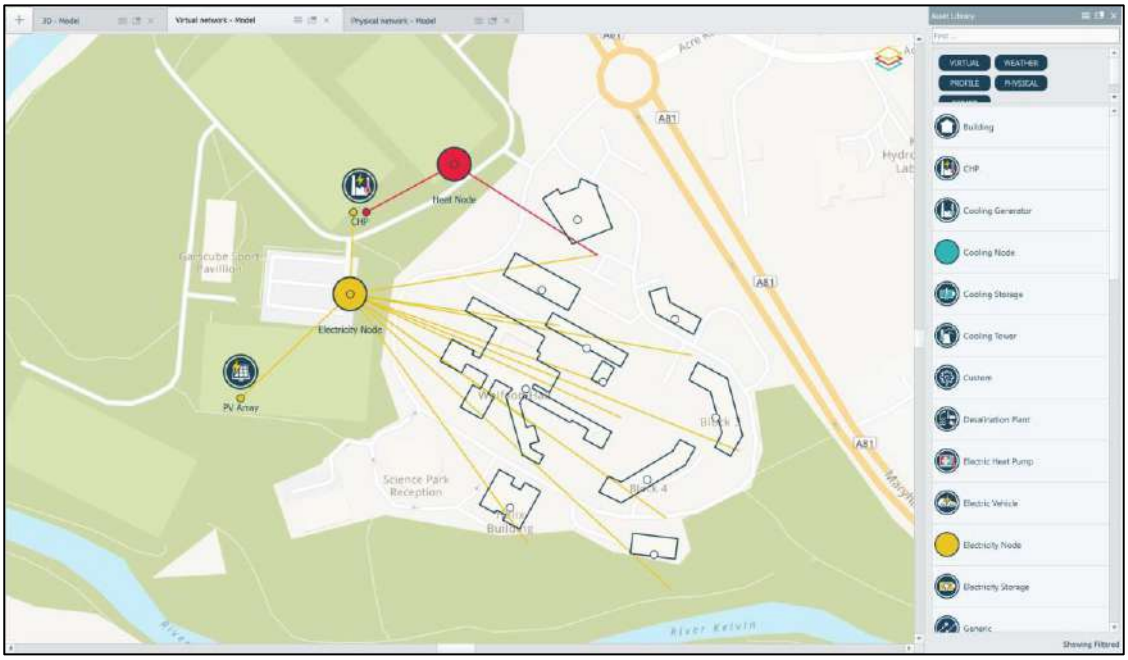

Figure 73 Drag/drop of assets from the Asset library onto the 2D 'Virtual viewer'

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Upon creation of a 2D virtual network users can also create a 2D physical network (previously known as 2D infrastructure (Level 2) network) for electricity and heating. The 2D physical network viewer is a single viewer that displays both electricity and heating/cooling physical networks.

With exception of network nodes, users can add objects displayed in the 2D virtual network to the 2D physical network by right-clicking the object in the Object browser or virtual network and selecting the 'Add to physical network' option.

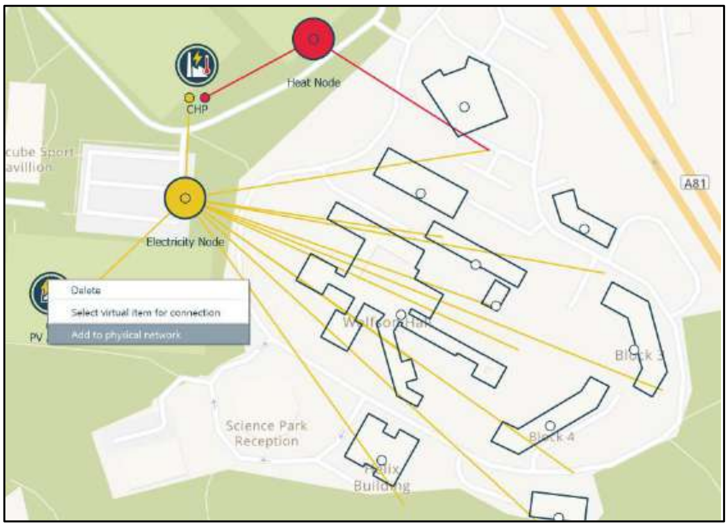

Figure 74 2D virtual network view 'Add to physical network' option.

To form physical connections between objects in the 2D physical network viewer, a user is to right-click the object of interest and select a 'Draw' option. E.g. the CHP object in the 2D physical network viewer enables a user to draw an electricity and/or heating physical connections (branch, pipe) from the CHP to another object.

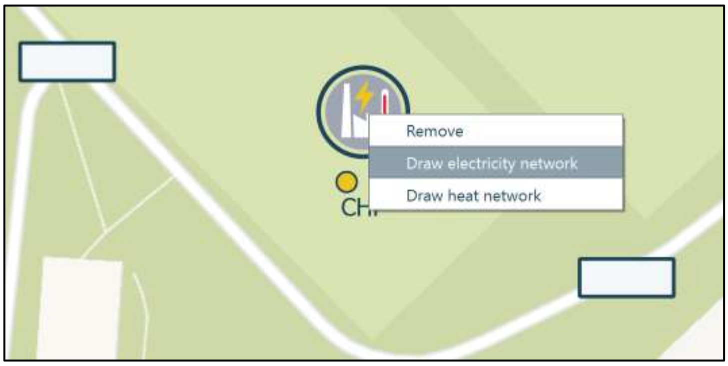

Figure 75 2D physical network viewer 'Draw' option.

The 'Draw [network type] name' is a polyline feature enabling users to form physical connections based on map topology. Heat junction(s) and bus(es) for heating and electricity physical network respectively, are drag/ dropped from the Asset Library onto the 'Physical network viewer' and connections formed.

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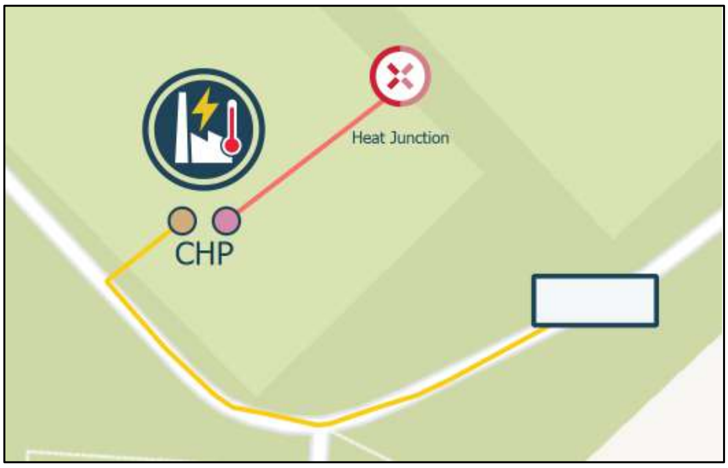

Figure 76 2D physical network viewer 'Draw [network type] name' polyline feature.

Upon forming and completing physical connections between objects in the 2D physical network viewer, simulations are performed via the Simulation hub. The action required to conduct the simulation were explained in Section B 6.2.2, so please refer back to this.

Results are analysed via the Analysis Inspector, which is explained in more detail in Section B 6.2.4, so please refer back to this.

5. Understand the potential supply of energy from Renewable Sources

It should be noted that the functions performed in the Section are to be completed by a SO WHAT Consultant using PLANHEAT software. If the user wishes to understand the potential for renewable energy sources in their area, then please contact info@sowhatproject.eu.

PLANHEAT is developed by RINA Consulting for the SO WHAT project and integration between the main SO WHAT software and PLANHEAT has been developed so that potential renewable energy sources for a given area can be assessed in the PLANHEAT software, and the results displayed in the SO WHAT tools. The renewable energy sources that can be assessed are as follows:

- Biomass
- Wind turbines
- Solar PV
- Solar thermal

Reference to the PLANHEAT instruction manual (provided by RINA Consulting, will detail how to operate it in conjunction with IES analytical software and models while also explaining its functionality in greater detail. Once the potential for supply of energy from renewable sources has been assessed, this can also be simulated in iVN for potential integration with existing manufacturing site or district models.

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Conclusion

Overall, this report has provided a manual for the SO WHAT commercial/advanced tool which can now be used as a step-by-step guideline to enable new users to investigate ways to recover and exploit their waste heat and/or cold (WH/C) resource potential, either by re-using this resource internally (on-site) or by distributing it externally (to local district buildings/sites through a district heating/cooling network).

How to install the necessary software and how to utilise the tools to develop a model appropriate for waste heat/cooling energy recovery and been explained as has how to prepare the models, upload data, run simulations, and review and analyses the results.

A methodology on how individual sites may identify relevant waste energy recovery technologies to investigate and model as well as the relevant building and data that would be best suited to this analysis has also been included.

Following this report, the next steps are to adjust it so that it can be formally used as a User Manual (mainly by removing the Executive Summary and Conclusion), and then to also create and Online Version which will act as D4.6 Delivery of self-learning modules. Following this, training videos will also be created as part of D7.6 Training Resources for Relevant Stakeholders.

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Annex A – Data Checklist

Demonstration Sites Data Checklist	Example				
Participant Organisation Name Code	IESRD				
Participant Location	Dublin (IE)				
Participant Sector	R&D				
Respondent Title	Facility Manager				
Industrial site information		Available? (Y/N)	Readily accessible? (Y/N)	Shareable? (Y/N)	Specify or Comment
Industrial site layout, plans, at a site level	*pdf, dwg, dxf files*				
Industrial site audit report and year of completion	*Audit report number and year of completion*				
Industrial site list of processes	*process = e.g. production line and components within this*				
Industrial site list of services	*service = e.g. boiler, chiller, air-compressing system, etc., that is not directly integrated as a component within a*				
Industrial site list of input and output material type(s), quantity unit and range(s) of temperature	*e.g. cold water (m^3), hot water (m^3), solids (kg), liquids (m^3), recycled (kg), etc. input temperature below 100°C,*				
Industrial site list of input and output product type(s), quantity unit and range(s) of temperature	*e.g. biscuits (kg), dough (kg), etc. output temperature within 75-100 °C range*				
Industrial site layout, plans, at industrial process level	*pdf, dwg, dxf files*				
Industrial site energy storage system type (thermal,	*e.g. ice thermal storage, 200 MW*				
Industrial site energy storage system location and	*pdf, dwg, dxf files or other diagrams*				
Industrial site and/or industrial process logistics strategy	*e.g. just-in-time manufacturing process, production line*				
Industrial site and/or industrial process final product stock capacity and location on-site	*e.g. final product stock constraints, average final product units stocked on-site, minimum and maximum stock*				
Are there any Industrial site energy sub-metering and/or production data monitoring systems installed? If so,	*e.g. Yes, overall energy consumption (gas, electricity, heat, etc.), i.e. for all manufactory site processes,*				
Where are the data collected from Industrial site sub-metering and/or monitoring systems stored?	*e.g. online database*				
Waste heat/cold recovery & Renewable heat/cold and electricity		Available? (Y/N)	Readily accessible? (Y/N)	Shareable? (Y/N)	Specify or Comment
Existing waste heat-to-power conversion technologies (including waste cold) in operation or installed	*e.g. ORC (Organic Rankine Cycle), etc.*				
Existing waste heat-to-heat recovery technologies (including waste cold) in operation or installed	*e.g. Heat recuperators/regenrators, Heat pumps, Sorption chillers, District heating or cooling, etc.*				
Existing other renewable energy systems (RESs) in operation or installed for heat/cold or electricity	*e.g. Solar Thermal Collector (STC), Cogeneration Heat and Power for heating or cooling (CHPH or CHPC), Solar*				
Document on any waste heat/cold recovery technologies and RESs	*e.g. Photovoltaics (Solar PV) panels area, inclination, orientation, type, manufacturer's data, electricity production; Solar Thermal Collector (STC) panels area, inclination, orientation, manufacturer's data;*				
Industrial site processes information, per process		Available? (Y/N)	Readily accessible? (Y/N)	Shareable? (Y/N)	Specify or Comment
Process name	*e.g. Biscuit production line X*				
Process component(s) name	*e.g. Oven X, Conveyer Y, etc.*				
Processed product category	*e.g. Biscuits*				
Processed product name	*e.g. Dry Biscuits*				
Processed product unit	*e.g. kg*				
Processed product maximum flow rate	*e.g. 1500 kg/hour*				
Production profile for process material inputs and outputs	*e.g. On continously*				
Process energy inputs (electricity, gas, heat, etc.), consumption (daily and/or weekly and/or monthly and/or	*e.g. Daily electricity consumption of X kWh, peak electricity demand of Y kW*				
Process inputs from industrial site service(s)	*e.g. Oven X is supplied with hot water by Boiler Y and*				
Process heat/cold output type(s) (air, water, gas, etc.), strategy (i.e. released into space or extracted?) and	*e.g. Exhaust air from Oven X, heat output released into industrial site space at temperature within 200-250 °C*				
Process waste heat/cold type(s) (air, water, gas, etc.),	*e.g. Waste heat from Oven X exhaust air used for*				
Are there any process energy sub-metering and/or production data monitoring systems installed? If so,	*e.g. Yes, Oven X energy consumption (gas, electricity, heat, etc.), exhaust air temperature, and production rate*				
Where are the data collected from process sub-metering and/or monitoring systems stored?	*e.g. online database*				

Figure 77 Sample of demo-site data checklist, part 1.

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Demonstration Sites Data Checklist	***Example***				
Participant Organisation Name Code	***IESRD***				
Participant Location	***Dublin (IE)***				
Participant Sector	***R&D***				
Respondent Title	***Facility Manager***				
Industrial site services information, per service		**Available? (Y/N)**	**Readily accessible? (Y/N)**	**Shareable? (Y/N)**	**Specify or Comment**
Service name	*e.g. Boiler X, Air-compressing system Y*				
Service peak operating capacity	*e.g. Boiler X thermal capacity = 350 kW, etc.*				
Service operating hours for each day/night of the week	*e.g. Boiler X operating hours are from Monday to Friday*				
Service percentage rating (against peak operating capacity) during operating and non-operating hours for	*e.g. Boiler X operated at 90% of operating capacity during operating hours, at 25% of operating capacity*				
Service intermittent periods during daily operation	*e.g. There are 3 intermittent periods of 30 minutes each*				
Service holiday and servicing periods	*e.g. Boiler X is usually shut down for servicing from 1st of*				
Service production calendar	*e.g. Boiler X production calendar is from 1st of Jan to*				
Service energy inputs (electricity, gas, heat, etc.), consumption (daily and/or weekly and/or monthly and/or	*e.g. Daily electricity consumption X kWh, peak electricity demand of Y kW*				
Service output to industrial site process(es)	*e.g. Boiler X is supplying this processes Y and Z*				
Service heat/cold output type(s) (air, water, gas, etc.), strategy (i.e. released into space or extracted?) and	*e.g. Exhaust air from Boiler X, heat output is released outdoor at temperature below 100 °C*				
Service waste heat/cold type(s) (air, water, gas, etc.),	*e.g. Waste heat from Boiler X exhaust air used for*				
Is there any service energy sub-metering and/or production data monitoring system installed? If so, please	*e.g. Yes, Boiler X energy consumption (gas), exhaust air temperature, and output hot water tempearature*				
Where are the data collected from service sub-metering and/or monitoring systems stored?	*e.g. online database*				
Automated Meter Reading (AMR) data and energy costs information		**Available? (Y/N)**	**Readily accessible? (Y/N)**	**Shareable? (Y/N)**	**Specify or Comment**
Fossil Fuel Yearly (kWh)	*e.g. 2250 kWh gas*				
Electricity Yearly (kWh)	*e.g. 1862 kWh electricity*				
Electricity bills	*Total energy costs for electricity, or break down of month energy bills in kWh / cost e.g. Jan - 100kWh, €60 feb - 120kWh, €70*				
Fossil fuel bills	*Total energy costs for fossil fuel, or break down of month energy bills in kWh / cost e.g. Jan - 100kWh, €60 feb - 120kWh, €70*				
Existing energy metering infrastructure (e.g. smart metering) and characteristics (time and space resolutions,	*e.g. electricity smart metering, 15-min time resolution, at a building level, remote data access and extraction*				
Existing energy supply tariffs and schemes (e.g. ToU	*e.g. Electricity Day/Night tariffs, or other time-of-use*				
Is there any building energy management system (BEMS)	*e.g. lighting control*				
Is there any smart sensor in the building (e.g. measuring	*e.g. yes, temperature sensor in building room/area X*				
Where are the data measured from the smart sensors stored?	*e.g. online database*				
General building information		**Available? (Y/N)**	**Readily accessible? (Y/N)**	**Shareable? (Y/N)**	**Specify or Comment**
Building ID	*e.g. is there any national/local building identifier*				
Building construction year	*e.g. 2002*				
Building condition (Bad, Fair, Good)	*e.g. Good*				
Building ownership	*e.g. Tenancy, Owner-occupied, etc.*				
Building hours of use (Morning & Evening & Night)	*e.g. 9am - 5pm Mon-Fri*				
Building type	*e.g. Office*				
Building address	*e.g. Office, Block 1, Street Name*				
Building HVAC system type(s) (e.g. heating/ cooling /	*e.g. Radiators for heating & Natural ventillation for both*				
Building HVAC fuel(s) utilised	*e.g. Gas for heating and DHW*				
Building floor area (GIFA / Net)	*e.g. 1987 m^2*				
Building floor plans	*pdf, dwg, dxf files*				
Building elevation plans	*pdf, dwg, dxf files*				
Building section plans	*pdf, dwg, dxf files*				
Building fenestration area	*e.g. 345 m^2*				
Building construction material type(s)	*e.g. Concrete frame construction*				
Building Energy Performance Certificate (EPC) level (with	*e.g. B3*				
Site photographs	*e.g. jpeg files*				

Figure 78 Sample of demo-site data checklist, part 2.

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