



Thermal Energy Resource Modelling and Optimization System

Replication Guide



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1 Introduction

The Horizon 2020 THERMOS project aims to accelerate the development of new low-carbon heating and cooling systems across Europe, and enable faster upgrade, refurbishment, and expansion of existing systems in line with the current ambitious EU energy and climate targets. The overall aim of the project is to provide the methods, data, and tools to enable more sophisticated, rapid, and cheap thermal energy system planning, with the THERMOS tool as a central point of reference.

The THERMOS tool makes District Heating and Cooling (DHC) planning processes easier, faster, and more cost-effective, supporting energy planners in the evaluation of the expansion of an existing system, the planning of an entirely new system, or in comparing the performance of a potential energy network with the deployment of individual solutions on buildings. This means that the tool does not only facilitate the rollout of energy efficient energy networks, but also supports the decarbonisation and refurbishment of existing systems, allowing users to prioritise renewable energy sources and climate targets.

This document, the THERMOS Replication Guide, is meant to support the replication and wide adoption of the THERMOS model across Europe: its main target audience are the expanding community of THERMOS users, trainers, and ambassadors. This document provides a high-level guidance on exploiting the methodologies and tools developed during the project, with special focus on the THERMOS Tool¹. Moreover, it contains facts and advices for using the THERMOS Tool, as well as examples and lessons learnt from the THERMOS pilot and replication cities' experience of employing it.

For further information, the reader should refer to other publications² of the THERMOS project, as indicated in the relevant sections, or to the online THERMOS Tool user manual³.

¹ See <https://tool.thermos-project.eu>

² See <https://www.thermos-project.eu/tool-support/publications/>

³ See <https://tool.thermos-project.eu/help/index.html>

2 Low-carbon district thermal energy planning – implementing the European Green Deal with THERMOS

Modern district energy systems in cities are considered amongst the most economic and efficient solutions to reduce GHG emissions and primary energy demand and allow cities to have a central role in the energy transition (UNEP, 2015).

District energy systems are increasingly climate-resilient; low-carbon and affordable: they combine district heating and cooling networks with elements such as combined heat and power (CHP), renewable energy, thermal storage, and heat pumps.

THERMOS is key to facilitate the development and efficiency improvement of district energy systems, including heating and cooling networks.

Key steps in developing a district energy system	THERMOS
1. ASSESS energy and climate policy objectives and strategies and identify catalysts	
2. STRENGTHEN the institutional multi-stakeholder coordination framework	✓
3. INTEGRATE district energy into national and/or local energy strategy and planning	✓
4. MAP local energy demand and evaluate local energy resources	✓
5. DETERMINE relevant policy design considerations	✓
6. CARRY OUT project pre-feasibility and pre-viability analyses	✓
7. DEVELOP a business plan and a detailed engineering design	
8. ANALYSE procurement options	
9. FACILITATE finance	
10. SET measurable, reportable, and verifiable project indicators	

Figure 2-1 – THERMOS fit in the District energy development phases. Source: (UNEP, 2015)

Local governments foster the development of district energy projects in order to achieve sustainable energy benefits on a local level, such as affordable energy provision, reduced reliance on energy imports and control of energy supply. The reduction of GHG emissions as a result of district energy planning processes has been perceived as a co-benefit rather than a main driver for emission reduction on a local level (UNEP DTU Partnership. Copenhagen Centre on Energy Efficiency, 2019). In this sense, it is important that cities include district energy projects within their Sustainable Energy and Climate Action Planning (SECAP) processes, putting in value the emissions reduction potential of these type of projects.

From a policy development perspective, THERMOS can contribute to SECAP development in local governments. THERMOS can provide the tools to assess thermal energy projects and policies promoting sustainable solutions at district and building level. These can turn into

official mitigation actions that could help local governments reach their local energy and emissions reductions goals.

In addition, THERMOS can also help local governments to identify new local sources for potential heat and cold production or recovery options that have not been evaluated before. Figure 2-2 shows a schematic approach on how local governments may frame district energy projects within SECAP development processes.

Currently, at European level, the SECAP structure under the Covenant of Mayors includes three pillars: mitigation, adaptation, and energy poverty. THERMOS-driven projects and initiatives should be framed mainly into mitigations actions, meaning that actions or projects will directly reduce GHG emissions at a city level. These projects can be driven by different motivations: energy efficiency improvement, increase of renewable energy generation or switching of fuel sources.

Figure 2-2 also illustrates how projects designed with THERMOS naturally fit into the SECAP process of the cities under “smart local heat and cold production or optimization projects” if conceived properly.

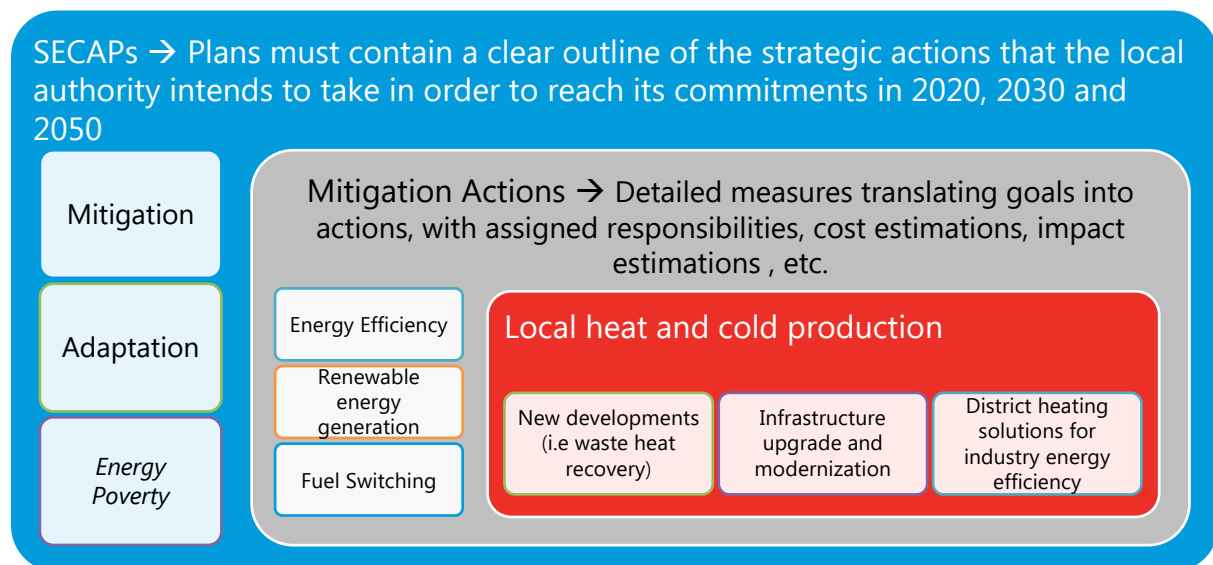


Figure 2-2 – SECAP development with THERMOS

Within their SECAP processes, cities can evaluate the alternatives provided by THERMOS as key mitigation actions. To develop this, it is recommended that cities follow the EUCom Reporting Guidelines⁴, which recognize projects in the field of district heating and cooling as *local heat and cold production projects in the city*.

⁴ EU Covenant of Mayors. SECAP Reporting Guidelines. March. 2020.
https://eumayors.eu/index.php?option=com_attachments&task=download&id=857

3 The THERMOS Adoption Process

Cities and other local stakeholders aiming to adopt THERMOS in their energy planning process should follow the process illustrated in Figure 3-1 below.

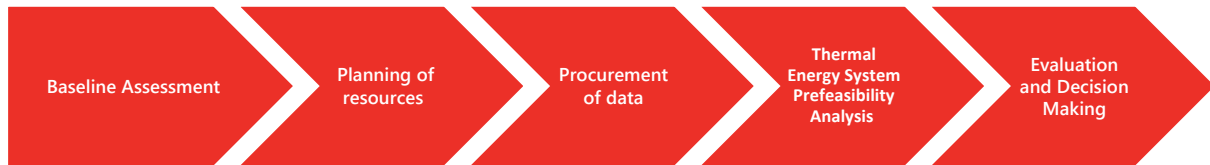


Figure 3-1 – THERMOS Adoption Process

3.1 Baseline Assessment

The Baseline Assessment phase aims to map out and assess the national and local framework conditions for a successful adoption of the THERMOS model. Throughout this section, the most relevant elements that should be considered for the adoption of the THERMOS tool are analysed. The analysis covers the following elements, highlighting relevant examples from the Pilot and Replication cities participating in the project:

- Policy and regulatory framework assessment
- Stakeholder identification
- Sustainability Goals and Key Performance Indicators
- Planning of Resources

In the next sections, we provide general guidance in order to carry out the baseline assessment in a given area of interest. Further guidance and examples can be found by consulting the THERMOS Baseline Replication Assessment Report⁵.

3.1.1 Policy and Regulatory Framework Assessment

In order to get started, it is important to define the policy and regulatory framework related to thermal energy planning in the targeted area in order to determine how it can affect the overall THERMOS adoption process.

It is necessary to examine the key pieces of legislation related to the overall thermal energy system and identify the main targets for its deployment, with special focus on the exploitation of renewable energy and residual heat sources, all the while taking into account the overall opportunities for achieving energy efficiency and environmental protection goals, and other

⁵ The full report is available [here](#). For chapters on individual cities, please visit the THERMOS city profiles [here](#).

local constraints such as building and construction regulations, urban development goals, supply chains and skillsets available.

Table 3–1 below illustrates the key framework criteria applying to the local authorities participating in the THERMOS project.

Criteria	Granollers	Jelgava	Islington	Warsaw	Cascais	Alba Iulia	London	Berlin
Signatory of CoM and has developed a SE(C)AP	✓	✓		✓	✓	✓	✓	✓
Goals on energy and GHG emissions reduction	✓	✓	✓	✓		✓	✓	✓
Participation of private utilities in the district planning process	✓			✓	✓			✓
Existence of regulations, ordinances that foster district and heating networks development	✓		✓	✓		✓	✓	✓
Existence of incentives for DH network infrastructure development	✓	✓	✓	✓		✓	✓	✓

*Table 3–1 – Summary of key policy and regulatory aspects in THERMOS cities
Source: (THERMOS Project, 2018)*

Finally, it is important to clarify which organisation or entity has the responsibility for local energy planning and how this responsibility fits into the overall local and regional planning processes.

3.1.2 Identification of Stakeholders

In order to ensure a successful and swift process, it is important to identify and engage the key stakeholders that will influence the development of the thermal energy planning project. Based on the experience of THERMOS, the key five stakeholder groups that need to be involved are:

- 1. National/Regional Government:** Energy and environment ministries, financial and fiscal departments, utility commissions, grid operators; energy agencies;
- 2. Local Government:** municipalities, planners, and regulators, building code officials, energy or facility managers, municipal utilities, environmental services units;
- 3. Business:** Utilities and subsidiaries, energy service and energy management companies, engineering firms and technology providers, local supply-chain companies;
- 4. End-users:** Industries, real estate, governments, building owner associations, hotels, and retail chains. Finance institutions: World Bank, regional development banks, GEF, finance institutions, pension funds;

5. Experts: Professional associations, international and local NGOs, industry groups, national and local experts.

The following charts provide a couple of examples on the composition of the Local Liaison Stakeholder Groups in the THERMOS cities of Jelgava (Latvia) and Granollers (Spain).

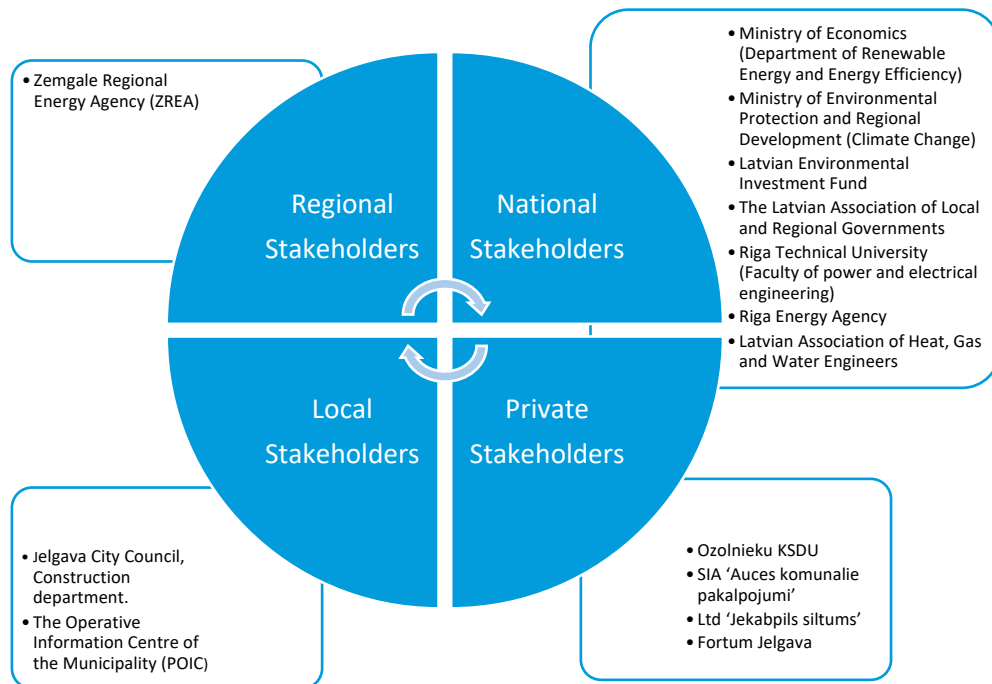


Figure 3-2 – Key stakeholders in Jelgava, Latvia

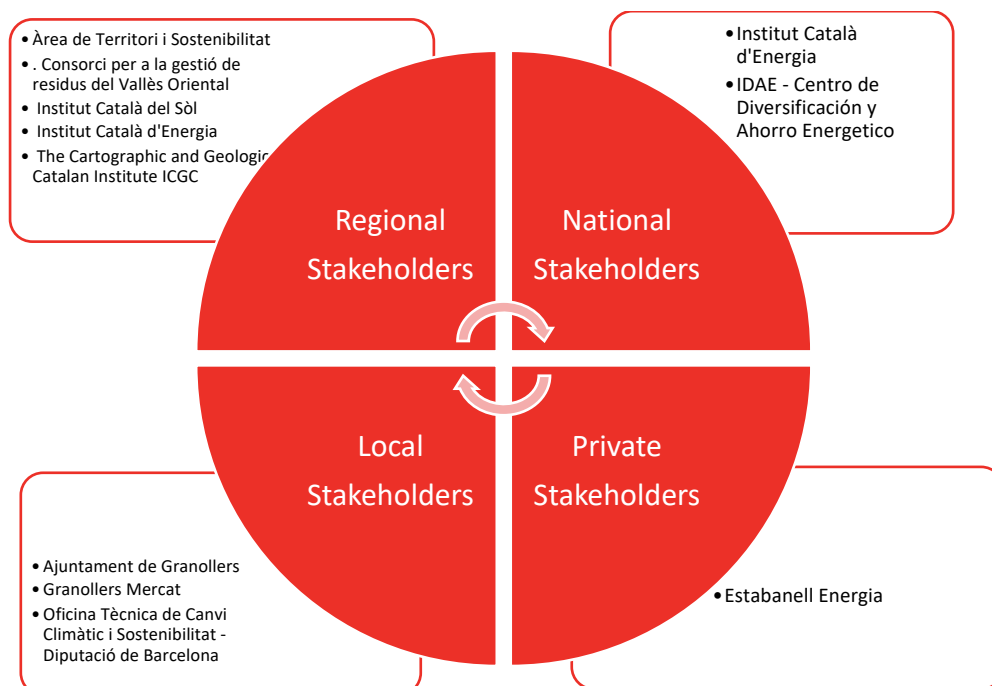


Figure 3-3 – Key Stakeholders in Granollers, Spain

3.1.3 Sustainability Goals and Key Performance Indicators

To mainstream thermal energy projects and planning processes with THERMOS into local sustainable energy and climate action processes (SECAPs), several KPIs should be identified and followed up. These should allow to quantify the thermal network performance and impact on a city's overall energy performance and GHG emission management processes.

Some examples of suggested KPIs, adapted from the SECAP Reporting Template (EU Covenant of Mayors) and the Celsius project⁶ are presented in Table 3–2 below.

Group of KPIs	Categories
Energy Supply and Demand (1)	A. Final Energy Consumption (MWh) B. Local Energy Supply (MWh) B2. Local/distributed electricity production (Renewable energy only) B3. Local/distributed electricity production B4. Local heat/cold production
District energy related GHG Emissions (1)	GHG emissions (tons CO ₂ equivalent)
District Energy Infrastructure (2)	Length of networks (km) Connected households to district energy networks (no. of households)
Economic KPIs (3)	Energy cost

Table 3–2 – Baseline Assessment KPIs

The project promoters should choose a small number of significant KPIs (2 or 3) taken from this set and establish the minimum objectives that should be reached by developing the project (e.g., emission reduction of 2,000 tons of CO₂ equivalent/year). These KPIs will help cities or local governments understand the impact of integrating new district energy project development (with THERMOS) into local planning processes.

3.2 Planning of Resources

The identification of a thermal energy system opportunity and its planning is a very lengthy and resource-consuming process. While THERMOS can speed up the process, local governments should prepare accurately to embark on this process in a consistent and sustainable way. Some of the key issues to be addressed include:

- **Governance model:** Initially, it will be necessary to identify the entity or organisation which is ultimately responsible for leading the project development and put in place

⁶ <https://celsiuscity.eu>



relevant decision making and communication processes. The key staff leading the project development activities should be identified and their availability secured.

- **Definition of a project plan:** once the organizational part of the project is clear, it is time to start designing a first draft of the project. Throughout this stage the project will be defined, including the scenario that will be replicated, local conditions, goals and KPIs, timeline, key policy and legislation regarding the project, major players involved in the process. The more thorough this process is, the more consistent the project will be, as a well-defined project will be easier to develop and less susceptible to unexpected events.
- **Engagement of critical stakeholders:** after having a well-defined project plan, the next logical step is the engagement of stakeholders already identified in the previous step. The stakeholder engagement is one of the most important aspects of the project since their involvement can guarantee the overall project success. It is a common practice to create a small Local Liaison Group (LLG). The LLG is composed of all entities which have interest in the project going forward, meets periodically and supports the project leaders to identify further stakeholders and help engage with them.

3.3 Procurement of data

The THERMOS tool allows to elaborate a thermal energy planning solution based on a vast set of technical, economic, and financial data.

The more precise and detailed the available data is, the better the solution the THERMOS tool will deliver. The procurement of data can be a lengthy and iterative task, lasting several weeks: in practice, once an initial set of data has been gathered, its introduction into the THERMOS tool will lead to the elaboration of a preliminary solution, which will highlight the need to gather further/better data. For these reasons, early in the adoption process, it is necessary to identify and start procuring the different sets of data, also leveraging on the group of supporting stakeholders.

In Table 3–3 below we illustrate the main categories of data that are needed to define and characterise a thermal energy planning problem to address it with the THERMOS tool. Many of these data can initially be derived or estimated by THERMOS, enabling the user to perform a basic analysis with minimal data procurement. However, it is important that supplementary data is added by the user wherever available to improve accuracy.

Category	Sub-category	Data
Energy	Demand data	Building annual demand
		Building peak demand
		Building peak/base ratio
		Heat profiles (Supply Model)
		Substation load profiles (Supply model)
	Existing resources	Existing network characteristics
		Current waste heat potential
	Expected network	Flow and return temperatures
		Thermal fluid type
		Required demand connections
	Equipment	Supply parameters
		Supply characteristics (Supply model)
		Substation characteristics (Supply model)
		Storage characteristics (Supply model)
Economic	Civil works	Network cost (both pipes & civil works)
		Pumping & mechanical costs
		Construction costs for heat supply
	Demand & Supply	Benchmark data
		Applied tariffs
		Supply equipment costs
		Emission costs
		Fuel price profiles (Supply model)
		Supply technologies costs (Supply model)
		Storage technologies costs (Supply model)
Technical	Geographical	Building location, including the location of energy centre (supply)
		Building's shape and size
		Building's height
		LIDAR
		Additional building information (demand profile, floor area, building addresses and types)
	Climatic	Heating degree days
		Ground temperature
	Emissions	Supply specific emissions
		Emissions limits
		Emissions profiles (Supply model)
	Individual building measures	Individual building heating and cooling systems
		Individual building insulation measures

Table 3-3 – THERMOS data types



3.4 Thermal Energy System Pre-Feasibility Analyses

The THERMOS tool allows to address thermal energy system masterplanning and pre-feasibility analyses tasks in a rapid and intuitive way, using a standardised and easily replicable approach.

Depending on the objectives of the analysis, there are two different network optimisation options that can be chosen:

- **Maximize network NPV:** the goal is to choose which demands to connect to the network in order to maximize the NPV for the network operator.
- **Maximize whole-system NPV:** the target is to choose how to supply heat to the buildings in the problem (or abate demand) at the minimum overall cost for the whole system

The main difference is that the second option also considers the effect of non-networked factors such as individual heating and cooling systems, building insulation measures, and emission costs. At the same time, this option does not account for the transfer of money between buildings and the network operator, so network operator revenues and energy sale tariffs to have no effect.

When using the first option, the impact of non-network factors can be accounted for by using the market tariff option, which as part of the optimisation process determines the energy sale tariff that beats the best non-networked system available for each building.

At the beginning of the project, the THERMOS development team discussed with the rest of the consortium about the objectives and the main features of the tool, in order to make sure that it suited the interests and needs of its target users (e.g., local authorities and energy planners). As a result, it was agreed that the tool would address the four main use cases illustrated below and further detailed in Section 4.5.1.

3.4.1 Adding new sites and connections to an existing network

This use case is aimed at allowing users to assess possible expansions of an existing district heating and cooling network. The THERMOS tool makes it much easier to compare different network expansion options within the same analysis, therefore avoiding repeated individual analyses and their associated cost, both in terms of money and time.

Under this use case the user can specify the structure of the existing network, the options for extending it (including new potential paths and buildings to be connected), and the criteria for selecting the best solution (Maximize network NPV).



The Warsaw case study described in the THERMOS Cities Case Studies publication⁷ is a good example of this scenario. The city of Warsaw already has an extensive district heating network, but, since several network energy efficiency measures have been applied to the network throughout the years, there is now additional thermal capacity to connect new neighbourhoods.

3.4.2 Planning a new network based on a given heat source

This use case allows the user to plan a new district heating network based on a given heat source. This scenario is targeted at new developments which want to implement a heat network with a single supply, which has certain characteristics, and is the key dimensioning factor in the project.

In this case, the user specifies the location and capacity of the energy source, the set of potential paths and buildings, and the criteria for selecting the best solution. The tool will try to include as many demands as possible in the solution. This optimisation will be performed based on the supply capacity of the heat source and on the economic parameters that affect the project's NPV; some examples of these parameters would be fixed costs, variable costs, or price of sold energy.

The Alba Iulia case study described in the THERMOS Cities Case Studies publication⁸ is an example of this use case. The city of Alba Iulia has identified a potential energy supply facility and considered a set of public buildings that could be served by a district heating network.

3.4.3 Designing a new network to supply a given set of buildings using one or more potential heat sources

This third THERMOS use case is similar to the previous one: the main difference is that in this scenario there are multiple thermal energy supply facilities being evaluated. This scenario is useful to compare different heat sources depending on their characteristics (such as capacity, costs, location, emissions impact), but also to combine them to try to find the best optimisation for the network.

The user specifies the set of buildings which must be served by the network, the location(s) of the potentially available heat source(s) as well as their characteristics, and the criterion for selecting the best solution.

Through this kind of analysis, energy planners can easily identify the best potential routes and heat sources for an identified set of buildings whose operators may be willing to shift from individual heating solutions to a district heating network. The solution will also provide an

⁷ See <https://www.thermos-project.eu/tool-resources/publications/>

⁸ See <https://www.thermos-project.eu/tool-resources/publications/>



optimisation for the best heat source to supply the network or a combination of them that satisfies the demand in a more feasible or economic way.

3.4.4 Assessing and comparing the performance of specific networks and individual non-network solutions

The tool also allows to compare the deployment of a proposed heat network with the installation of individual solutions, such as heat pumps or solar thermal systems. To do so, the user can specify the characteristic parameters of the alternative individual solutions, such as their costs and emissions, and allow the tool to determine the best solution according to a global system optimisation objective (Maximize whole-system NPV).

The user is also able to select independent sets of buildings and set different individual options that might be feasible for those clusters. The tool will then choose the best solution from the compiled options based on the optimisation criteria provided by the user.

The aim of this use case is to provide an easy way for energy planners to compare the viability of implementing a district heating network against other specific systems used as an alternative. Thus, this improves the decision-making process regarding the area where the network will be developed, by achieving a faster and more precise solution.

Also in this use case, the Warsaw case study has been chosen as an example, as the evaluation conducted over the Białołęka District also contemplates the installation of less emission intensive individual heating solutions as an alternative option to connecting the building to the heat network.

3.5 Evaluation and Decision Making

Once the first meaningful results are extracted from the THERMOS tool, an iterative process is likely to start. During this process, the results will be presented to decision-makers, and the outcome of such presentation will lead to the identification of several further planning questions that will be answered by procuring additional data and estimating alternative scenarios utilising the THERMOS tool.

In this regard, the KPIs established at the beginning of the process, as outlined in section 3.1.3, will serve as a quantitative measure of how far or close the current thermal planning solution ranges from the original objectives.

The THERMOS tool, described in Section 4, provides very detailed information regarding the solution it has identified, such as financial and economical estimates, supply and pipework details and thermal energy sale revenues. This information is very valuable for the following phase of the project development, which can either be the set-up of a public tendering process or the development of a detailed technical design.

4 Working with the THERMOS Tool

4.1 THERMOS Tool Basics

4.1.1 Scope

The THERMOS tool aims to support energy planners in accurately, rapidly, and cheaply identifying the options for thermal energy networks in any given area. By iteratively designing and developing the methodology and modelling algorithms in collaboration with users from local authorities and project developers, we have created a software which can produce consistent results - regardless of the geographic scale on which it is applied.

Our goal is to make it simple for THERMOS users to obtain accurate results and information through an easy-to-use application which reflects the detailed models required to underpin local network planning.

4.1.2 Definitions

Before we start, let us provide a few key definitions to understand the rest of the sections below. In THERMOS, we can initially define a thermal energy planning **problem** by choosing the elements that are involved in it: one or more thermal **energy supplies** (generally located in a building or represented by a point on the map), a number of distinct thermal **energy demands** (usually identified with buildings), and a set of **paths** and **connectors** that interconnect demands and supplies.

These elements are generally referred to as **candidates**, as they may or may not be part of the optimised THERMOS thermal energy planning **solution**. Candidates can be either:

- **Required** - they must be part of the solution
- **Optional** - they may or may not be part of the solution
- **Forbidden** - they will not be considered in the problem

Each of these candidates is characterised by detailed energy, economic, and technical **data** such as thermal energy demand, thermal energy sale tariff and maximum pipe size. All the categories, subcategories and the types of data were summarised in Table 3–3. This data can be initially imported by the user or estimated by the application, and later adjusted by the user with various procedures, which are explained in section 4.4.

Thanks to candidate data, a problem can be defined in various levels of accuracy, as presented in section 4.5.

Finally, once a problem is fully defined, the user can choose the options for the optimisation process that will be used, and the THERMOS tool will then elaborate a **solution** to thermal energy planning problem, defined as a sub-set of the candidates that belong to the problem.

A THERMOS solution is complemented with a vast set of graphical and quantitative information presented in section 4.6.

4.1.3 Requirements

Technical skills

THERMOS is intended to support people who already have a moderate to sophisticated understanding of thermal networks and are assessing the feasibility or in the early stages of planning a network. Other than that, not much more is needed since THERMOS is an open-source web-based tool and a comprehensive training programme can be found online.

IT equipment

As THERMOS is available as an online tool, the only technical requirement is to have access to a web browser, preferably Google Chrome or Firefox. Because the processing power does not come from the user's computer but from the tool servers itself, computer specifications such as the need for a high-performance processor or graphic card are not important. THERMOS also securely stores the projects online in each respective account, not using any of the computer's memory.

4.2 Demand Estimation in THERMOS

When elaborating a thermal network optimisation solution, a fundamental ingredient is the annual and peak demand associated to each building candidate. These values are estimated by the THERMOS tool based on the data available to it. The tool will always use the best available estimate by choosing, in order of preference, from user provided data, benchmarks or the integrated 3D and 2D shape-based regression models.

It is useful to understand the full process followed by the tool, because by appreciating it, a user can figure out which data is needed and can prioritise its retrieval. In order to estimate annual demand and peak demand values for a given building candidate, the THERMOS tool will follow the prioritised process below:

1. Determine **building height**, if possible, using:
 - Any user-specified height field;
 - LIDAR heightmap data, if available.
2. Determine **building floor area**, using:
 - Any user-specified floor area field;
 - The footprint area and height, if available from step 1;
 - The footprint area alone.
3. Determine **annual demand**, using:
 - Any user-specified annual demand fields;

- Any benchmark field associated to the building, applied using floor area;
- A shape-based regression model using 3D information and degree-days (if height is available from step 1);
- A shape-based regression model using 2D information and degree-days (if height is not available from step 1).

Table 4–1 illustrates the approach outlined in the steps above. The table also indicates the order of priority, i.e., user-entered demand values (presented from the top row) are always used in preference to anything else.

Data					THERMOS ESTIMATION
Annual demand (kWh/year)	Variable benchmark (kWh/year)	Floor area (m ²)	Constant benchmark (kWh/year)	Height (m)	Annual demand (kWh/year)
V ₁	n/a	n/a	n/a	n/a	User provided demand value
null	V ₂	V ₃	V ₄	n/a	V ₂ × V ₃ + V ₄
null	null	null	null	V ₅	3D prediction (based on height)
null	null	null	null	(LIDAR)	3D prediction (based on LIDAR)
null	null	null	null	null	2D prediction (based on surface)

Table 4–1 – THERMOS Annual demand calculation or estimation process

V₁ to V₅ represent the different data values that may be provided by the user. In case of demand estimation based on benchmarks, three parameters are used:

- Variable benchmark (kWh/m²/year)
- Floor area (m²)
- Constant benchmark (kWh/year)

Considering these three values, the estimation of the demand is done by applying the following equation: **Demand = Constant benchmark + Floor area × Variable benchmark**

4. Finally, the tool will determine **peak demand**, using:

- the user-specified peak demand field;
- the peak/base ratio field (if available) multiplied by the annual demand (converted into kW);
- the built-in regression model based on annual demand.

In the next sections, we will illustrate how the user data discussed above can be entered in the THERMOS tool, and how it can be used to define a problem and to obtain accurate results.

4.3 Managing Data in THERMOS

The THERMOS tool can elaborate a thermal energy planning solution based on a vast set of technical, economic, and financial data. The more precise and detailed the data available is, the better the result will be.

Table 4–2 provides an overview of the main data types used in THERMOS, illustrating whether they can be entered via the tool's user interface (UI) or by uploading a GIS file. In fact, the first step in order to define a problem is to create a **map** in THERMOS using any of these two methods.

If a map is created via the UI, the building and path information is uploaded from the free OpenStreetMap⁹ dataset, with no additional energy, economic and technical information. The tool will then use its 2D model algorithm to estimate the demand of each building as a function of the footprint of the building and local ambient temperatures derived from the degree-days value. Due to the lack of information on building shape, height and destination, this method leads to rougher estimations. However, if LIDAR data is also uploaded for the same location, the tool will then use its 3D model to better estimate demands.

Alternatively, a user can upload custom GIS shapefiles with paths and buildings, and associate energy, economic and technical information to each building and path in the files.

Once a map is created, most parameters can be set or adjusted via the UI. Further, a set of these parameters can be downloaded in an Excel file, modified, and then uploaded again. Similarly, a GIS file corresponding to an existing map can be downloaded, modified in an external GIS application such as the free open source QGIS¹⁰, and then uploaded again, creating a new map.

For users that intend to upload their data, it is important to mention that any uploaded information will be safe and only accessible in their user account, and that only the user can decide who is allowed to view their maps by adding them as additional project users. Moreover, the THERMOS tool does not store any user data on the web, and all its information is stored in a physical server on site at CSE, where it is kept secure.

⁹ <https://www.openstreetmap.org/>

¹⁰ <https://qgis.org/en/site/>

Category	Sub-category	Data	Input and edit		
			UI	GIS	Excel
Energy	Demand	Buildings annual demand	✓	✓	✗
		Buildings peak demand	✓	✓	✗
		Buildings peak/base ratio	✗	✓	✗
		Heat profiles (Supply Model)	✓	✗	✓
		Substation load profiles (Supply model)	✓	✗	✓
	Existing resources	Existing network characteristics	✓	✗	✗
		Current waste heat potential	✓	✗	✗
	Expected network	Flow and return temperatures	✓	✗	✓
		Thermal fluid type	✓	✗	✓
		Required demand connections	✓	✓	✗
	Equipment	Supply equipment parameters	✓	✗	✗
		Supply characteristics (Supply model)	✓	✗	✓
		Substation characteristics (Supply model)	✓	✗	✓
		Storage characteristics (Supply model)	✓	✗	✓
Economic	Civil works	Network cost (pipes and civil works)	✓	✗	✓
		Pumping & mechanical costs	✓	✗	✓
		Heat supply construction costs	✓	✗	✗
	Demand and supply	Benchmarks and ratios	✗	✓	✗
		Applied tariffs	✓	✗	✓
		Supply equipment costs	✓	✗	✗
		Emissions costs	✓	✗	✓
		Fuel price profiles (Supply model)	✓	✗	✓
		Supply technologies (Supply model)	✓	✗	✓
		Storage technologies (Supply model)	✓	✗	✓
Technical	Geographical	Building location	✓	✓	✗
		Building shape and size	✗	✓	✗
		Building height	✗	✓	✗
		LIDAR ¹¹	✓	✗	✗
		Additional building information	✓	✓	✗
	Climatic	Heating degree days ¹²	✓	✗	✗
		Ground temperature	✓	✗	✓
	Emissions	Supply specific emissions	✓	✗	✗
		Emissions limits	✓	✗	✓
		Emissions profiles (Supply model)	✓	✗	✓
	Individual building measures	Building heating & cooling systems	✓	✗	✓
		Building insulation measures	✓	✗	✓

Table 4-2 – THERMOS data types and input methods

¹¹ Light Detection and Ranging; remote sensing method used to examine the surface of the Earth.

4.4 Setting up a problem in THERMOS

4.4.1 Using OpenStreetMap

As discussed, via the THERMOS user interface a map is created based on OpenStreetMap geometry: buildings, paths and connections shapefiles are built based on the public information available for the selected area.

The tool will provide initial thermal energy demand estimates for each building based on the building polygon shape using the 2D model, or, only for those cases in which building height, or a LIDAR layer, is available using the 3D model, in both cases Eurostat or user-set degree days information will be used. Further, standard network-related technical and civil works cost estimates will be provided by the THERMOS tool using its default values.

4.4.2 Using GIS files

This is the recommended option for those users who have accurate demand and cost information on their case study area, as the results of the optimised thermal energy problem solution will be more accurate. There are three available GIS format options to upload: GeoPackage, GeoJSON or shapefiles.

This task requires some preparation and the use of a GIS software such as QGIS. The key steps are illustrated in the next sections.

Creating a buildings layer in a GIS program

The THERMOS tool needs **polygons** or **multipolygons** for building outlines. When preparing GIS files are, if the corresponding information is available and depending on the demand estimation method chosen, we recommend including the following attributes:

- **Identity** (text): an identifier. Presents a building in the tool (a text identifying the different buildings such as cadastral reference)
- **Annual Heating Demand (kWh/year)** (numeric): annual energy demand for the whole building considering all different users in it.
- **Peak Heating Demand (kW)** (numeric): peak energy demand for the whole building considering all different users in it.
- **Annual Cooling Demand (kWh/year)** (numeric)
- **Peak Cooling Demand (kW)** (numeric)
- **Building height (m)** (numeric): height of the building in metres

¹² This field will be pre-populated with a relevant value based on the project's location, derived from Eurostat. If the location is outside the Eurostat area, the tool provides a default value of 2000 °C days, and the user can enter a different value (relative to a 17°C base temperature), e.g., based on <https://www.degreedays.net/>.



- **Floor area (m²)** (numeric): the building's internal floor area (considering all floors)
- **Heating benchmark (variable, kWh/m²/year)** (numeric) Parameter to be multiplied by the internal floor area in order to provide the energy consumption of a building, after adding it to the constant value (see below).
- **Heating benchmark (constant, kWh/year)** (numeric constant): Parameter to be added to the variable component (see above).
- **Cooling benchmark (variable, kWh/m²/year)** (numeric) Parameter to be multiplied by the internal floor area in order to provide the energy consumption of a building, after adding it to the constant value (see below).
- **Cooling benchmark (constant, kWh/year)** (constant numeric): Parameter to be added to the variable component (see above).
- **Peak/base ratio** (numeric): if present and no peak demand value is known, the peak demand will be estimated as the annual demand multiplied by this factor.
- **Connection count** (numeric): the number of end user connections the building contains. This affects only the application of diversity curves within the model.
- **Residential** (logical): if available and set to 1, this factor will improve the quality of built-in estimation model results.
- **Building group** (any value): for any building with a coinciding building group, the optimisation will only consider connecting one of them to the network, allowing users to consider building groups with an independent distribution network.
- **User-defined field** (any value): this attribute can be used by the user to add any field that is not included in the ones already mentioned. The user can attach this attribute to more than one imported field.

Uploading the buildings shapefile in THERMOS Tool

After generating the GIS file, the building data can be uploaded on the database import section of the tool. At a minimum, the following formats: .shp, .dbf, .shx, .prj and .cpg need to be imported together (multiple pick).

A drop-down "**Allocate fields**" menu will appear, in which the fields of the uploaded shapefile can be matched with the aforementioned fields.

Allocate fields for buildings ?

Name of the GIS file

Field	Meaning
Annual Cold Demand	None
Annual Heat Demand	None
Category	Annual heat demand (kWh/yr)
Central	Max. heat demand (kWh/yr)
Constraint	Min. heat demand (kWh/yr)
Demand Profile	Annual cooling demand (kWh/yr)
Edificabilidad_m2t	Peak cooling demand (kW)
Name	Peak heat demand (kW)
Network Status	Building height (m)
Peak Cold Demand	Fallback building height (m)
Peak Heat Demand	Floor area (m2)
Residential	Heat benchmark (kWh/yr)
TxtMemo_min	Heat benchmark (kWh/m2/yr)
Type	Cooling benchmark (kWh/yr)
id	Cooling benchmark (kWh/m2/yr)
	Peak/base ratio
	Connection count
	Identity (text)
	User-defined field (any)
	Residential (logical)
	Building group (any value)

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Figure 4-1. Matching table for buildings

Creating the Paths and connections layer in a GIS program

The database will use **lines** for paths and connections. To consider networks the model needs a set of candidate paths, which the tool will connect to buildings.

The user needs to create a layer containing the paths of the studied area. For paths, the following attributes may be defined:

- **Identity** (text): an identifier. This value is only for presentation of the line. It must be a value identifying the different paths.
- **User-defined field** (any value): this attribute can be used by the user to add any desired classifications. The user can attach this attribute to more than one imported field.

As in the case of buildings, these attributes are optional. If they are not included in the GIS file, the tool will estimate them. If the user does not have enough information regarding the paths, the default layer loaded in THERMOS (OpenStreetMap) can be used.

Uploading the paths and connections shapefile in THERMOS Tool

A line shapefile including this information shall be created and uploaded (at least .shp, .prj, .shx, and .dbf files) on the database import section of the tool. A drop-down “**Allocate fields**” will appear, in which the fields of the uploaded shapefile can be matched with the above-mentioned fields.

Allocate fields for roads ?

Name of the GIS file	
Field	Meaning
Civils	None
Network status	None
id	Identity (text)
	User-defined field (any)

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Figure 4-2 – Matching table for paths

4.4.3 Importing LIDAR layers

In both cases, whether a map was created from OpenStreetMap or from custom GIS files, THERMOS allows to check for LIDAR coverage for the area under study, as well as to upload LIDAR data layers. If the area has already LIDAR coverage, THERMOS will depict a map with a shape as the one shown in Figure 4-3. Figure 4-2 Otherwise, the user may upload a file.

LIDAR coverage is not mandatory but building height data will improve the quality of demand estimates produced from the built-in 3D regression model. Building height data can be extracted from a field associated to the building polygons GIS files, or extracted directly from OpenStreetMap, if available for the area in question.

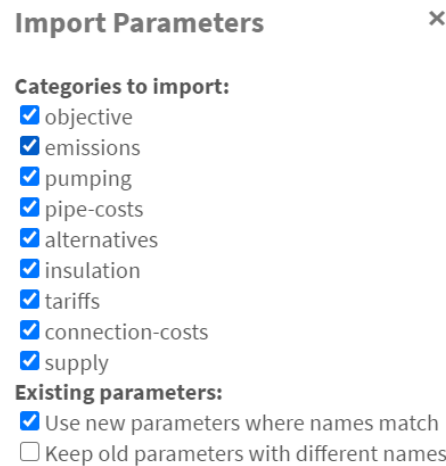


Figure 4-3 – Map of an area with LIDAR coverage in THERMOS tool.

4.4.4 Exporting and re-importing map and project information

For already created maps and problems, there are several ways to modify the main parameters in a convenient way. First of all, the THERMOS user interface allows selecting a group of similar candidates and modifying their parameters together.

Secondly, it is possible to download a MS Excel spreadsheet containing all project data, to modify it externally and then to upload it again. This allows for a quick modification of case related data found in the side menu, such as tariffs, pipe costs, insulation, and the supply optimisation problem. If the process is done properly, the pop-up menu allowing to choose the set of parameters to be modified illustrated in Figure 4-4 will appear.



Import Parameters x

Categories to import:

- ☒ objective
- ☒ emissions
- ☒ pumping
- ☒ pipe-costs
- ☒ alternatives
- ☒ insulation
- ☒ tariffs
- ☒ connection-costs
- ☒ supply

Existing parameters:

- ☒ Use new parameters where names match
- ☐ Keep old parameters with different names

Figure 4-4 - Spreadsheet editable parameters

This feature cannot be used to modify information associated with spatial features, such as peak and annual demands, and path lengths.

For modifying spatial features, users can download the current project (or the whole map) in GIS Geojson format, so that it can be modified externally (e.g., using the QGIS tool) and then used to create a new modified problem or a new map. This functionality is also useful for users who have created their project from OpenStreetMap but would like to introduce changes in the project's geometry.

4.5 THERMOS Problem analysis functionalities

Currently, THERMOS offers two complementary functionalities to analyse a thermal energy problem: network optimisation and supply optimisation.

The network optimisation functionality allows to determine an optimal network solution to satisfy the thermal energy problem described in the current project. Four main use cases have been identified for this functionality, and they are described in section 4.5.1 below.

Once, using the network optimisation functionality, a network solution employing one or more supplies has been determined, the supply optimisation functionality allows to analyse in more detail the supply(ies) that can satisfy all the demand served by the network, considering different demand profiles and several energy supply technologies. This functionality is presented in section 4.5.2.

4.5.1 Network optimisation

At the beginning of the project, the THERMOS development team discussed with the rest of the consortium about the objectives and the main features of the tool, in order to make sure that it suited the interests and needs of its target users (e.g., local authorities and energy planners). As a result, it was agreed that the tool would address the four main use cases illustrated below.

A - Adding new sites and connections to an existing network

This use case aims to allow users to assess possible expansions of an existing district heating and cooling network.

1. First, the user needs to define the existing heating network. In doing so, the user must select all the demand and supply points of the network and the existing connections. As outlined in the User Manual, the user can either select the elements of the network individually or use the two selection buttons (draw a polygon or a rectangle) available on the upper left corner of the map. Where better information is available, the user can choose to manually override the default values for demand and supply. Once the network has been defined, the user needs to categorise it as 'required' (red, following the colour code. Hint - use the 'c' keyboard shortcut), as shown in Figure 4-5. This is needed because the tool is now forced to include the existing network in the solution. After that, the user needs to select the paths, go to the Edit menu (hint - use the 'e' keyboard shortcut) and mark the "Exists" checkbox. This tells the tool that the installations for this part of the network are already in place. Under this assumption, the costs are considered to be null and the tool will naturally prefer this path.
2. The user then defines the potential candidates for expansion of the network, following the same process described in the first step. However, the potential candidates should be instead categorised as 'optional' (blue as set in the colour code), as shown in Figure 4-5. By doing this, the tool will only incorporate into the final solution those candidates which meet the requirements for optimisation (see step 3). Additionally, the user can exclude certain candidate buildings or connections from the final solution by selecting and categorising them as 'forbidden' (in white) which is the default status of all candidates when the map is first generated.
3. The user then must select the objective of the optimisation, between maximising the network NPV or the whole-system NPV. In the Objective section of the network problem left section of the tool, the user can choose from:
 - **Maximize network NPV:** the project's profitability is analysed from the network operator standpoint. This means that the optimisation will connect as many demands as possible, presenting the option with the highest NPV throughout the project's lifespan. The impact of non-network factors (individual systems, insulation,

and emissions costs) can be accounted for using the market tariff, which chooses a price to beat the best non-network system. The main considerations made in this option are:

- Minimise the sum of the present value of all connections;
 - The present costs for capital and operating expenditures in the network;
 - The present cost for emissions by the network supply.
- **Maximize whole-system NPV:** the goal is to choose how to supply heat to the buildings in the problem (or abate demand) at the minimum overall cost. The internal transfer of money between buildings and network operator is not considered, so there are no network revenues and tariffs have no effect. The main assumptions made for this optimisation are:
 - The sum of the present costs for capital and operating expenditures within *and outside* the network;
 - The present cost for emissions by network supply *and individual systems*.

Further, in the same section of the tool the user can set several other parameters such as the project lifetime, discount rate, financing options for capital costs, emission limits and costs, maximum number of supplies and the computing resources affecting the optimisation process results.

4. After pressing 'Optimise -> Network', if a solution is found, the tool will provide a description of the optimal solution based on the features of the existing network, the potential candidates, and the selected optimisation objective.



Figure 4-5 - Candidate selection example

B - Planning a new network based on a given heat source

The second THERMOS use case allows the user to plan a new district heating network based on a given heat source.

1. The user first defines the existing heat supply source in the map, which can be selected individually, setting the supply parameters as needed. Once the supply point has been identified, it must be categorised as a heat plant (hint - use the 's' keyboard shortcut) and as a 'required' element (in **red**, according to the colour code), as shown in Figure 4-6.
2. The user then selects the set of candidate buildings and connections that could potentially comprise the new district heating network. The set of potential demands and connections can be selected either manually or using the two selection buttons on the upper left corner of the map and categorize them as 'optional' (in **blue**). As in the first use case, the user can exclude buildings and connections from the analysis by categorising them as 'forbidden' (in **white**).
3. The user finally selects the optimisation criterion and presses 'Optimise -> Network' to start the simulation.
4. If a solution is found, the tool will provide a description of the optimal solution based on the features of the existing supply source, the potential candidates, and the selected optimisation objective.



Figure 4-6 – Existing heat supply example

C - Designing a new network to supply a given set of buildings using one or more potential heat sources

The third THERMOS use case is similar to the second, besides that in this scenario there can be multiple heat supplies.

1. The user selects the set of buildings (demand points) to be incorporated into the new district heating network, either individually or through the two selection buttons available, and categorises them as 'required' (in **red**, according to the colour code), overriding the default heat demand values where appropriate.
2. The user then selects the potential heat sources, categorising them as supply points (hint – use the 's' keyboard shortcut) and as 'optional' (in **blue**), and setting the supply parameters.
3. After selecting the optimisation criterion to be followed by the solver, the user presses the 'Optimise -> Network' button.
4. If a solution is found, a description of the optimal solution (i.e., heat sources to be included in the potential heat network and routes to follow) is provided by the tool, in accordance with the chosen optimisation objective. The tool will choose the best solution whether it is to provide the whole demand with one of the supplies or by combining multiple supplies.



Figure 4-7 – Multiple supplies example

D - Assessing and comparing the performance of specific networks and individual non-network solutions

The tool allows for the assessment of the introduction of non-networked building heating and cooling and insulation measures as an alternative to the connection of a building to the proposed heat network.

The aim of this use case is to provide an easy way for energy planners to compare the viability of implementing a district heating network against individual measures used as an alternative. In this way, it improves the technical and policy decision-making process regarding the area where the network will be developed.

1. To do so, the user can set, in the Individual Solutions tab of the Tools menu, the characteristic parameters for the alternative solutions, such as costs and emissions.
2. Then, the user can select buildings, either independently or in groups, and, by using the edit mode, define which individual solutions might be feasible for those building groups;
3. After that, a possible network has to be set out in the problem as in use cases A, B or C;
4. Finally, at least a part of the buildings must be set as optional and "Maximize whole-system NPV" has to be chosen as the main optimisation objective;
5. The tool will then compare, for each building, the individual systems with the possibility of connecting it to the network and, if it is possible, choose the solution which allows to supply heat at the minimum overall cost. In Figure 4-8 below, an example of solution is shown: buildings circled in orange are connected to the network, and buildings circled in green are upgraded with insulation or individual solutions;
6. Finally, in the Results Summary tab, the tool will provide the most relevant data regarding the individual systems installed, such as number of buildings using an individual solution, their capacities and costs, as well as the emissions produced.

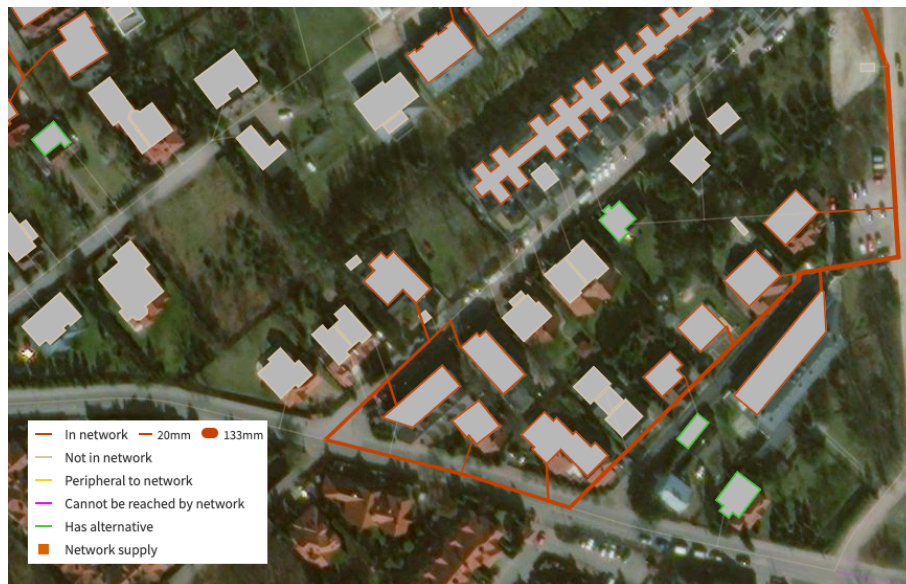


Figure 4-8 - Example of result of mixed network and non-network solution.

4.5.2 Supply optimisation

For any given project with an associated network solution, the tool provides the opportunity to optimise the different supplies involved¹³. Moreover, it identifies which technologies should be included in the network over the whole year, providing a “base load”, and which of them should be only used in a specific season for “peak load” supply.

Supply definition

For a supply optimisation to be performed, firstly the supply problem must be defined. To do so, the parameters used for the optimisation are divided into three categories:

- Profiles;
- Technologies;
- Objective.

Profiles

To calculate a more accurate estimation of the demand, the tool allows to define figures related to heat demand profiles, fuel type prices, emissions and substations, each set for a certain number of standard days of the year.

The first step is setting the different standard days that will be considered. As an example, the default options offered in the tool are: Normal Weekday, Normal Weekend, Winter Weekday, Winter Weekend and Peak Day. Anyhow, users can create as many standard days as they want just by pressing the “+” icon and editing their relative frequency, which corresponds to the number of times that such standard day will occur throughout the year, and the time precision, defining the number of time slots available in each standard day.

Once different day options have been set, profiles must be defined. For the set time precision, there could be:

- **Heat Profiles:** for each type of demand (i.e., Residential, Commercial, Flat) there will be a different profile. Values are relative to the maximum value for that heat profile across the year. The default heat profiles can be modified, or new profiles can be created by pressing on the “+” icon.
- **Fuel (and Emissions):** for each fuel there is a price profile, in c/kWh units, as well as a “grid offer” profiles that describes the price paid by the grid operator for the electricity produced by CHP units. The default fuel price profiles can be modified, or new fuel price profiles can be created by pressing on the “+” icon. Also, in the sections below it is

¹³ Currently, the supply optimisation is performed on a single supply that represents the sum of all the supplies identified in the solution.

possible to edit the pollutants emissions associated to each technology, expressed in g/kWh;

- **Substation Load:** there will be a separated load profile for every defined substation, with values expressed in MW.

Technologies

This part of the supply optimisation user interface allows to define equipment involved in covering the system's demand, which could be summarised as supply technologies, substations, and storage technologies.

Regarding supply technologies, for each of the input solutions the following parameters can be defined:

- Lifetime (years);
- Fuel;
- CHP capability;
- Capacity (MW);
- Power/fuel ratio (%);
- Heat/fuel (%);
- Substation;
- Capital costs;
- Operating costs.

Most of these values have already been mentioned or have an obvious meaning, but others would need some context. This is the case of both aforementioned ratios, the Power/fuel ratio is only considered for CHP representing the amount of electricity generated as a function of fuel consumption, while the Heat/fuel one is associated with the supply's efficiency, as it describes the amount of heat produced as a function of used fuel.

Figure 4-9 portrays the tool's screen where these parameters can be defined, as well as example values for three different supply technologies.

Supply technologies

	Technology	Lifetime	Fuel	CHP	Capacity	Power/fuel	Heat/fuel	Substation	Capital cost			Operating cost		
		yr			MW	%	%		k€	€/kWp	€/kWh	k€	€/kWp	€/kWh
✗	Geothermal	40	Electricity ▾	<input type="checkbox"/>	0,1	n/a	420,0	None ▾	0	500	0	0	58	0
✗	Wood boiler	20	Wood ▾	<input type="checkbox"/>	0,6	n/a	85,0	None ▾	0	500	0	0	14	0
✗	Gas boiler new	20	Natural gas ▾	<input type="checkbox"/>	2,0	n/a	90,0	None ▾	0	60	0	0	1	0

[Add plant](#)

Figure 4-9 - Supply technologies

This tab can also be used to input information regarding storage facilities or substations. This way the generated solution does not only depend on the profile's distribution among different supplies, but also allows for the optimisation of said demand by softening demand peaks.

Figure 4-10 depicts the input format for substations, needed for supplies that either use (e.g., heat pumps) or produce (CHP) electricity, and thermal energy storage technologies as well as all the available parameters.

With regards to substations, the headroom (capacity) is maximum power the substation can draw from its grid connection and transfer it towards the supply. Supply technologies which use electricity cannot ever draw more than the headroom in any time interval. Conversely, the alpha ratio accounts for the proportion of the headroom (power) that the substation can accept from the CHP supply and transfer to the grid.

Substations

Name	Headroom MW	Alpha %
<input type="text" value="A substation"/>	<input type="text" value="40"/>	<input type="text" value="80,0"/>

Storage technologies

Name	Lifetime yr	Capacity MWh	Capacity MW	Efficiency %	Capital cost k€	Capital cost €/kWp	Capital cost €/kWh
<input type="text" value="Storage"/>	<input type="text" value="50"/>	<input type="text" value="40,0"/>	<input type="text" value="10,0"/>	<input type="text" value="90"/>	<input type="text" value="1"/>	<input type="text" value="10"/>	<input type="text" value="0"/>

Figure 4-10. Substation and storage technologies characteristics

Objective

This section provides the opportunity to define the different criteria that impact the supply optimisation result financials. This tab is divided into four separate sections, each covering different aspects of the optimisation. These sections are:

- **Accounting period:** sets the project lifespan, as well as the discount rate;
- **Model options:**
 - defines the curtailment cost, which is the financial loss incurred for each kWh of demand that is unmet.
 - provides the option to allow heat dumping, meaning that CHP engines would be allowed to produce excess heat in order to sell electricity;
- **Emission costs:** characterizes the emission cost (€/ton or £/ton) of the most important pollutants;
- **Computing resources:** limits the optimisation process by implementing a maximum runtime and a minimum variation between iterations.

4.6 THERMOS Solutions

The tool presents a THERMOS solution in two different formats: both are explained in detail below.

4.6.1 Network Optimisation

Map View

A THERMOS solution can be displayed by means of an interactive map.

This map depicts the thermal network developed by the tool as result of the optimisation process. The aim of this map is to provide a graphic rendition of the solution which is immediate to understand: the user can intuitively and rapidly get an initial idea of the key solution features, such as the geographical reach of the network and the number and location of the connected buildings.



Figure 4-11 - Example of a map solution

Solution Summary

The most interesting part of a THERMOS solution is the quantitative data that the optimisation provides in the Solutions Summary view of the tool.

Economic and financial figures

This is one of the most defining features of the optimisation, since the ultimate objective of using the tool is to identify profitable thermal planning solutions.

The tool provides a breakdown of capital costs, operating costs and revenues considering each element of the solution: pipework, heat supply and demands/buildings. Further, the economic

value of emissions is also considered when it can be monetised. In case individual building solutions are considered in the problem, the cost summary also considers individual measures and insulation measures.

For capital costs, the user can choose to display either their total value over the chosen period (considering principal value and interests), only their principal value, or the total net present value. For other costs, the user can choose to display either their total value over the chosen period, their annual values, or their total net present value.

Cost summary	Network	Individual systems	Insulation	Emissions	Optimisation
Item	Capital cost (€)	Operating cost (€)	Operating revenue (€)	EC (c/kWh) ¹⁴	NPV (€)
Pipework	1,35 M	--	--	--	-1,35 M
Heat supply	2,14 M	13,56 M	--	--	-9,33 M
Demands	0	--	20,9 M	--	11,08 M
Emissions	--	0	--	--	0
Network	3,49 M	13,56 M	20,9 M	4,38	399,59 k
Emissions	--	0	--	--	0
Individual Systems	--	0	--	--	0
Insulation	--	--	--	--	--
Whole system	3,49 M	13,56 M	--	--	-10,68 M¹

Figure 4-12. Cost summary view

Additionally, the Levelized Cost of Heat (LCH) is also presented. Similarly to the Levelized cost of Energy (LCOE)¹⁴, this value is obtained by dividing the total net present value of capital and operating costs by the total amount of thermal energy produced, discounted over the project lifetime at the discount rate both set in the Objectives section. The LCH value allows to compare the thermal energy network solution obtained with other technologies and solutions, provided that the assumptions behind the LCH calculations (inflation, discount rates, lifetime) are equivalent.

Energy figures

In thermal network pre-feasibility studies, energy-related figures are particularly important not only to determine the overall network profitability, but also to strategically steer project

¹⁴ https://en.wikipedia.org/wiki/Levelized_cost_of_energy

development towards choosing different supply solutions or connecting certain customers first.

Pipework	Demands	Supplies			
Classification	Count	Capacity W	Demand Wh/yr	Conn. cost €	Revenue €
Unclassified	116	11,71 M	18,5 G	0	37,23 M
Apartments	179	17,37 M	27,13 G	0	54,62 M
Clinic	1	128,96 k	215,84 M	0	433,67 k
Commercial	4	661,57 k	1,16 G	0	2,32 M
Fire station	2	321,15 k	559,09 M	0	1,12 M
Hotel	1	386,94 k	735,64 M	0	1,47 M
Industrial	2	180,63 k	275,95 M	0	555,9 k
Office	1	95,32 k	148,06 M	0	298,12 k
Place of worship	2	218,83 k	352,91 M	0	709,82 k
Public building	1	1,67 M	3,33 G	0	6,66 M
Residential	29	3,37 M	5,51 G	0	11,08 M

Figure 4-13. Network Demands view

For this reason, the THERMOS tool gives result estimates on the demands connected to the network and the chosen supply. Some examples of the kind of data the tool provides are demand and supply peak capacity and yearly estimations, capital expenditure or revenues generated by the energy sale, among others. These figures are presented depending on the classification applied. The number of buildings connected in each category is also provided.

Pipework	Demands	Supplies						
Name	Capacity Wp	Output Wh/yr	Pumping Wh/yr	Capital €	Capacity €	Heat €	Pumping €	Coincidence %
	4,88 M	12,46 G	0	825,28 k	5,85 M	6,8 M	0	62
	8,73 M	23,92 G	0	2,58 M	10,48 M	13,06 M	0	62
WiZink Center	9,9 M	27,83 G	0	2,86 M	11,88 M	15,19 M	0	62

Figure 4-14. Network Supplies view

Technical figures

With the objective of making things easier for local governments when contacting suppliers or setting up tendering processes for the development of a network, THERMOS presents detailed

technical data, reducing time and efforts needed to identify the needed infrastructure elements.

<div>Pipework</div> <div>Demands</div> <div>Supplies</div>						
Civils	Ø mm	Length m	Cost €	Cost €/m	Losses Wh/yr	Capacity W
Soft	20-30	908,16	111,57 k	122,85	106,33 M	70,58 k
Soft	30-40	3,97 k	565,57 k	142,47	467,05 M	146,49 k
Soft	40-50	2,2 k	361,07 k	164,33	300,74 M	260,49 k
Soft	50-60	1,85 k	344,39 k	185,77	300,39 M	412,92 k
Soft	60-70	1,42 k	294,82 k	207,16	257,45 M	604,37 k
Soft	70-80	774,82	178,87 k	230,86	152,65 M	844,69 k
Soft	130-140	383,01	144,05 k	376,1	98,24 M	3,41 M
Soft	140-150	129,37	52,23 k	403,69	34,19 M	4,01 M
Soft	150-160	192,74	81,97 k	425,28	51,84 M	4,74 M
Soft	170-180	38,67	18,75 k	484,95	10,98 M	5,87 M
Soft	190-200	182,9	98,26 k	537,23	53,61 M	7,59 M
Soft	200-210	110,94	62,72 k	565,36	33,07 M	8,55 M
All		16,26 k	3,55 M	218,45	2,81 G	8,55 M

Figure 4-15. Network Pipework view

Examples of this data are a breakdown of the pipework elements presented in Figure 4-15: civil works, pipe diameters, length of the line installed for each diameter, final cost (considering the kind of pipe used as well as the civil works performed to get it in place), total yearly thermal losses and heat capacity. All this data is classified depending on the pipe diameter as well as on the civil works.

Further, as shown in Figure 4-16 below, the tool can display the yearly emissions produced by the heating network. In this case, the tool performs a classification depending on the system element which is generating the emissions (either the heat network itself, individual systems, or any defined counterfactual).

Furthermore, it classifies the emissions produced by the heat network in terms of “Heat”, which accounts for the emissions from the heat supply, and “Pumping”, which refers to the ones released by power needed for the heat distribution.

Cost summary	Network	Individual systems	Insulation	Emissions	Optimisation	
Cause	co2		pm25		nox	
	t/yr	¤	t/yr	¤	t/yr	¤
Network	2,15 k	0	0	0	0	0
Total	2,15 k	0	0	0	0	0
Counterfactual	0	0	0	0	0	0
Net	2,15 k	0	0	0	0	0

Figure 4-16. Emissions view

The emissions considered by the tool are Carbon Dioxide (CO₂), Nitrogen Oxides (NO_x) and Particulate Matter 2,5 (PM_{2.5}), which is the subset of PM10 particles that have aerodynamic diameters less than or equal to 2.5 µm. These are the main pollutants that affect worldwide population, either increasing Greenhouse Effect or directly on health. The data is provided either on tonnes of generated emissions per year or, if the user defines tariffs or taxes on emissions, yearly cost.

4.6.2 Supply optimisation

Total cost summary

Once a solution has been generated, the tool returns a summary of the costs for all technologies involved in the optimisation, as well as their specific power generation throughout the whole project. In order to fulfil this task efficiently, two parameters are optimised by the model:

- Power plant distribution
- Storage selection

Firstly, the tool provides a breakdown of all costs into capital costs, operating costs, fuel costs and results of electricity export, if considered. The user can choose which technologies to consider by setting them in the technologies tab of the supply problem, as described in section 4.5.2.

Supply technologies								Heat production for all days		
Item	Capex	Opex	Fuel	Export	Emissions	Total	PC	Source	Wh/yr	Wh total
	¤TOTAL	¤TOTAL	¤TOTAL	¤TOTAL	¤TOTAL	¤TOTAL	¤PV			
Geothermal	50 k	116 k	208,57 k		61,95 k	436,52 k	323,15 k	Geothermal	876 M	17,52 G
Wood boiler	213,87 k	119,77 k	1,9 M		0	2,23 M	1,64 M	Wood boiler	3,67 G	73,4 G
Gas boiler new	22,34 k	7,45 k	385,67 k		63,64 k	479,1 k	345,13 k	Gas boiler new	578,51 M	11,57 G
Storage	7,95 k					7,95 k	7,95 k	Storage	167,39 M	3,35 G
Total	294,17 k	243,21 k	2,49 M	0	125,58 k	3,16 M	2,32 M	Total	5,29 G	105,84 G

Average unit cost of production: 2,98 ¢/kWh

Figure 4-17 – Total cost summary for the supply

Furthermore, whenever the emissions have an associated cost, their economic impact is considered. Lastly, an average unit cost of production (c/kWh) is calculated by weighing the costs and the overall generation of each technology. This value can be found in the bottom-left end of this section. An example of the results is presented in Figure 4-17.

Plant and storage

The results summary continues describing the characteristics of the supply plant and the thermal storage. An example of how the values is presented is presented in Figure 4-18.

Plant	Peak	Output	Capex	Opex	Fuel	Export	Emissions	Store type	Store size	Peak flow	Capital cost
	W	Wh/yr	€TOTAL	€TOTAL	€TOTAL	€TOTAL	€TOTAL		Wh	Wp	€TOTAL
Geothermal	100 k	876 M	50 k	116 k	208,57 k	0	61,95 k	Storage	600 kWh	144,6 kWp	7,95 k€
Wood boiler	427,74 k	3,67 G	213,87 k	119,77 k	1,9 M	0	0				
Gas boiler new	372,37 k	578,51 M	22,34 k	7,45 k	385,67 k	0	63,64 k				

Figure 4-18 – Supply plant and thermal storage solution

For the description of the plant's attributes, a table similar to the one shown in the cost summary has been used. The main difference is the addition of installed capacity and total output for all technologies included in the supply summary, this allows the user to identify which is primary heat source and which would be the backup. Also, by providing the economical parameters associated with its performance, it is possible to identify why would a technology be chosen over its alternative.

Storage is described in terms of size, peak flow, and capital cost. Also, even though at this point this information has a more descriptive character, the following sections provide more graphic results, which help understand how storage is used specifically for every case.

Heat production

This section provides a detailed description of the system's heat production. To do so, the tool presents the results in two different formats, graphs, and tables, which will present as many options as different day types were defined in previous steps. The expected aspect for heat production results is presented in Figure 4-19.

As it can be seen, for this particular example, there would be 5 different day types: 2 for summer (weekend and weekday), 2 for winter (weekend and weekday) and one for peak days. If the user has more data available it is possible to implement further analysis considering, among others, the possible (future) costs of emissions and the energy export into the grid.

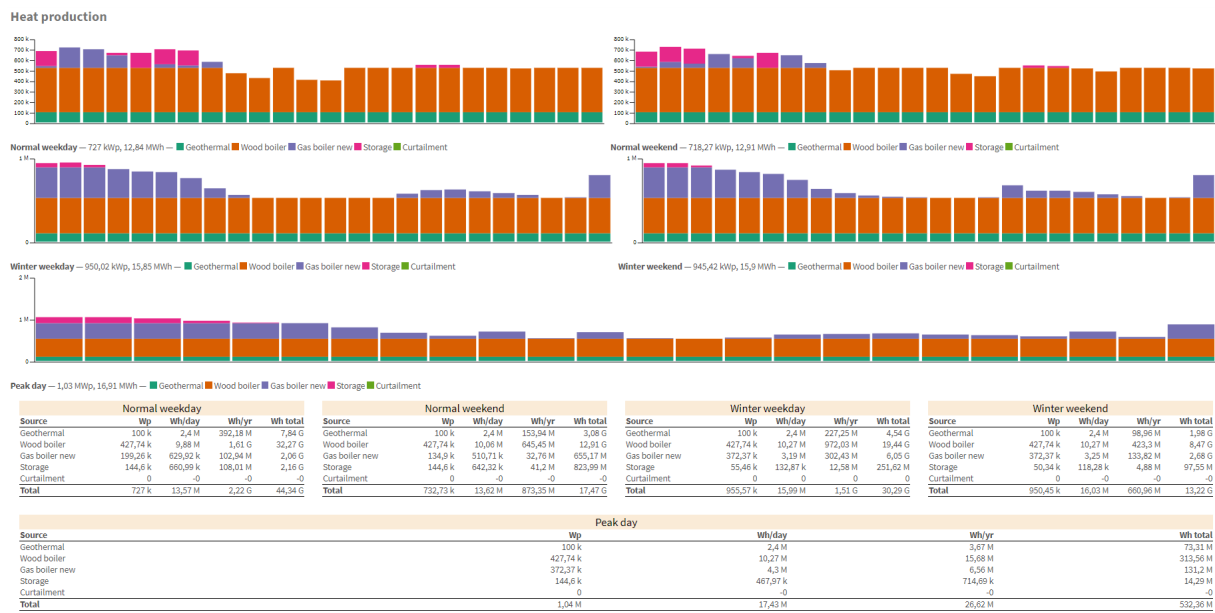


Figure 4-19 – Heat production – General depiction

The first part, depicting the graphic results, shows the supply distribution used to cover the expected demand. To do so, it uses a bar diagram with as many columns as timeslots have been previously defined, coinciding with the relative frequency set when the different day types were characterised. For the purpose of representing all different technologies used to cover the demand (supplies and storage facilities but also curtailment), different colours are assigned. This legend, as well as the peak demand and daily output, are presented in the bottom part of the graph. An example of the expected results is presented in Figure 4-20, portraying the technologies used to cover a "Normal weekday" demand profile.

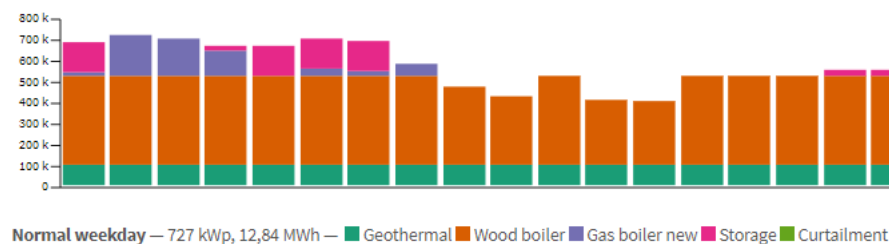


Figure 4-20 – Heat production - Graphic results

As it can be noticed, this section complements the "Plant and Storage" one, as it eases the identification of primary and backup technologies. Also, it allows to understand how storage or curtailment are used. It is important to pay attention to the units, detailed in the vertical axis, as they may vary between day types.

For the depicted example, geothermal energy would be the primary energy source, the wood boiler would be used as a secondary supply, used to cover the base load but reduced when needed, while peak loads would be covered using a gas boiler. It is interesting to note that, for

this particular case, storage is not used to face the demand as soon as needed, but it is rather stored to soften demand peaks.

The second part, the one showcasing analytical results, provides accurate values to complement the graphics. Different technologies are characterised according to their installed capacity and their output, presented in daily and total figures. An example on how information would be presented for a certain day type is portrayed in Figure 4-21.

Normal weekday				
Source	Wp	Wh/day	Wh/yr	Wh total
Geothermal	100 k	2,4 M	392,18 M	7,84 G
Wood boiler	427,74 k	9,88 M	1,61 G	32,27 G
Gas boiler new	199,26 k	629,92 k	102,94 M	2,06 G
Storage	144,6 k	660,99 k	108,01 M	2,16 G
Curtailment	0	-0	-0	-0
Total	727 k	13,57 M	2,22 G	44,34 G

Figure 4-21 – Heat production – Analytical results

This data may seem redundant, but it gains particular interest when comparing different days. When doing so, it allows the user to understand what variations between the different day profiles mean, in an accurate way.

For instance, while daily production depends on the chosen profile and the technology's installed capacity, yearly values depend on the reoccurrence of a given day type. This means that, for a specific case, such as the one in the example, storage might not be representative during peak days and thus it wouldn't been interesting to increase it. In the other hand, looking at a Normal weekday, the backup could be covered by an achievable storage capacity increase, saving a yearly amount of more than 100 MWh in natural gas, with its corresponding economic and environmental impact.

Fuel consumption and grid export

Similarly, fuel consumption and grid export solution are also presented as both tables and graphics. The main difference between this section and the previous one is that, while heat production characterises the results depending on the technology used, fuel consumption does it depending on the source used to power this technology. Figure 4-22 and Figure 4-23 provide an illustration of how tables and graphs are displayed.

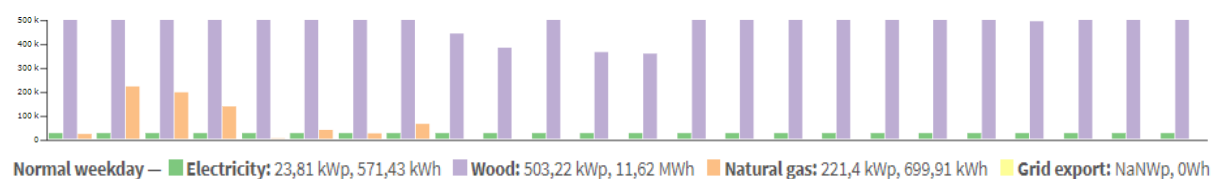


Figure 4-22 – Fuel consumption and grid export graphics for a normal weekday

As it can be noted, even though the presented magnitude is not the same, both graphics and tables have the same format as the ones explained in the previous section.

Normal weekday				
Fuel	Wp	Wh/day	Wh/yr	Wh total
Electricity	23,81 k	571,43 k	93,38 M	1,87 G
Wood	503,22 k	11,62 M	1,9 G	37,97 G
Natural gas	221,4 k	699,91 k	114,37 M	2,29 G

Figure 4-23 – Fuel consumption and grid export tables for a normal weekday

Consequently, for different technologies using the same fuel, such as geothermal and aerothermal pumps, independent values can be found in the heat production tab but not in this one, as both would use electricity as their fuel.

Emissions

The application also provides a short summary about the emissions generated in terms of production and associated costs, which can be expressed either yearly or throughout the technology's lifetime, based on user choice. As of right now, the emissions considered are the CO₂, PM_{2.5} and NO_x emissions. Figure 4-24 exemplifies how results are presented in this last section.

☒ Yearly ☐ Lifetime

Emission	Quantity g/yr	Cost €/yr
CO ₂	253,7 k	6,28 k
PM _{2.5}	0	0
NO _x	0	0

Figure 4-24 – Emissions results summary



5 Key Learning Experiences and Implementation Challenges

5.1 Integrated planning and governance structures

During testing and implementation of THERMOS in pilot and replication cities participating to the project, it was realised that not all local authorities have 100% responsibility or influence in district energy planning processes. In this context, the adoption of THERMOS for the identification of new projects and their development may be limited. To make the adoption of THERMOS relevant, local authorities need to possess a deep understanding of district heating and cooling planning processes and need to be able to effectively engage different stakeholders (such as utilities, energy agencies, and potential clients).

When it comes to private organisations who generally do not have control on local energy planning, their interest in THERMOS can be driven by its usefulness, which at the same time depends on the user's competences and skills.

Large firms specialised in DHC systems tend to develop their own bespoke tools to perform prefeasibility analyses. However, due to the THERMOS tool's versatility and rapidity, throughout the project it has been observed that several of these users have chosen to utilise our tool as the first step in their identification and assessment process, as it allows them to compare network solutions and generate alternatives in a quick and efficient way.

On the other hand, smaller companies which have yet to develop their own tools or non-specialised users have also embraced the tool, considering it accurate and accessible enough to be adopted as their default method for evaluating DHC systems.

5.2 Data procurement and management

In executing a pre-feasibility study with any tool, the use of accurate and appropriate data will determine the accuracy of the final solution.

As mentioned before, THERMOS has an internal hierarchy to select the energy demand estimations used by the optimisation process, ranging from a simple 2D estimation model, which only requires the footprint area of a building and local degree days data to roughly estimate its thermal energy demand, up to more accurate ones that perform estimations based on benchmarks or LIDAR 3D data. Therefore, data management from acquisition to exploitation, must be a thorough and careful process.

Firstly, it is important to assess the data that will be needed to perform the analysis, select the sources, and check their availability. Ideally the user would always use real demand or development costs data, but this is not always available, and certainly it is not accessible to everyone. We recommend that users spend some time defining the pool of attainable information and selecting the most reliable options. This process may take a few days to complete.



Secondly, once information has been gathered, it is as important to exploit it properly to obtain high-quality results. To this end, having a GIS and data mining expert has proven to be highly helpful, since it helps integrate the information in the most complete way and prevents possible format errors that can end up delaying the analysis significantly.

It is recommended that users have a look at the several case study publications¹⁵ developed during the THERMOS project, that offer practical examples on collected datasets and their preparation.

Lastly, throughout the whole Horizon 2020 project, THERMOS has been validated by both external and internal stakeholders. Using an agile methodology, the tool has managed to integrate new or modified features requested by the users while being developed. By doing so, some of the partners who had real data from already deployed networks were able to check both the tool's economic accuracy compared to actual DHC project costs as well as the deviations with respect to quotations received from DHC experts.

5.3 Stakeholder engagement

As district heating developments tend to be quite big and involve a lot of parties, as well as a considerable investment, it is important that the project is not only successful from the implementation point of view, but also that it is useful for the community.

Ultimately, the entity responsible for the district heating project's compliance with public requirements is the one that will either obtain a profit or a benefit from it. In these kinds of developments, given their scope and cost, it is highly uncommon for a private company to be the prime promoter of the project. On the contrary, as it mainly benefits the community and affects cities' infrastructure, it is usual to find governmental agencies interested in achieving environmental sustainability or local social/community benefits promoting these developments. That is why the first identifiable stakeholders in this type of projects are governments and public entities.

However, private associations or lobbies interested in the fulfilment of the development might want to take part as stakeholders from a strategic point of view. The reason being the discussion of the technology options, which would then turn it into a more standardised solution, thus bringing them a benefit.

In the same segment, other private stakeholders can be found. In this case private companies, usually local, that could directly benefit from the project, either by being the developers or participating in the project. It is also interesting to include them as stakeholders as most of the times they will exploit the investment and provide the final service to consumers.

¹⁵ <https://www.thermos-project.eu/tool-support/publications/>



Depending on the country, private contractors could have more or less participation in the decision-making process regarding energy planning, but nevertheless they always provide high-value practical insight that can improve the overall performance of the project. Another advantage of including private entities is that it eases the operation, since they are familiar with the development and can exploit it in a more efficient way.

Users can also benefit from the tool's visualisation capabilities. It was demonstrated that THERMOS can be used to effectively illustrate a specific network as well as its economics, a task that may result complex even for specialised companies who possess their own tools. This has been identified as a significant advantage as it allows users to present their results to other project stakeholders and perform changes in a quick way, improving communication and thus easing the collaboration with the final clients. Also, THERMOS easily allows users from different organisations to access the same projects and work collaboratively on them from different locations.

5.4 Skills and resources needed

As mentioned before, THERMOS is an open-source tool accessible online, having few technical requirements with regards to IT equipment. A standard web browser is sufficient to use the THERMOS tool, while to prepare GIS files and data for import, relevant software (such as the free and open source QGIS¹⁶ tool, which has been used to prepare the data for many THERMOS case studies) and a sufficiently powerful computer are recommended.

With regards to the skills needed to use the THERMOS tool, plenty of material is available on the THERMOS website Training section¹⁷, and it is highly recommended that every user reviews such material, consisting of recorded webinars and other documents. Thanks to this material, and assuming the users have certain knowledge on energy planning, it is already possible to start developing a pre-feasibility analyses using the tool. As already mentioned above, having a GIS and data mining expert has proven to be highly helpful to correctly handle the data preparation and upload processes.

Also, depending on the project's complexity, the need to have specific know-how may increase. The chosen heat supply or the use of state-of-the-art technologies in either the network or the demand buildings (such as thermally activated building structures or closed loop geothermal systems) may imply the need of expert knowledge in order to accurately estimate the THERMOS tool input parameters.

In addition, we have verified on a few occasions that there is a general lack of understanding on how district energy planning and project development processes fit into the SECAP

¹⁶ See <https://qgis.org>

¹⁷ See <https://www.thermos-project.eu/get-involved/training/>



processes. It is crucial for cities and stakeholders in district energy planning processes to identify DHC projects options as actions that reduce GHG emissions in their territories, hence helping them to reach their energy and emissions reduction goals.

5.5 Efforts and Time

The amount of time necessary to complete an assignment with the THERMOS tool might be consistent or subject to high variability, since it depends on multiple factors like the availability of data, the skill of the users, and the level of detail of the result sought.

As discussed above, the procurement and preparation of data in GIS format may take several weeks, particularly if stakeholders need to be engaged and several meetings organised.

However, once data is ready and organised a skilled user may be able to produce a first set of results in less than a day. Then, the analysis of the initial results will determine a new set of questions that can be tackled by the tool considering alternative scenarios, which may or may not need further data mining, stakeholder meetings, and information procurement.

Having to provide a ballpark estimate, we believe that, once the needed data is available, a user already familiar with THERMOS can prepare a pre-feasibility study featuring several alternative scenarios in less than a week.

6 THERMOS Tool availability

A free-access standard version of the THERMOS Tool for public use will be available online at least until 31 March 2024 at the following address:

<https://tool.thermos-project.eu>

Following the completion of the THERMOS project at the end of March 2021, the free-access standard version has been updated to the latest version of the software, and it now incorporates certain restrictions on functionality. These include:

- lower prioritisation allocated to free-access users in optimisation run queues;
- maximum limits on map size upload capability;
- maximum limits on the duration and number of weekly optimisation runs.

Additionally, as foreseen in the Horizon 2020 THERMOS grant agreement, the source code of the tool is available for download under GNU general public license V3 terms¹⁸ at:

<https://github.com/cse-bristol/110-thermos-ui>

Each organisation or individual capable of doing so may choose to use the source code to compile and install a private instance of the tool on their servers and run it locally. In this case, the organisation will also be responsible for maintenance and any eventual development of the application in compliance with the GNU general public licensing terms. If and organisation or individual uses this public THERMOS system in its work, academic or commercial, it must include this citation:

This work includes results from the THERMOS heat network model (<https://www.thermos-project.eu>). For more information about THERMOS contact the Centre for Sustainable Energy (<https://www.cse.org.uk>).

Alternatively, it is also foreseen that the Centre for Sustainable Energy, in cooperation with other THERMOS consortium partners such as the Spanish firm Creara, will provide access to an unrestricted premium version of the THERMOS tool reserved for paying users, who will also be offered a separate dedicated instance of the tool and technical support. The premium version is thought for users aiming to perform specialised work requiring full unrestricted use of THERMOS functionalities especially for commercial and for-profit purposes.

Further information can be found on the [THERMOS Tool](#) webpage.

¹⁸ See: <https://www.gnu.org/licenses/gpl-3.0.html>

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