THERMOS

Thermal Energy Resource Modelling and Optimization System

District Heating & Cooling
Case Studies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723636. The sole responsibility for any errors or omissions made lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained therein.

Deliverable No:	Deliverable 3.9
Workpackage Title:	WP 3, Building and embedding the THERMOS application
Date Submitted:	31 March 2021
Dissemination level:	Public (Preliminary version not for distribution)
Document file Name:	210331_THS_D3.9_CREARA_THERMOS_Case_Studies_V2_FINAL

Deliverable Authors:	**Contributors and Reviewers:**
Paolo Michele Sonvilla (Creara)	Adrian Cañamares (Creara)
Juan Varo López (Creara)	David Perez Navarro (Creara)
Deva Martínez de la Rosa (Creara)	Carlos Seguí Peidro (Barrio la Pinada)
Pablo González Reed (Creara)	María Gil (Mosaik Systems)
Martin Holley (Centre for Sustainable Energy)	Duncan Faulkes (Bristol Council)
Tom Hinton (Centre for Sustainable Energy)	Grzegorz Caputa (EKOTERM)
Rita Ehrig (Dena)	Piotr Mrowiec (EKOTERM)
Inga Kreicmane (ZREA)	Javier Dorao Sanchez (DCN)
Valdis Rieksts-Riekstins (Fortum-Jelgava)	Ricardo Corrales Baruque (DCN)
Dariusz Koc (KAPE)	Marta Chillida Munguet (Granollers)
Wojciech Stańczyk (KAPE)	Marc Vives Llovet (Granollers)
	Carlos Dapena Gonzalez (Parc de l'Alba)
	Ilze Polikarpova (Salaspils Siltums)
	Jevgenijs Sulga (Salaspils Siltums)
	Roberts Kaķis (Salaspils Siltums)
	Rhys Sully (Sustainable Energy Ltd)

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1 Introduction

The European Union climate objectives require local governments to promote the development of high efficiency energy projects to achieve the objectives of affordable energy supply, reduction of imports dependence and optimisation of energy consumption, whilst reducing emissions of greenhouse gases and other pollutants. The European Green Deal is the roadmap created for achieving economic sustainability in the EU, turning climate and environmental challenges across all policy areas into opportunities, assuring that this transition will be just and inclusive for all.

Modern district heating and cooling systems, which are increasingly low-carbon and cost-effective, have proved to be instrumental in achieving these goals, since they can be integrated with elements such as cogeneration, heat pumps, renewable energy, and thermal storage.

The THERMOS project, financed within the Horizon 2020 Research and Innovation programme, aims to accelerate the development of low-carbon district heating and cooling systems across Europe, and to enable faster upgrade, refurbishment, and expansion of existing systems. The overall aim of the project is to provide the methods, data, and tools to enable more rapid, cheap and sophisticated planning of thermal energy systems.

The key outcome of the project is the THERMOS software tool, that makes district heating and cooling systems 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 in buildings. 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.

The THERMOS tool was designed using an Agile methodology. In this way, while the tool was being developed by the consortium, the partner local authorities throughout Europe were using it to address their own local thermal energy planning case studies and providing feedback to the developers. These cities were also organised in twinning exchanges so they could seize each other's knowledge and experience and mutually support each other.

It became obvious that user input was a key part of the tool development. Due to this, THERMOS partners decided to use its training and capacity building programme to attract prospective users, providing them the option of developing their own case study. Further, many of these case studies were performed by private organisations, which helped gather additional information from their point of view, as well as mainstreaming the tool.

This document gathers the most interesting cases studies that were developed during this phase.

2 Executive Summary

This report presents the work carried out by a group of THERMOS tool users, supported by THERMOS consortium partners. It includes eight case studies illustrating the reason for their selection, the stakeholders involved, the information that was researched in order to start the work, the results obtained, and the conclusions reached:

- **Barrio La Pinada** and Creara worked together to evaluate the possibility of developing a new model of urban development which bases its profitability not only in economic parameters but also in social and environmental ones; with this purpose the THERMOS tool has been used to perform the first representation of the network for this new urban development that has not started construction works yet;
- **Bristol City Council,** supported by the Centre for Sustainable Energy, has used the THERMOS tool to do rapid assessments of heat network extensions, for example adding a new connection to a network. The implementation of the tool for this purpose will allow the business development team at Bristol City Council to quickly respond to new enquiries with reasonably high confidence that the connection can be made and there is enough heat capacity;
- The municipality of **Granollers**, supported by Creara, used the THERMOS tool to simulate the construction and optimization of a new district heating network in the industrial complex of **EcoCongost**. The objective was to evaluate the state of the art and viability of the integration of more renewable energy sources and increased energy efficiency for industries and other businesses located in the area;
- Dena, in cooperation with Tilia GmbH, have used the THERMOS tool to examine how to integrate a larger share of renewable energy sources into the existing heating grid of the city of **Kyivska**, Ukraine. A great potential for cost and greenhouse gas emission reductions lies in the modernisation and restructuring of the existing grid, and to explore this potential is one of the main objectives of the city authorities.
- **Madrid Nuevo Norte** is a public initiative to regenerate 300 hectares of land in the North of the Spanish capital. Within this case study, the THERMOS tool has been used by **Distrito Castellana Norte** and Creara to verify if heating and cooling demand could be covered in a profitable way with a 4th generation heating and cooling network based on geothermal energy, and then to identify the most profitable areas for network implementation;
- **Parc de l'Alba** and Creara have used the THERMOS tool in the analysis of the feasibility of extending the existing district energy network to the residential and other buildings that will be built in the area, since their aim is to extend their already profitable district energy network and continue the sustainable urban development of the park;

- **Salaspils** is the case study in which Salaspils Siltums, ZREA and Fortum have tested the THERMOS tool and compared it with existing processes to evaluate the tool as it could make the heat network planning faster, more efficient, and more cost effective. The analysis with the tool has been performed to pursuit their aim of intensifying the reduction of fossil fuels on the demand side by connecting more customers to the district heating network;

- The Polish city of **Żywiec** was supported by EKOTERM and KAPE to analyse with the THERMOS tool specific locations identified for a possible expansion of the district heating network, with the purpose of satisfying their aim of improving the air quality of the city.

This document will allow consultancies, project developers, local authorities and other stakeholders to learn from the THERMOS experience in order to address the following topics:

- how to identify and engage the key stakeholders that will influence the development of the thermal energy planning project;
- how to identify and procure the information needed to develop a robust local thermal energy planning analysis and prefeasibility study;
- how to correctly structure and develop a prefeasibility study using the THERMOS tool;
- how to present and discuss the analysis results with relevant project stakeholders;
- how to replicate and disseminate the results of these processes.

Additionally, this report provides examples on how the projects explored with THERMOS could be part of the local Sustainable Energy and Climate Action (SECAP) processes and the challenges that might be faced.

Table 2-1 offers an overview of all the case studies presented in the document.

	Use case	Type	Total demand [GWh/year]	Supply technology
Barrio La Pinada	New network design	Mixed	9.4 (heat)	Geothermal/ Aerothermal
Bristol City Council	Verification of the capacity and quick assessment of heat network expansions	Mixed	Not applicable[1]	Biomass boiler , gas boilers and gas CHP
Ecocongost	Simulation of the construction and optimisation of a new DH network	Industrial	122 (heat)	Boiler
Kyivska	Study the modernisation and restructuring of the DH network	Residential	3.1 (heat)	Geothermal; Natural gas; logwood boiler
Madrid Nuevo Norte	Assessment of 4th generation heating and cooling network and of most profitable areas for network implementation	Mixed	90.9 (heat)	Geothermal
Parc de l'Alba	Analysis of the possibility of expanding the existing DH network	Mixed	170 (cold)	Natural Gas Combined Heat and Power (CHP)
Salaspils	Testing and comparison of the THERMOS tool with their current methodology	Residential	2.5(heat)	Biomass and natural gas HOB, solar collectors
Żywiec	Analysis the possible expansion of the current DH network	Mixed	2.2 (heat)	Coal boilers

Table 2-1. THERMOS case studies overview

[1] The objective for this case study was to illustrate a specific way of using THERMOS to evaluate individual requests for connection to an existing network. The focus here is to see if there is enough capacity in terms of pipe size (in this case used as a proxy for heat) to supply the additional load, with a key element of the study being accuracy validation against a detailed hydraulic model. Therefore, the demand input is not applicable here.

3 Barrio La Pinada – Valencia, Spain

3.1 Introduction

Barrio La Pinada is a private urban development located in Paterna, close to the city of Valencia, which is expected to cover 320,000 m^2. The project's design has been strongly influenced by its sustainability, aiming to generate a social impact by the definition of a new model of urban development which bases its profitability not only in economic parameters, but also in social and environmental ones. To achieve this goal, Barrio La Pinada will be the first Spanish project to be co-designed by the residents of its more than 1,500 dwellings.

3.1.1 City/area energy background

As a municipality, Paterna is a signatory of the Covenant of Mayors since 2009, with a declared emissions reduction goal of 20% by 2020.

Barrio La Pinada aims to promote sustainable urban development from a private standpoint. The projects metrics regarding sustainability are of the highest standard, as they have been derived from the Sustainable Development Goals as well as the National and European goals. The specific areas that the project considers to be tackled are:

- Mobility;
- Energy;
- Circular economy;
- Sustainable Housing;
- Local Economy;
- Water management;
- Climate change;
- Diversity of ground use;
- Innovation;
- Social inclusion.

To do so, some of the targets set at the beginning of the project were: 100% of energy to be provided using RES, more than 1000 neighbours to be involved in the project's co-design, 80% waste reutilization, 40% of used materials need to be recycled and less than one car per neighbour.

The leading developer companies, Sustainable Towns, Trebe and Mosaik Urban Systems are relying heavily on R&D to achieve these goals. That is why there are several collaboration agreements with field experts, which will enable them to overcome these issues in an innovative and efficient way. Some examples of R&D projects involved with Barrio La Pinada are the following:

- AUDERE (Advanced Urban Delivery and Refuse Recovery), which will carry out a pilot project in Barrio La Pinada during 2021, whose main objective is to design and develop an intelligent system for the collection of municipal solid waste and last mile logistics using autonomous vehicles and 5G connectivity, and demonstrate its technical, economic, social, and environmental feasibility;

- "Lions 2 Life Second-Life Battery Farm" financed by the EIT Climate-KIC, which will be one of the first demonstrators of recycling and reuse of electric mobility batteries for energy storage in future districts and sustainable homes. It aims to:
  - Increase first and second use of battery life;
  - Boost the reuse of scarce materials, such as lithium;
  - Open the access to energy storage for end customers at affordable prices;
  - Promote the creation of innovative business models related to the circular economy and distributed clean energy;
- Wood2Reno – "Delivering affordable and sustainable housing in Europe", which is being funded by the European Union under its Horizon 2020 Program. It consists in reducing on-site construction time (for high-rise and single-family projects) in which a solution is provided for the assembly and placement of cross laminated timber (CLT) framing panels on façades with a self-sealing joint, which reduces labor risks and operator costs.

3.1.2 THERMOS involvement set up

Barrio La Pinada got involved in THERMOS through the Train the Trainers program. After familiarising themselves with the tool, Mosaik Urban Systems, Sustainable Towns' subsidiary, decided to develop their own case study in order to complete the course. The project chosen for the case study would depict the neighbourhood's future DHC, which incorporates a Dynamic Closed Loop (DCL) geothermal energy.

3.2 Overview of the case study analysed with THERMOS

3.2.1 Introduction

This case study envisions the first representation of the heat network. As there are no specific tools for this task, promoters who have yet to develop their own design tool may find it difficult to generate the network, as well as to notice the impact of different parameters.

Figure 3-1. Barrio La Pinada's Eco-friendly housing and biopools

Even though the development process started 3 years ago and is almost finished, urbanization permits are still pending. Once land demarcation changes, the project is expected to be carried out in 5 stages which would last 5-10 years.

One of the most interesting aspects about this project are the stakeholders, which could be divided into:

- Developers;
- Neighbours;
- Researchers;
- Public entities.

As mentioned previously, Barrio La Pinada is a private development, which makes its developers the most important stakeholders. Barrio La Pinada, Mosaik Urban Systems, as well as their parent company, Sustainable Tows, all take part in ZubiLabs.

Zubilabs defines itself as a business agent aimed to create companies for a better future, focused on obtaining a triple impact: economic, environmental and social. To do so, the company relies heavily on R&D, so a positive outcome would not only validate their methodologies but also provide expert insight into sustainable development. Also, Barrio La Pinada is expected to set the bar regarding the future model of urban development in Europe, which would render all partners involved as leaders in their fields.

Neighbours also represent an important part of the development, as it has been the first eco-neighbourhood designed in collaboration with its future inhabitants. As of right now, more than 4,000 people have shown interest and more than 400 future inhabitants already got involved with the project. This has been achieved through different events, where field experts aid by providing training and organising workshops.

Regarding research, most of the project’s obstacles have been solved through R&D partnerships with both private and public entities. The most tangible consequences obtained have been the added value of knowledge acquisition through problem solving as well as understanding other partner’s motivation due to their involvement in the project.

Lastly, as the project aims to spearhead sustainable urban development both in Spain and Europe, public entities would also benefit from the press. Mainstreaming the project, as well as setting it as an example of achievable success, would allow to shape future standards for urban developers.

3.2.2 Case study definition

Barrio La Pinada is a new urban development which has not started construction works yet. This provides the opportunity to create the network from scratch, matching the characteristics of a new network case study.

From the project's 75 planned buildings only two of them will not be included in the project, as they belong to a public school which is already built. Regarding the construction stages, most of the buildings are planned, the only exception being the Imagine Montessori La Pinada School. This building, also promoted by ZubiLabs, was created as a pilot project aiming to assess the results of implementing their self-developed building techniques, which ended up providing outstanding results.

Figure 3-2. Imagine Montessori School

The total demand to be satisfied is 9.4 GWh including residential and office demands. Even though this could be differentiated in terms of demand, it would not be possible to classify buildings depending on their use. As the BLP project aims to ease balancing work and personal life, the office spaces will be integrated in the residential building, having no dedicated buildings for any typology.

The main characteristics of the demand are illustrated in Table 3-1.

	Demand
Tot. energy demand	
- Residential	7.52 GWh/year
- Commercial	1.88 GWh/year

Table 3-1. Main characteristics of the demand

The supply is also a new construction that will use RES as its source, specifically 60% of the demand will be covered using DCL geothermal energy and the remaining 40% using aerothermal heat pumps. Even though this division is acknowledged, in order to perform a conservative case study, the costs considered will be those of a geothermal power plant, which are higher, and thus more restrictive. The main characteristics of the supply are presented in Table 3-2.

	Supply
Technology	Geothermal/Aerothermal
Fuel used	Electricity
Maximum capacity	5 MW
Fixed costs	200,000 €
Capacity costs	500 €/kW
Annual O&M costs	30 €/kW
Supply costs	1.4 c€/kWh

Table 3-2. Main characteristics of the supply

The network's planning also accounts for a storage system, as well as PV panels, that will not be included in the model. A case study implementing it through the THERMOS supply optimisation functionality could be performed in the future.

3.3 Case Study development and results

3.3.1 Data preparation

As it was a new development, the case study could not be based on data from OpenStreetMap. Instead, GIS files had to be developed from the CAD files used by the urban developer.

For both supply costs and pipe costs the values were estimated from previous experiences. In order to validate them, national price generation databases were consulted, such as CYPE[2] or BEDEC[3]. The information collected from these sources confirmed that the estimated prices were quite higher than the standard, fitting the case study's conservative character.

Tariffs were estimated based on the developer's objective, as Barrio La Pinada not only envisions the implementation of this technology, but also wants to do it in an affordable way for their neighbours. Based on this, a tariff was defined based on other DHC public information which proved the system profitability. Once this was done, the tariff was reduced until the project earnings matched the ones expected by the developers.

Regarding LIDAR and degree days, they were both taken from the recommended sources.

[2] www.generadordeprecios.info/#gsc.tab=0

[3] www.itec.es/banco-precios-bedec/

3.3.2 Results

Network topology

Barrio La Pinada plans to connect all the neighbourhood's demands to the DHC network. This is the reason why almost all buildings were set as required. The only ones left out of the case study were two in the southernmost end of the development, which correspond to a school. The reason for this choice is that those buildings are already constructed, and thus will not be a part of the upcoming development.

Figure 3-3. BLP Network depiction

According to the results, all of the selected demands could be satisfied, not even using all of the available supply capacity. 73 buildings were connected, covering 100% of the proposed demand and only leaving out the aforementioned school.

The optimisation determines that from the available capacity (5 MW) only 3.3 MW would be needed to cover the project's demand. The associated capital investment of 2.14 M€ is in line with other developments utilizing geothermal energy.

Other project values, such as revenues, fuel costs or capacity costs, are significantly high, the reason being the decision to evaluate the project with a 50-year timespan. As a result, the annualized cost and revenues, which are average, add up to considerable amounts.

Pipework solution	
Length	6.76 km
Total Cost	1.35 M€
Linear Cost	200 €/m
Losses	1.85 GWh/year
Capacity	3.88 MW
Demand solution	
Total Undiversified Peak Demand [4]	6.16 MW
Demand	9.2 GWh/year
Revenues	0.405 M€/year
Supplies solution	
Total Capacity Required	3.88 MWp
Output	11.05 GWh/year
Capital cost	2.14 M€
Operating cost: O&M	0.12 M€/year
Operating cost: heat production	0.15 M€/year

Table 3-3. Network solution

Another remarkable fact of this case study is the pipework extension. Adding up to nearly 7 km, it turns out to be quite a large network. Anyhow, this could be easily reduced by optimising the project's road plot, which could be done by modifying its GIS files. This will allow to remove redundant paths, thus reducing total network length.

Financial analysis

As described throughout this document, the most important fact to be considered when analysing the project's financials would be the decision to not consider economic profitability as the development's main driver. Instead, Barrio La Pinada aims to provision their inhabitants using a clean and innovative technology, but also maintaining a price which is not prohibitive for modest dwellings.

[4] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

In order to achieve this, the case study's methodology has been modified. Instead of setting the tariff and allowing the tool to decide which demands to connect for the project to be profitable, an initial tariff was defined and then reduced until the minimum positive NPV (considering a time horizon of 50 years and a discount rate of 3%) was achieved, thus obtaining the minimum profitable tariff (15 €/kW + 3,4 c€/kWh), which explains the project's low NPV.

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	-1.35 M€			-1.35 M€
Heat supply	-2.14 M€	-0.27 M€/year		-9.33 M€
Demands			0.41 M€/year	10.74 M€
Emissions	Not included at this stage			
Network	**-3.49 M€**	**-0,27 M€/year**	**0.41 M€/year**	**0.06 M€**

Table 3-4. Economic solution

The most significant constraint regarding the project's financials would be the early stage of the project. As of now, this means there is little information regarding the future costs of the project, which complicates an accurate estimation of the costs. This could be easily fixed by developing a more in-depth study. Some actions that could be taken to achieve this objective could be asking pipeline specialists for prices and construction companies for estimated civil costs, among others.

From this point on, the best path to improve the project's financials would be the development of more accurate inputs rather than optimising the ones already used. This case study could be considered as a first sketch of the network which proves its potential profitability to project stakeholders, but the data should be improved in order to present it to potential investors.

3.4 Conclusions

3.4.1 *Status quo* of the case study

As of right now, Barrio La Pinada is almost completely designed and some construction works have already started, but the municipality's approval is still needed to start the full development. This case study has proven the feasibility of the proposed solution, which encourages the project developers to maintain their commitment to the implementation of this technology.

3.4.2 General reflections on using THERMOS in developing the case study

Considering that this case study began as a part of the THERMOS Train the Trainers program, it could be said that its development expanded over a couple months. Anyhow, for an experienced user, including data treatment and implementation, it should take around a week or two at most.

As mentioned previously, users were not familiar with neither THERMOS nor GIS, which slowed the work a bit. On the other hand, for specialised projects such as this one, promoting circular economy and sustainable urban development, it is important to possess the expert knowledge that allows to create an accurate case study. Otherwise, some of the information such as materials used, and their price would have been difficult to retrieve.

3.4.3 Challenges

The project's main challenge is the need for the modification of local urban planning in order to make the land developable. Once this has been done, the project will be ready to start its building stages. This will likely happen in the close future, but there is not a specific date yet. In this regard, even though Paterna is a signatory of the Covenant of Mayors, they have yet to develop a SECAP, which could act as a driver for the project as well as help mainstreaming it. Also, the project could benefit from a stronger support from the municipality's side.

3.4.4 Future outlook

Since the THERMOS timespan urged the development of the case study, more time could be used to contrast these values and assure their accuracy.

Once data has proven to be accurate, there are aspects of the project that were not taken into account, like PV panels or storage, there is room to keep developing the case study by developing a supply problem.

Also, the project is currently looking for investors and THERMOS could be used to mainstream the project, as well as its profitability.

3.4.5 Scope for replication

Barrio La Pinada is a very specific case study with easily recognizable characteristics, such as being a private development or designing an eco-neighbourhood. This case study would help any urban developer which aims to design a new project, specifically if the economic profitability is not the most important factor.

The case study could also be used by any public entities who want to analyse the possibility of sustainable urban development or eco-neighbourhoods. From the technology's standpoint, any private or public investor interested on implementing a geothermal DHC network could surely draw interesting conclusions from this case study.

4 Bristol Redcliff Network Extension – Bristol, United Kingdom

4.1 Introduction

This case study is based in Bristol, UK and looks at using THERMOS to do rapid assessments of heat network extensions, for example adding a new connection to a network. Normally this follows a process of comparing the new extension with a feasibility or design document, checking it is within scope and agreeing to install it, but if the new connection is not covered in the design a more detailed and time-consuming assessment is required.

Using THERMOS for this purpose is to enable a quick response to connection enquiries, checking the key parameters of pipe capacity and heat generation capacity. As undertaking connection enquiries is not specifically within the intended scope of THERMOS, a check was done on accuracy, by comparing THERMOS outputs with a detailed hydraulic model that had previously been created for this network.

To set up the model, data from GIS and hydraulic models were used to create a network project. After testing, this was changed to represent the current as-built network so that the effect of adding new connections could be seen. The work has shown that the THERMOS model has a good level of accuracy compared with a detailed design and hydraulic model carried out by expert consultants. It has also shown that the modelling of additional connections can be carried out quickly.

4.1.1 City/area energy background

Bristol City Council has been actively planning heat networks for over 10 years to help deliver affordable, low carbon heat across the city and to contribute towards their net-zero carbon target by 2030. The Council were the first in the UK to declare a Climate Emergency in 2018 and have produced the Mayor's Climate Emergency Action Plan alongside an overarching Climate Strategy to achieve a carbon neutral, climate resilient Bristol by 2030. The Action Plan commits to delivering *"significant low carbon energy infrastructure in the city, including expansion of the district heating network to provide heat to buildings around central Bristol from low carbon sources".* [5]

The Council has initially been developing a City Centre network (see Figure 4-1) which it hopes to expand in the future making use of low or zero carbon heat sources such as waste heat, local water ways and old mine workings. The case study described below concerns the Redcliffe network area indicated in the Figure 4-1.

[5] www.bristol.gov.uk/documents/20182/33379/Mayor%27s+Climate+Emergency+Action+Plan+2019+FINAL

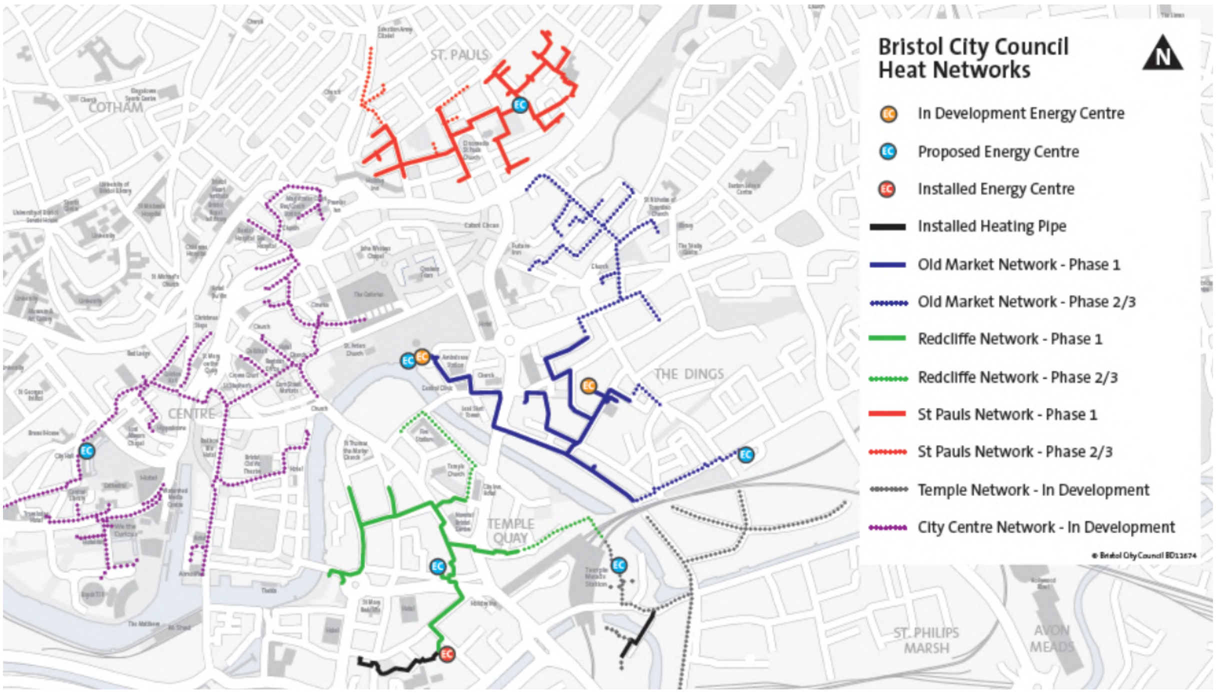

Figure 4-1. Planned development of Bristol's City Centre heat network

4.1.2 THERMOS involvement set up

The case study was a collaboration between Sustainable Energy Ltd (SEL), Centre for Sustainable Energy (CSE) and the Energy Infrastructure Team from Bristol City Council (BCC), who devised and ran the study over the period from December 2020 to March 2021. Much of the data for the model came from work previously carried out by SEL, which CSE imported into a version of THERMOS including combining different data sources from GIS, CAD and Excel to create the different project models used in the case study.

A small section of the city heat networks was used for this case study, to demonstrate the principle of additional connection modelling in action. Set up work was minimised by using pre-existing GIS data and hydraulic model data to create a project within THERMOS.

4.2 Overview of the case study analysed with THERMOS

4.2.1 Introduction

The motivation behind the case study development was to establish if THERMOS could work as a feasibility assessment for new connections to an existing network. In Bristol the networks are in their first phase of development with mainly new buildings being connected. Although there is a phase plan, the actual timing of the phasing is only loosely defined. As a consequence, there are many connection enquiries that come forward outside of the plan and it is important to quickly assess if these connections can be accommodated and what impact they have on remaining network capacity locally and at the energy centre. The intention was to find a quick, easy and cheap way to assess a new connection and to know when a more detailed assessment may be required.

This project was selected for a case study because it represented a typical connection enquiry. The area of the project had been extensively studied and was in construction so the project information could be used to test the outputs of THERMOS. In particular, the tool outputs were compared with the outputs of hydraulic modelling carried out at detailed design stage, in effect calibrating the THERMOS outputs. This allowed an assessment of the accuracy of pipe sizing in THERMOS. Once the accuracy was assessed, THERMOS was tested for ease of use and quality of output for doing rapid assessments.

The analysis considered a section of the 'Redcliffe' heat network in Bristol as modelled in THERMOS and shown in the figures below.

Figure 4-2. Redcliffe network showing existing pipe route and agreed connections.

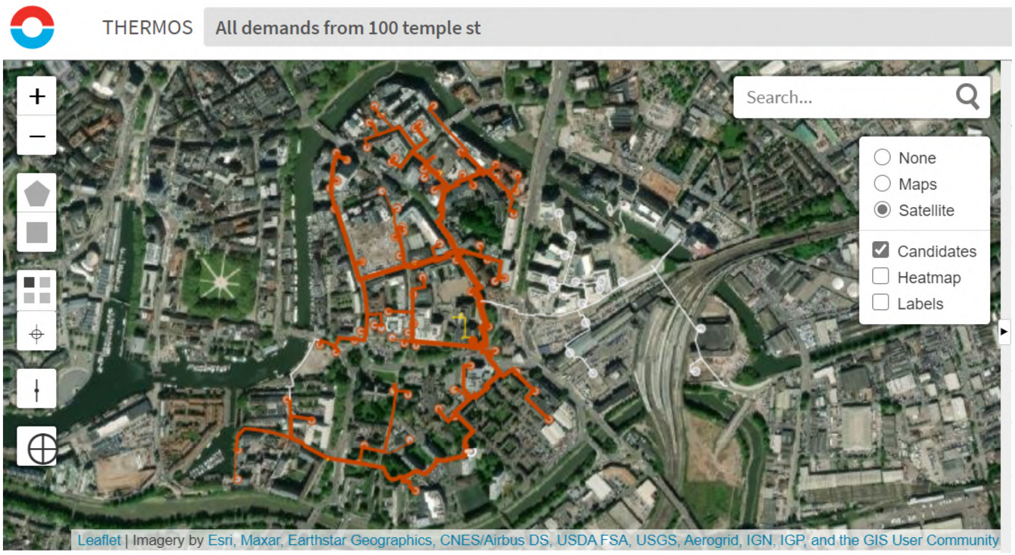

Figure 4-3. Redcliffe network showing final extent of proposed connections.

The goal of the case study is to use THERMOS as a quick assessment tool for new connections as they are added to the network. This will allow the business development team at Bristol City Council to quickly respond to new enquiries with reasonably high confidence that the connection can be made and there is enough heat capacity.

4.2.2 Case study definition

This case study has used THERMOS to consider network expansion of a development comprising eight new buildings by considering the addition of one or more buildings to this network. The wider network plan is to ultimately connect around 60, mostly existing buildings.

The key output was to evaluate the capacity of the installed pipes and identify if adding additional buildings would risk exceeding the supply capacity of the pipes local to the building or of the installed supply generation for that phase of development.

For the purpose of this case study this means avoiding:

- Undersizing the pipe, which means the pressure drop will be too big as the model assumes more heat can flow than may be the case;
- Oversizing the pipe, which means that it underestimates how much heat can flow through a pipe and may result in rejecting a customer unnecessarily.

The objective setting within THERMOS was to 'Maximise network NPV' although the analysis principally concerned technical capacities of supply and demand rather than financial viability. Supply was reviewed in terms of the power delivered through the pipe from the energy centre to check planned capacity was not exceeded.

4.2.3 Results

The final built out heat network as represented by THERMOS modelling of all future demands was compared with data from the detailed hydraulic model. The THERMOS results were exported to Excel and pipe identifiers and location were checked against the CAD network drawing and classified in the following way using the incremental pipe sizes in the 'Pipe Costs' table in THERMOS:

- Pipes equal in size;
- One pipe size smaller in THERMOS;
- One pipe size larger in THERMOS;
- Two pipe sizes larger in THERMOS.

A total of 47 pipes were compared, which was a sample of 1,365 metres of pipe out of a total of 5,969 metres comprising the entire network. The results are illustrated in Figure 4-1.

Pipe size as calculated by THERMOS compared to hydraulic model	No. of pipe segments	Total length of pipe segments (metres)
Equal	29	957
One size smaller	10	175
One size larger	6	195
Two sizes larger	2	36

Table 4-1. Results of pipe sizing accuracy checks

The results indicate that 70% of pipe segments compared were equal in size, and that 97% matched within one pipe size.

This suggests that for this network THERMOS can be used as a reliable proxy for detailed hydraulic modelling. Where a pipe has been sized by THERMOS equally or smaller than the existing pipe, there is a high confidence that there is sufficient capacity available to service the additional load. Having established the accuracy of the model, the next step looked at how easy it was to add loads and assess the output. Scenarios were created based on the **phase one demands** model by adding loads on two branches to understand how much spare capacity existed on that part of the network.

In this case calculated pipe size was used as the parameter of interest due to the unavailability of 'as-built' heat capacity data; when the modelled pipe size exceeded the 'as-built' pipe size, branch capacity is also likely to have been exceeded. In future analysis, pipe heat capacity data will also be considered.

By incrementally increasing the building loads at the end of the lines until the 'as-built' pipe size is exceeded, available capacity for a particular area can be identified. This is considered to be very useful information; for example, if there is a request to supply 1,000kW peak load to a new site on a pipe extension, a rapid answer can be provided by looking at the pipe sizing at the existing building at the end of the line. Using THERMOS, a building can be added in the right place with the agreed load which, if serviceable, will then reduce the end of line capacity and quantify any spare capacity remaining. A quick check of pipe capacity at the energy centre can also be undertaken to see when overall supply capacity is close to being exceeded. Additionally, by referring to the accuracy modelling (Table 4-1), parameters are available which indicate at which point a full hydraulic check is required using the detailed hydraulic model.

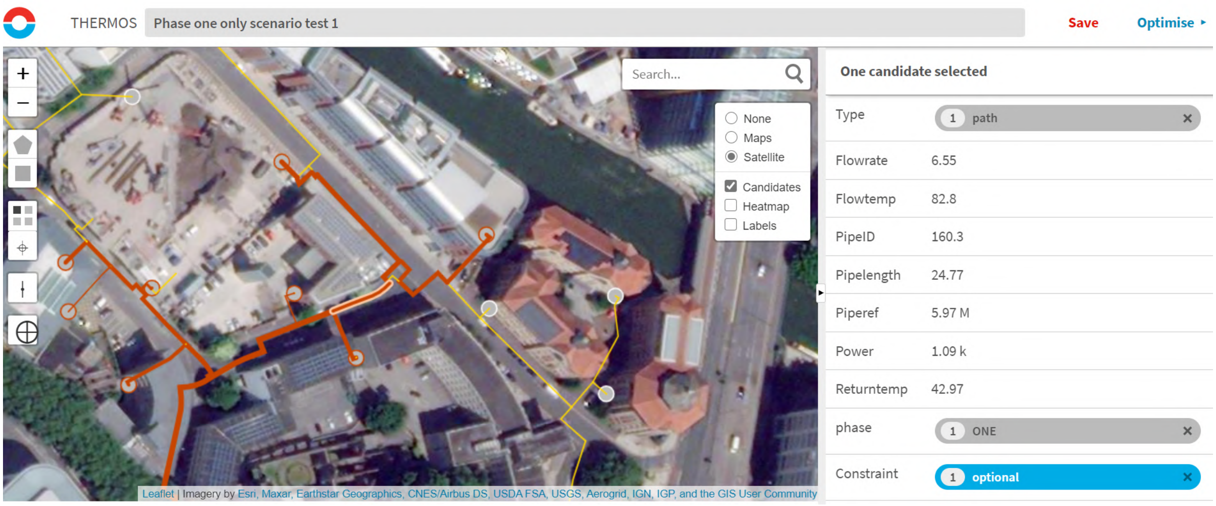

Figure 4-4. Example showing 'as-built' specification of highlighted pipe section

In the example above the highlighted pipe is being checked for two new loads that have been added at the ends of the network. Figure 4-4 shows that in the data table to the right of the network map a 160mm diameter pipe ('PipeID 160.3') is installed at the highlighted section of the network. This data was imported as the GIS data field and the pipe sizing came from the NetSIM hydraulic design. Figure 4-5 then shows the same network diagram but the data table has been scrolled down to show the THERMOS calculated pipe size for these connections. Here, with new demands added, THERMOS has calculated that a 100mm diameter pipe is required, indicating there is sufficient capacity available for these connections because the pipe needed is smaller than the one that is installed. The energy centre diversified supply peak is 5.05MW in this scenario.

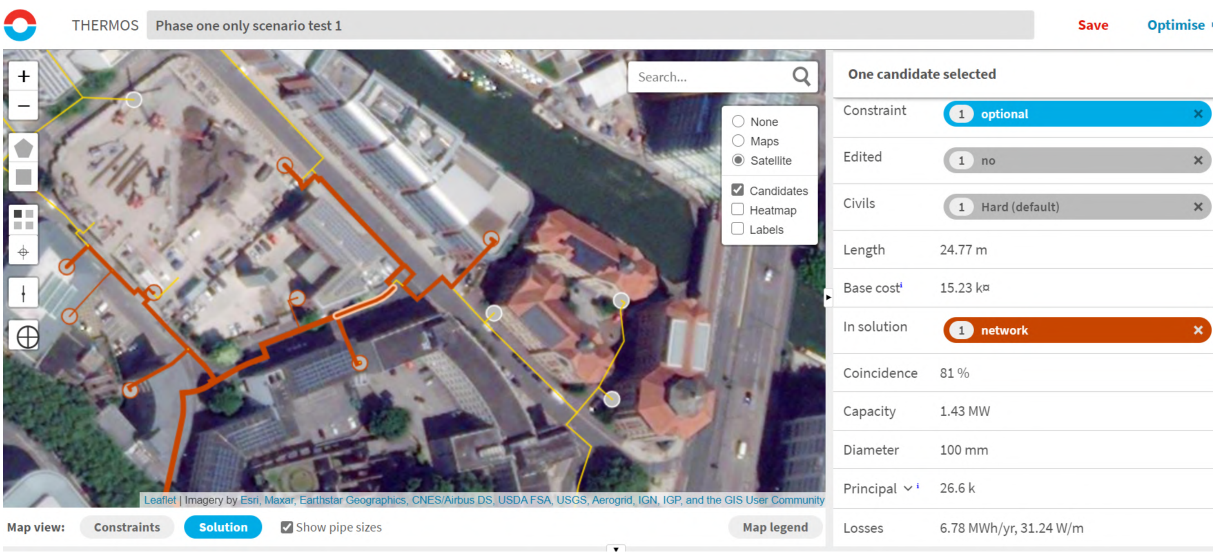

Figure 4-5. Same example showing modelled specification of highlighted pipe section with new demands added

To check the loads that could be added to this section of the network a new scenario was created with two new loads rated at 1.75MW and 2MW. The model was then re-run to calculate the pipe sizes required for these two new connections. Looking at the same section of pipe as before (that was previously calculated to be 100mm), it can be seen that the modelled pipe size has increased to 150mm (see Figure 4-6). This new pipe size of 150mm would therefore indicate that full capacity will almost have been met once these loads are added as the installed design pipe size is 160mm.

At this point in the work an accurate hydraulic check of the piping would be needed to confirm the details, but it is clear that this method using THERMOS offers a rapid and straightforward preliminary check to see whether anticipated loads are likely to be acceptable. It also usefully allows the diversified energy centre peak load to be reviewed at the same time to check available capacity; in this case, the addition of the two new loads has increased the supply peak load from 5.05MW to 7.37MW.

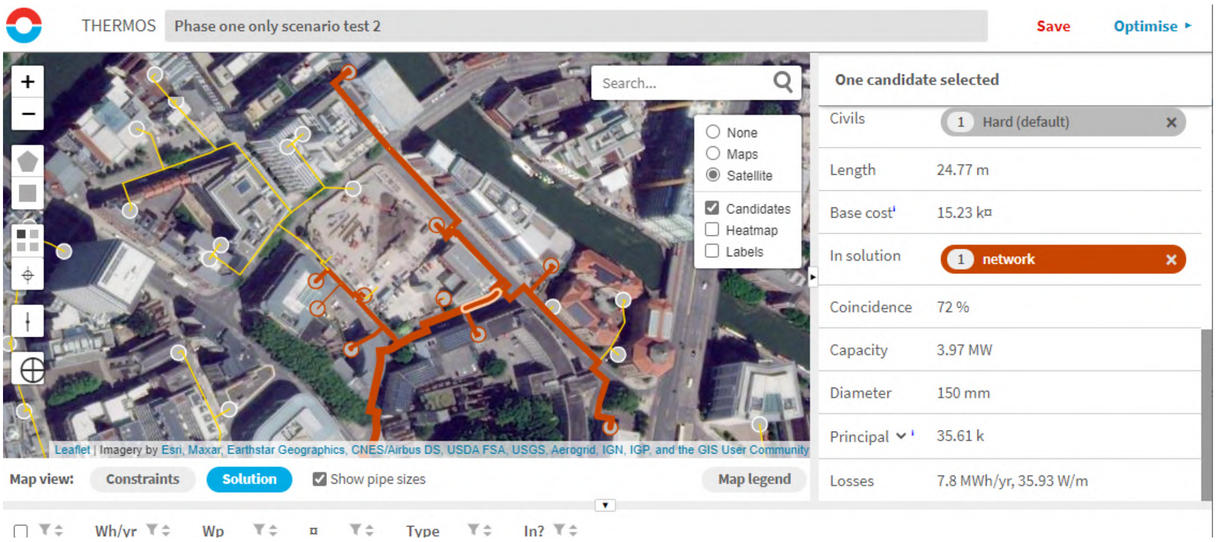

Figure 4-6. Example showing network extended from that in Figure 4-5 and reaching capacity

4.3 Case Study development and results

4.3.1 Data preparation

The following data were used to supplement the default data used by THERMOS to generate the required maps prior to network optimisation analysis:

- Output from NetSim hydraulic model in the form of GIS Shape files of the existing network;
- CAD drawing of as built network route;
- Excel file of building heat demands;
- OpenStreetMap of buildings.

The method employed was as follows:

1. Combine GIS data with the as-built CAD drawings;

2. Upload to THERMOS;
3. Run two models:
   - one which includes all the future demands;
   - one which just includes the phase 1 demands.

THERMOS can display information from the original GIS files - on the network data the following fields were retained:

- Flow rate;
- Flow temperatrue;
- PipeID - pipe diameter;
- Pipelength;
- Pipe reference;
- Power - in kW, delivered in phase 1;
- Return temperature.

In the map generated to model **all future demands**, the PipeID field was compared with the THERMOS calculated pipe diameter (because the pipes are sized for future loads). The comparison allowed a check on the accuracy of THERMOS outputs. Ideally the pipe heat capacity would also be compared, although unfortunately this data had not been included in the shape file data set.

In the map generated to model **only phase one demands**, the PipeID field was compared with the THERMOS calculated pipe diameter to see at what point additional loads cause the THERMOS pipe diameter to exceed what is installed. Typically, the phase one loads are so small the THERMOS calculated capacity of the pipe is much smaller than what is installed because it was designed to allow for a large future capacity. However, towards the ends of network runs, pipes are smaller and spare capacity is lower so this capacity will be used up more quickly. In this way, THERMOS can be used to add loads quickly and identify where pipe capacity is limited.

For this analysis, only the peak demands of the buildings were of interest; annual demands and costs were of secondary importance.

4.4 Conclusions

4.4.1 *Status quo* of the case study

The case study has shown that the THERMOS model has a good level of accuracy compared with a detailed design and hydraulic model carried out by expert consultants. It has also shown that the modelling of additional connections can be carried out quickly. To get the benefits of using this approach the existing network first needs to be created as a project within THERMOS and optimised for comparison of pipe sizes and capacities.

4.4.2 General reflections on using THERMOS in developing the case study

Although it took longer than expected to prepare data and set up the case study, THERMOS was easy to use and gave good results. Staff from the Energy Infrastructure Team at Bristol City Council involved in using THERMOS had previously undertaken online training on the tool and had direct experience of heat networks but lacked GIS expertise. Overall, it was felt that the case study successfully demonstrated a way of obtaining quick answers that are relatively low cost compared with the existing practice of using consultants to check the data.

4.4.3 Challenges

The THERMOS user's lack of experience of using GIS techniques meant that the setup of the projects within THERMOS was harder than anticipated. However, once the projects are set up then there should be a relatively low maintenance effort to keep them up to date. Making more use of the spreadsheet download/upload facility will also help in this regard.

4.4.4 Future outlook

Looking ahead, the intention is to import all the detailed heat network designs and constructed projects across Bristol into THERMOS to take advantage of its ability to model future connections. However, Bristol City Council will first need to weigh up the cost of doing this against the benefits of being able to review connections quickly and cheaply review connections on a regular basis.

4.4.5 Scope for replication

This case study may be of interest to other system owners who are looking for a cheap and easy way to assess connections to an existing network. To do this data on the existing network is required in a form that is easy to import to THERMOS and so some experience of GIS techniques is advisable. The data for the existing system should include pipe sizes, loads, capacity and geographical data. Results from this case study indicate that THERMOS produces an acceptable level of accuracy when compared against detailed hydraulic modelling techniques, but users may wish to undertake their own comparison in replicating this study.

Acknowledgements

The case study was developed and written by Duncan Faulkes of the Energy Infrastructure Team at Bristol City Council with support from Rhys Sully of Sustainable Energy Ltd, and Tom Hinton and Martin Holley from the Centre for Sustainable Energy.

5 EcoCongost – Granollers, Spain

5.1 Introduction

The city of Granollers aims to implement actions to contribute to the Spanish National Integrated Energy and Climate Plan 2021-2030, the National Pact for Energy Transition in Catalonia and the European Commission's initiative "Clean Energy for all Europeans".

5.1.1 City/area energy background

Sustainable energy planning started in Granollers in 1999 with the approval of the first Local Agenda. Energy efficiency and the promotion of renewable energy sources (RES) are key goals for the city through Local Agenda 21 (2009). The transition of Local Agenda 21 to the 2030 agenda aims to also integrate the sustainable development goals (SDGs). Granollers' local government periodically approves a four-year programme (PAM) which includes actions to be promoted with the objective of addressing the SDGs. Until now the PAM was focused on more qualitative objectives, however, presently each implemented action is linked to quantitative objectives for the city's long run sustainability.

Energy planning towards an energy transition has been a goal for Granollers since it signed the Covenant of Mayors agreement in 2008. In 2009 Granollers approved its Sustainable Energy Action Plan (SEAP) and it accepted a wider scope of commitments as well as approving its Sustainable Energy and Climate Action Plan (SECAP) in 2016, providing adaptation measures for these commitments. The original SEAP dictated that a 20% increase in energy efficiency and another 20% increase in the use of RES should be achieved by 2020, aiming at a reduction of GHG emissions of 20%. The new SECAP goes further by aiming to reduce emissions by 40% by 2030. By 2017, several actors reached the projected reduction in emissions, where the tertiary and industrial sector achieved to reduce their emissions by 30%. Approximately 98,875 tons of CO2 (as of 2017) are emitted by the industrial sector, making projects like EcoCongost pivotal to achieve the city's goals.

5.1.2 THERMOS involvement set up

The simulation of the construction and optimization of a new DH network using the THERMOS tool in the Ecocongost industrial complex is aimed at evaluating the state of the art and feasibility of the integration of more renewable energy sources and increased energy efficiency for industries and other businesses located in this area. The EcoCongost project has the particularity that it needs to integrate industrial steam distribution into the DH network supply. An update was performed in the THERMOS tool to include this option and was consequently put to trial throughout this case study.

Engagement of different stakeholders and information procurement were generally achieved through bilateral meetings and direct contacts. In some cases (mainly for industrial companies), it was necessary to organize industrial site visits, external visits to other DH network projects, and invitations to public meetings presenting DH network project evaluation to obtain further information and to obtain stakeholders' interest.

5.2 Overview of the case study analysed with THERMOS

5.2.1 Introduction

EcoCongost intends to evaluate the feasibility of the implementation of a district heating network in Granollers' industrial district aimed at reducing GHG emissions, producing and meeting local heat demands with an increased share of RES and boosting circular economy.

This project focuses on two industrial areas (highlighted in Figure 5-1) in the municipality of Granollers where energy efficiency and renewable energy implementation is managed and optimized individually by each company, rather than collectively, hence there is no previous experience with DH networks in the area. The implementation of the DH network proposed by EcoCongost looks to increase economic feasibility due to economies of scale, and to improve organizational and technical aspects that will optimize the distribution and generation of energy. It also sets to reduce the industries' carbon footprint by offering a renewable alternative to their current primary energy source: natural gas – guaranteeing a sustainable business model for the future.

Figure 5-1. Location of the case study's area

Biogas can be sourced from a nearby composting plant which has an anaerobic digester with a consistent production surplus. Additionally, local producers of biomass have been approached to guarantee local provision of the resource, increasing the sustainability of the project and an available local forest biomass of 18,000 tons/year (63 GWh/year) was estimated.

In 2019, improvements planned by the consortium of organic matter treatment facilities led to a higher potential of local biogas generation. The new projects would allow to increase biogas production in the near future up to 11,339,657 Nm^3/year. Approximately 69% will be used for cogeneration and the rest will be upgraded together with the biogas produced in the wastewater treatment plant. A new plant will be built to dry sludge using biomass and the dried sludge itself as a source. Additionally, sludge waste thermal energy may also be available, leading to a higher availability of renewable resources.

The project was originally aimed to develop an industrial network supplying steam covering an industrial heating demand of 112 GWh/year. During the first phase of development, the network was estimated to have a pay-back period of seven years and would require a power plant of 20 MW according to feasibility studies run by the Granollers city council.

The use of the THERMOS tool is crucial to optimise the network design, study the outputs, and obtain the most efficient parameters. Factors other than NPV optimization were considered when deciding if the network should be developed, namely CO_2 emission reduction and energy efficiency improvements.

At present, there is no established date to start the deployment of the project. Several network managers of district heating networks in Spain have shown interest to finance the project and Granollers has applied to European funds to finance part of it.

The EcoCongost case study aims at introducing a DH network supplying industrial steam using local energy sources. The main goals of the EcoCongost project are to:

- Make a pre-feasibility study for an early-stage planning of the DH network given available energy sources, namely natural gas, biogas, biomass, and waste sludge thermal energy;
- Evaluate an industrial heat network as a solution to achieve GHG emission reduction and help transition towards a carbon-neutral economy;
- Determine construction costs for the available routes in order to compare the original considered paths with other alternatives;
- Evaluate different primary energy sources to compare the emission reduction against economic feasibility;
- Analyse connection cost estimates for each of the industries involved;
- Analyse and evaluate the expansion of the network, supplying energy to more industries and industrial areas.

Regarding stakeholders, a couple clusters have been identified and classified within the EcoCongost project:

- **Customers:** industrial companies located in the industrial districts that could be connected to the heat network. Individual industries and the industrial park business association have been directly involved providing information and communicating within member companies;

- **Energy providers:** different stakeholders were contacted to define the existing local energy supply potential. Enquiries were made regarding generation profiles, energy transport and storage specifications, primary energy costs and their relationship with fossil fuel prices;
- **Public authorities:** public stakeholders were contacted to obtain information regarding benchmark ratios and values, future energy cost predictions, replicability and financing opportunities;
- **Private promoters and developers:** to validate the project concept and the underlying economic assumptions several private specialized companies were contacted. Simultaneously, visits were performed to existing heat networks to understand them and engage local industries;
- **Private financers:** were approached to overcome the barriers related with the economic aspects of the project and help understand the existing financing alternatives and connected risks.

5.2.2 Case study definition

Heat Demand

Building in the industrial district require high amounts of heat (distributed using steam and hot water) for their industrial processes. Heat demand sources have been differentiated within the industrial district: sanitary hot water, ambient heating, and industrial process demands. Information was collected using different methodologies and sources, described in more detail in section 1.3.1: Data preparation.

A completely new DH network needs to be designed and optimized to cover for the demands of the industrial district. Two different demand scenarios have been considered to perform this case study:

- Demand scenario 1: only considering the real industrial demand: 108.96 GWh/year;
- Demand scenario 2: considering the real industrial demand + all additional activities (such as ambient heating and sanitary hot water demand): 122 GWh/year.

The energy demand covering industrial buildings has been differentiated between flat demand (which includes industrial buildings which are working 24 hours a day) and working hour demand (for industries which require a demand for 8 hours a day). The main characteristics of both demand scenarios are illustrated in Table 5-1.

	Demand (real industrial demand)	Demand (real industrial demand + additional activities)
# of buildings involved	8	23
- Residential	-	-
- Industrial	8	22
- Commercial	-	2
- Other	-	-
Tot. energy demand	108.96 GWh/year	122 GWh/year
- Residential	-	-
- Industrial	108.96 GWh/year	6.66 GWh/year (8h) 115.5 GWh/year (flat – 24h)
- Commercial	-	0.075 GWh/year
- Other	-	-

Table 5-1. Main characteristics of the demand.

The following energy alternatives have been considered and are available to supply energy to the DH network:

- Biogas: a nearby anaerobic organic waste treatment plant can provide an available surplus of 16.7 GWh/year to the network. This amount could be much higher after the waste treatment facilities build new plants and upgrade the biogas produced;
- Biomass: factors considered to define the biomass heat supply were the seasonal and peak heat demand, boiler requirements, and biomass availability. Different types of biomass are considered, differentiating between biomass coming from pruning remains and other sources. Local production can provide 18,000 Tn/year of biomass;
- Wastewater treatment sludge: sludge from nearby wastewater treatment plants, together with biomass might produce waste thermal energy supplying 2,784 MWh/year. There are currently no signed agreements for the supply of this fuel, however, the possibility to integrate this energy source as fuel in the future has been considered as one of the possible scenarios for this case study;
- Natural gas: two high efficiency back-up boilers are included in the set-up to meet peak demand and provide flexibility – enabling 22.5 MW peak demand.

The generation plant has been designed to comprise 3 different boilers:

- 1 primary boiler (run on renewable energy sources): 10 MW boiler that supplies the baseline demand and is intended to be operating 100% of the time throughout the year and will only stop for maintenance purposes;

- 2 natural gas boilers:
  - A 10 MW boiler that will enable to cover the peak demand of the network. This boiler is intended to be operating less than 25% of the year;
  - A second 10 MW boiler is intended to be used as a back-up to cover demand when the primary boiler is under maintenance.

To represent the plant as a generation unit in THERMOS, a single boiler with a total capacity of 20 MW has been considered. The capacity, annual costs and supply costs are estimated according to the total number of hours that each boiler should run, considering just one of the natural gas boilers (10 MW) and the primary boiler (10 MW). Two configurations have been suggested for the primary boiler:

- Configuration 1 – the primary energy source and capacity for the primary boiler are:
  - Primary biomass resource: 91,000 MWh/year;
  - Biogas: 9300 MWh/year.
- Configuration 2 – the primary energy source and capacity for the primary boiler are:
  - Primary biomass resource: 91,000 MWh/year;
  - Biomass (pruning remains): 780 MWh/year;
  - Wastewater sludge: 2,784 MWh/year;
  - Biogas: 9300 MWh/year.

	Supply (Configuration 1)	Supply (Configuration 2)
Technology	Boiler	Boiler
Fuel used	Biomass + Biogas + Natural gas	Biomass + Biogas + Wastewater sludge + Natural gas
Maximum capacity	20 MW	20 MW
Fixed costs	1,512,000 €	2,038,000 €
Capacity costs	98.6 €/kWp	98.6 €/kWp
Annual O&M costs	26.84 €/kWp	27 €/kWp
Supply costs	2.106 c€/kWh	1.585 c€/kWh
CO_2 emissions	0.0224 g/kWh	0.0193 g/kWh
$PM_{2.5}$ emissions	0.5124 g/kWh	1.686 g/kWh
NO_x emissions	0.2308 g/kWh	0.7919 g/kWh

Table 5-2. Main characteristics of the supply

The main characteristics of both supply scenarios are presented in Table 5-2. In this case study, industries are undecided whether to produce sanitary steam by using energy from the network due to the high capital investment needed for its installation. Hence, even though this cost should be considered, the installation costs of producing sanitary steam to the industries has not been considered because the number of industries to be connected could not be defined. Hence, it was decided that a fixed capacity cost would not be added to the supply configuration. Nevertheless, industrial demands are stable throughout the year, meaning that fixed costs of the network are assured, and therefore only these fixed costs were considered for this case study.

5.3 Case Study development and results

5.3.1 Data preparation

Different heat source demands have been identified and differentiated within the industrial complex: hot sanitary water, ambient heating, and industrial processes. Information regarding these demands has been collected using different methodologies (either benchmarking or using real data). Throughout the case study, real data has been used when available, otherwise statistical data has been introduced into the tool.

Real data has been obtained through surveys and direct communication with industries and businesses. Data regarding municipal buildings (public, commercial and businesses) has been collected from monitorization data.

Benchmarking data has been collected for the different heating demands as follows:

- Industrial heating demand (includes hot water, superheated water and low temperature steam): Benchmarking data obtained is based on the economic activity code (CNAE - National Classification of Economic Activities), consumption factors defined by IDAE (Institute for Energy Saving and Diversification), and cadastral information obtained from the city council GIS maps;
- Sanitary hot water demand: Benchmarking and statistical data – data has been collected based on cadastral data, as well as consumption factors defined in the current legislation;
- Ambient heating demand: THERMOS estimations have been performed based on information gathered regarding the building volume (LIDAR data), surface area (GIS maps), and DegreeDays (www.degreedays.net) of the city of Granollers, which is readily available online.

In order to upload demand and building information to the THERMOS Tool, a single energy demand (accounting for space heating, sanitary water and industrial process needs) needs to be assigned to a building with all the information variables placed in it (name of enterprises, type of activity, etc.).

- When several buildings belong to a single user, the whole demand can be assigned to a single building to be considered by the tool;
- In case more than a one user is located in a building, the heat demands can be summed up.

Regarding the emissions considered for each energy source, data has been collected from databases offered by the "Generalitat de Catalunya" for the calculation of atmospheric contaminants[6] and biomass run boiler emissions[7]. Table 5-3 shows the emissions considered for the combustion of each primary energy source.

Primary Energy Sources	CO_2 (g/kWh)	$PM_{2.5}$ (g/kWh)	NO_x (g/kWh)
Natural gas	0.1077	0.0051	0.2436
Biogas	neutral	0.0129	0.2161
Biomass	neutral	0.7114	0.2286
Biomass (pruning remains)	neutral	1.7888	0.5747
Wastewater treatment sludge	neutral	53.881	25.6673
Electricity	357	-	-

Table 5-3. Emissions considered for the combustion of each primary energy source.

This information is important since one of the objectives of the report is to evaluate the difference in emissions between the proposed scenarios. Emission limits have been defined as follows:

- Biogas: limit defined by the municipal waste consortium;
- Waste sludge: limit defined by the "Besos Tordera" consortium;
- Biomass: emissions set by the technical prospect for sizing of the biomass boiler;
- Natural gas: the quantity is variable to be able to cover the peaks and rapid variations of demand.

The costs of the DH network have been collected and validated through conversations with private promoters and developers. Construction costs have been calculated based on the project's budget and technical evaluation. The average piping network installation cost has been calculated as 1063 €/m which has been used for all the piping in this case study.

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[6] http://mediambient.gencat.cat/web/.content/home/ambits_dactuacio/atmosfera/la_contaminacio_atmosferica/inventari-emissions/docs/guia_fe_2013.pdf

[7] http://icaen.gencat.cat/web/ca/energia/renovables/biomassa/BiomassaCAT/.content/09_publicacions/cercador_publicacions/documents/Guia-emissions-en-calderes-de-biomassa-web.pdf

Costs regarding energy sources and distribution costs have been collected from energy providers. Fixed costs per capacity (€/kW) have not been considered and rates (€/kWh) have been calculated to match the true cost of industrial steam generation (at the lowest and most competitive price). The connection costs to the network have not been calculated or considered since industries are undecided whether to connect to a sanitary steam network due to the high capital investment needed for its installation, and therefore the number of industries to be connected could not be defined. Table 5-13 presented in the Ecocongost - Information Annex shows the heat delivery costs of the three delivery options considered.

Lastly, regarding the network topology, the study did not just consider local streets or roads for the installation of the DH network. In order to widen the possibilities for the construction of the DH network other possible alternative network paths following nearby train tracks and a river basin have been considered. A GIS has been prepared and uploaded to THERMOS to explore the possibility of building the heat network in places other than local streets or roads.

5.3.2 Results

The results presented in this section are presented as four different scenarios:

- Scenario 1: supply configuration 1 (using biomass, biogas, and natural gas in the primary boiler) only considering the real industrial demand;
- Scenario 2: supply configuration 2 (using biomass, biogas, natural gas, and wastewater sludge) only considering the real industrial demand;
- Scenario 3: supply configuration 1 (using biomass, biogas, and natural gas in the primary boiler) considering the real industrial demand and all additional activities;
- Scenario 4: supply configuration 2 (using biomass, biogas, natural gas, and wastewater sludge) considering the real industrial demand and all additional activities.

Scenario 1 and Scenario 2

Figure 5-2. THERMOS solution network layout overview for scenarios 1 and 2

Figure 5-2 shows the optimal path THERMOS has identified for the implementation of the DH network, which is highlighted in dark orange. The optional paths which were not chosen can be appreciated in a lighter orange colour. It is worth noting that for some of the industrial buildings, the demand entered in the Thermos Tool has been defined at one concrete point rather than whole building(s), making it easier to enter all the data into the tool. A long pipeline with a few smaller pipes diverting on either side connects the supply point with the eight industrial buildings. The same optimal path was found for both scenarios 1 and 2 since the demand side remains the same and the changing variable is the type of primary energy source used in the primary boiler. Hence, the only part of the table that changes between the two scenarios is the supply solution. Table 5-4 shows the network solution for scenarios 1 and 2.

Pipework solution		
Length	1.86 km	
Total Cost	2.18 M€	
Linear Cost	1170 €/m	
Losses	17.47 GWh/year	
Capacity	14.43 MW	
Demand solution		
Total Undiversified Peak Demand [8]	19.22 MW	
Demand	108.96 GWh/year	
Revenues	4.79 M€/year	
Supply solution	**Scenario 1**	**Scenario 2**
Total Capacity Required	14.43 MWp	14.43 MWp
Output	126.41 GWh/year	126.41 GWh/year
Capital cost	2.93 M€	3.46 M€
Operating cost: O&M	0.39 M€/year	0.39 M€/year
Operating cost: heat production	2.65 M€/year	2.02 M€/year

Table 5-4. Network solution for scenarios 1 and 2

Scenario 1 - Financial analysis

Table 5-5 describes the economic solution provided by the tool for scenario 1.

	Capital cost (M€)	Operating cost (M€/year)	Operating revenue (M€/year)	NPV (M€)
Pipework	-2.18	-	-	-2.18
Heat supply	-2.93	-3.04	-	-66.9
Demands	0	-	4.79	100.82
Emissions	Not included at this stage			
Network	**-5.11**	**-3.04**	**4.79**	**31.75**

Table 5-5. Economic solution for scenario 1

[8] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

A 25-year perspective and a 1.5% discount rate has been considered for the economic analysis. This rather low value for the discount rate has been used to compare the results obtained with the tool with a technical report performed by the consultant company "Aiguasol", which used the same discount rate (the same is true for all four considered scenarios). Due to this low discount rate the NPV of the project is very attractive and its installation would prove to be very viable. Although not presented in this report, it is worth pointing out that carrying out the same economic analysis using a 5% discount rate also returns a positive NPV. The annual operating revenue exceeds the annual operating costs by 1.75 M€, and the initial capital cost for the network according to the tool would be paid off within the first 3 years.

Scenario 2 - Financial analysis

Table 5-6 describes the economic solution provided by the THERMOS tool for scenario 2.

	Capital cost (€)	Operating cost (€/year)	Operating revenue (€/year)	NPV (€)
Pipework	-2.18	-	-	-2.18
Heat supply	-3.46	-2.41	-	-54.19
Demands	0	-	4.79	100.82
Emissions	Not included at this stage			
Network	**-5.64**	**-2.41**	**4.79**	**44.46**

Table 5-6. Economic solution for scenario 2

Once again, as for scenario 1, considering a 25-year perspective and a 1.5% discount rate the NPV for the network is very attractive and its installation would be economically viable. The NPV for scenario 2 is higher than scenario 1 (by 12.71 M€), which is a good result considering that the capital costs of the network at present value are only somewhat higher in scenario 2 than scenario 1. This is due to the higher operational costs for scenario 1 caused by higher supply costs of the primary energy sources used.

The possibility to add wastewater sludge as a primary source for power production proves to be economically convenient. However, the use of this energy source also poses some challenges since its use has more particulate matter and NO_x emissions. The extra costs of adding bag filters and other emission prevention measures have been considered, however, in the future more stringent measures are likely to be put in place by the city council or the EU, which could incur in extra costs.

Scenario 3

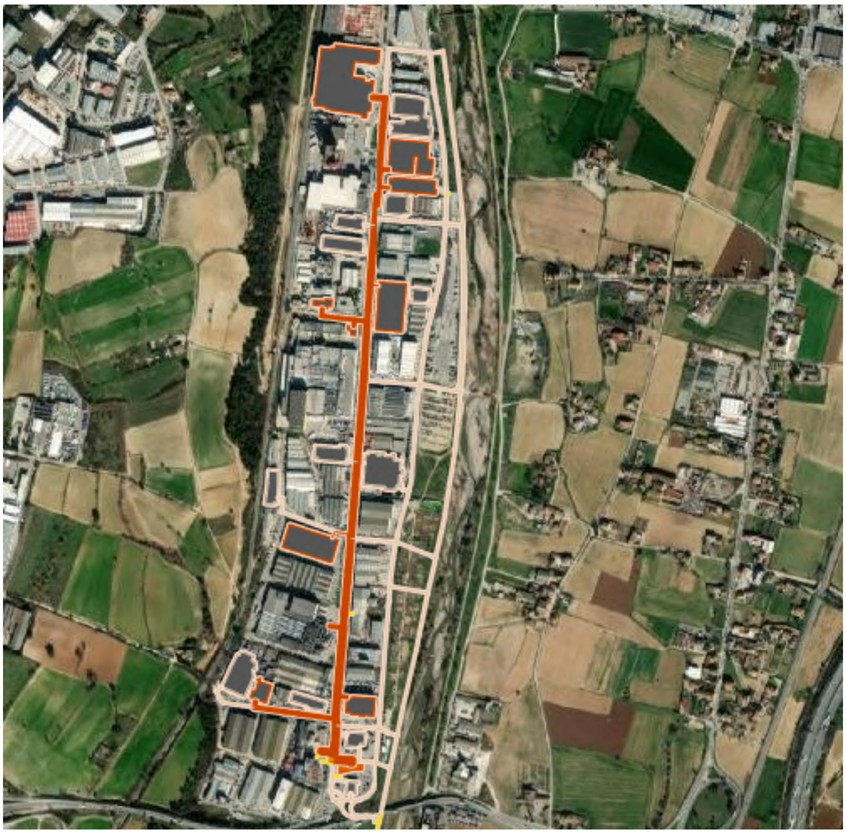


Figure 5-3. THERMOS solution network layout overview for scenario 3

For this scenario, since both the real industrial demand and additional activities in the district are considered, more buildings have been added as optional possibilities to be included in the DH network. The optimal path and buildings identified by the tool are highlighted in a dark orange colour, whilst the optional paths and buildings which have not been chosen to be included in the network can be appreciated in a lighter orange colour. Under this scenario, 24 buildings have been identified to be connected to the network – (2 commercial and 22 industrial). Table 5-7 shows the network solution for scenario 3.

Pipework solution	
Length	1.97km
Total Cost	2.3 M€
Linear Cost	1170 €/m
Losses	18.21 GWh/year
Capacity	16.02 MW
Demand solution	
Total Undiversified Peak Demand [9]	19.39 MW
Demand	122.16 GWh/year
Revenues	5.38 M€/year
Supplies solution	
Total Capacity Required	16.02 MWp
Output	140.36 GWh/year
Capital cost	3.09 M€
Operating cost: O&M	0.43 M€/year
Operating cost: heat production	2.95 M€/year

Table 5-7. Network solution for scenario 3

Logically, the total length of the pipework solution is longer for scenario 3 than for the first two scenarios since more buildings are connected to the network. In turn, the pipework cost installation and capacity are also higher. The revenues are also higher for this scenario given the higher energy demand, leveraging the increased costs of installation. Lastly, given the greater demand, the supply solution needs to be higher, having a higher energy output and therefore a bigger annual capacity cost and heat production cost of fuel.

[9] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

Scenario 3 - Financial analysis

Table 5-8 describes the economic solution provided by the THERMOS tool.

	Capital cost (M€)	Operating cost (M€/year)	Operating revenue (M€/year)	NPV (M€)
Pipework	-2.30	-	-	-2.30
Heat supply	-3.09	-3.38	-	-74.11
Demands	0	-	5.38	113.04
Emissions	Not included at this stage			
Network	**-5.40**	**-3.38**	**5.38**	**36.62**

Table 5-8. Economic solution for scenario 3.

The NPV considering a 25-year horizon and a 1.5% discount rate is once again positive. In comparison with scenario 1 (which uses the same renewable sources of fuel), the capital and operating costs logically increase because of the larger installed capacity and amount of fuel burned to meet the demand. Nevertheless, the operating revenues also increase in a higher proportion, leveraging the higher production costs, and in result the NPV for this scenario exceeds the one provided for scenario 1 by approximately 5M€.

Scenario 4

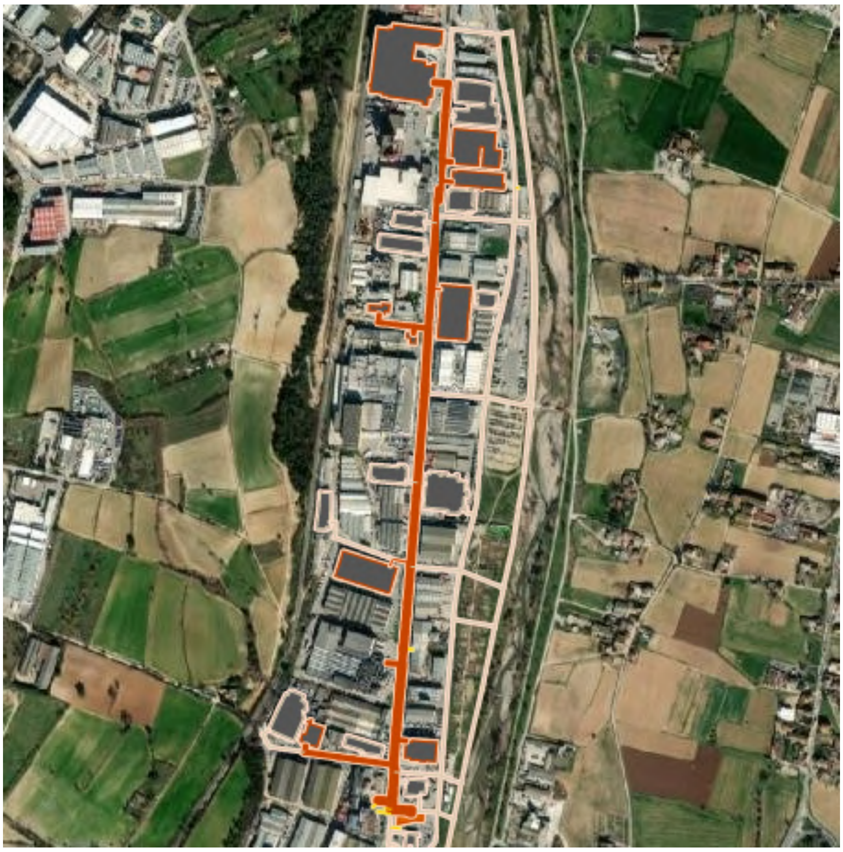


Figure 5-4. THERMOS solution network layout overview for scenario 3

The layout for the optimal solution provided by the THERMOS tool for this scenario is the same as for scenario 3 given that the demands are the same (2 commercial buildings and 22 industries). Table 5-9 shows the network solution for scenario 4.

Pipework solution	
Length	1.97 km
Total Cost	2.30 M€
Linear Cost	1170 €/m
Losses	18.21 GWh/year
Capacity	16.02 MW
Demand solution	
Total Undiversified Peak Demand [10]	19.41 MW
Demand	122.35 GWh/year
Revenues	5.38 M€/year
Supplies solution	
Total Capacity Required	16.05 MWp
Output	140.63 GWh/year
Capital cost	3.62 M€
Operating cost: O&M	0.43 M€/year
Operating cost: heat production	2.25 M€/year

Table 5-9. Network solution for scenario 4

The pipework and demand solutions are very similar to the ones presented in scenario 3. The most noticeable different between these scenarios is the supply solution (since scenario 4 introduces wastewater sludge into the power production mix). By introducing this energy source, the capital cost and heat production cost of fuel is significantly reduced.

[10] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

Scenario 4 - Financial analysis

Table 5-10 describes the economic solution provided by the THERMOS tool.

	Capital cost (M€)	Operating cost (M€/year)	Operating revenue (M€/year)	NPV (M€)
Pipework	-2.30	-	-	-2.30
Heat supply	-3.62	-2.68	-	-59.94
Demands	0	-	5.38	113.04
Emissions	Not included at this stage			
Network	**-5.92**	**-2.68**	**5.38**	**50.79**

Table 5-10. Economic solution for scenario 4

The NPV considering a 25-year horizon and a 1.5% discount rate is once again very attractive, partly due to the low discount rate used, and in fact presents the best results out of the four considered scenarios. Since the real industrial demand and all additional activities are considered on the demand side, the operating revenue is equal to scenario 3 and higher than scenarios 1 and 2. Additionally, since this scenario considers the integration of wastewater sludge into the fuel mix, which as seen in scenario 2 would be more economically viable than using purely biomass and biogas, the operating costs are significantly lower than the ones for scenario 3 and compensate the slightly higher capital expenditure.

Therefore, it can be concluded that the most satisfactory scenario from an economical point of view is scenario 4 since it presents the best results whilst also considering all the demands of the industrial district, which is closer to reality than merely considering the real industrial demand. However, and as shown in the following section "environmental analysis", scenario 4 has higher particulate matter and NO_x emissions, which could present a problem to meet municipal, national, and EU environmental objectives. Additionally, legislations regarding pollutant emissions are becoming ever more stringent, which may affect the economic results in the future.

Environmental analysis

An analysis has been performed to understand the differences in emissions between the four scenarios for the primary boiler which runs on renewable energy sources. Hence, a comparison of the second back-up boiler run on natural gas has not been included, which is why the CO_2 emissions are considered neutral. The emissions released by the primary boiler for each scenario are presented in Table 5-11. It is noticeable that for scenarios 2 and 4 which use wastewater sludge as a fuel source, the emission of $PM_{2.5}$ and NO_x increase significantly.

	CO_2 (t/year)	$PM_{2.5}$ (t/year)	NO_x (t/year)
Scenario 1	neutral	64,72	29,2
Scenario 2	neutral	213,13	100,12
Scenario 3	neutral	71,86	32,42
Scenario 4	neutral	237,1	111,38

Table 5-11. Emission data

5.4 Conclusions

5.4.1 *Status quo* of the case study

Considering the results presented previously, the implementation of a new DH network for the Ecocongost industrial district is viable when installing a power plant run using renewable energy sources (biomass and biogas). If wastewater sludge can be considered as an extra component for power production, the powerplant would become more profitable, however it would have a considerable increase in particulate matter and NO_x emissions.

It is worth noting that it is only feasible to connect buildings whose demand is monitored (in order to have real and accurate data), and those that have an elevated energy demand.

5.4.2 General reflections on using THERMOS in developing the case study

The THERMOS tool has proved to be useful developing this case study and gives validity for its use in future case studies with similar specifications. The results provided by the tool were very similar to the results originally produced by an internal group of experts and gave the team the opportunity to contrast and validate their calculations. It also allowed the team to expand on the project. There was only a slight deviation in the estimation of operational costs, where the tool overestimated some figures, probably due to inexact demand data. Additionally, despite some energy results not being completely precise, the economic solutions returned are satisfactory.

If the tool were not available, an external consultant would have had to be hired to perform the work and analysis regarding the installation of the network (with the corresponding additional costs). The tool also simplified and quickened the analysis of whether nearby businesses and industries close to the heat network could be good candidates for connection.

There are, however, possible improvements for the tool. The heat demand approximation for the industrial district is not valid because the ambient heating and cooling demand data used by the tool is not exact. The THERMOS heat map shows a huge demand required for climate control within buildings which, in reality, are neither heated nor cooled. Only offices require climate control, however the tool estimates demand for all the parts of the buildings (including warehouses and production plants). An interesting result is provided by the tool when the possibility of constructing the piping network on a dirt track is given as an option. Despite this alternative being cheaper, the tool still chooses the route over the paved road as the optimal solution.

Generally, the tool is fairly user friendly and highly specific skills are not needed to obtain satisfactory results from it. Nevertheless, without real data it is very difficult to define the peak demand for the industrial sector, and it is also complicated to attain its approximation – and even when obtained it usually leads to imprecise results. More specialized skills are needed to do this, and it is convenient to have real demand data.

The time needed to perform the case study using the tool required roughly two weeks full time work. The most complicated part was to define the demand side of the case study, which required quite a lot of time due to the preparation of statistical data and contacting businesses and industries. The time needed to perform the case study will also depend on the number of models tested and analysed.

5.4.3 Challenges

The tool allows to study DH project alternatives, in an area of the municipality of Granollers that offers opportunities to take advantage of renewable energy generation from organic waste treatment facilities, promoting a circular economy in local systems. This occurs in an industrial zone with high energy demand, that needs support after a year with a sanitary crisis like the covid-19 which caused a significant negative rate of change on industrial production in Spain (-32,4% between February and April 2020, peak of the crisis).

Furthermore, an infrastructure like the Ecocongost industrial DH network would mean a resilient solution to address energy transition for the main consumers in the municipality, the industrial sector. The consumption of Natural Gas for the industrial and big commercial sector is about 60% of total consumption in the municipality and thermal energy needs are the main drivers for this large demand.

The main challenge, however, is to reach agreements with all actors participating in this energy transition, defining roles and responsibilities by jointly or individually investing in producing, selling, and distributing renewable energy produced locally.

On the one hand, the public waste treatment facilities, the compost plant, and the wastewater treatment plant which are close-by to the industrial facilities have their own projects and motivations and currently have no interaction with the industries. In addition, the local authority, Granollers, has no experience in the energy sector (except for installing two small district heating systems or several solar systems for public buildings). The local authority needs to settle the role to establish how it will be fostering an inclusive energy transition at a local level.

On the other hand, the private sector and the main companies of the industrial sector have been interested in the project, but before making any commitment they need a clear estimation of the connection costs to the district heating network and the price the energy will have for them.

Granollers will use the THERMOS tool to analyse different scenarios and alternatives to boost these agreements across actors.

Another challenge the case study faces in order to be included in the city's sustainable energy and climate action process are political and legislative barriers such as lack of political commitment with the local authority role and lack of clear legislation on local energy communities, which are necessary to put into place rules and incentives that are thought out in a socially rational way and develop models of energy communities and distribution networks.

However, despite these barriers, the local government looks to promote industrial activity, attraction of new industries and reduction of emissions. Some industries have already achieved their targets for the reduction in CO_2 emissions, which could pose a barrier for the implementation of the DH network. Nevertheless, given the higher efficiency of centralized systems, the heat district network is very capable of offering solutions to some of the targets the local government aims to achieve in the coming years.

5.4.4 Future outlook

It is up to the city council, as well as the waste treatment facilities and the main industries to get the project set up and going. Nevertheless, external financing and private investors could help to set up the project, and it would be enough to have a few companies on board (for example, a small consortium) for the project to be economically viable. In fact, a balance could be found between private and public investments, integrating private investments promoted by initiatives led and perhaps sponsored by the local government.

The project could be expanded by considering an additional factor: medium temperature networks, which could connect more buildings to the network and would likely increase the profitability of the network. It would be interesting to investigate how a hot water network could be set up taking advantage of the water vapour condensates for industries and businesses that require less thermal heat demand. This would create a network that could feed both high energy demand industrial buildings with high temperature steam and saturated water, as well as lower residual heat for residential buildings and offices. This option cannot currently be performed due to limitations in the tool and lack of time, but future studies could try to implement a lower temperature network in a separate map, and the budgets of both high and medium temperature networks integrated into one solution.

Thermal and electric power needs could also be satisfied with solar systems installed on industrial roofs, which could create synergies with the DH network. Industrial customers' demand usually coincides when solar energy is available, and the storage of excess thermal energy could be planned in the design of the network. In the future these solar systems and other residual energy coming from industrial processes must be included in the analysis.

5.4.5 Scope for replication

This is the first case study in which the THERMOS tool has been used to analyse the viability of the implementation of a DH network for an industrial district. The successful results of this project could be used for other projects taking place throughout Europe. In Spain, for example, heating networks in industrial districts are currently not widely developed, however that poses a great potential for their implementation, and this case study could be used as a model for replicability. An example of industrial district energy networks is the "*Ciudad agroalimentaria de Tudela*", which is composed of a district heating and cooling network.

The replicability of this project is basic for the transition towards a more sustainable and circular economy, since there are many industrial districts which have wastewater treatment plants nearby whose biogas and surplus of dried sludge can be used as a primary energy source for heat generation and supply. In Granollers there is also a composting plant that is increasing its capacity and producing more biogas which will be upgraded in the near future. This biogas can be injected into the natural gas grid and used as a transport fuel as the waste facilities plan to do. It could also be locally used as a renewable energy supply in the same way as the dried sludge hypothesis used in the case study.

The increase in NOx and PM emissions due to the burning of sludge in comparison to biomass can be mitigated with air pollution control techniques and the control of combustion temperatures.

This case study could be ideal for replication in an industrial district with a high temperature energy demand, and if possible, real available consumption data. An interesting and challenging aspect of this case study that could interest other developers is the correct estimation procedures to quantify energy demand, which could present an opportunity to improve the process of data and the definition of demand.

5.5 Ecocongost - Information Annex

Steam heat distribution conditions		
Supply pressure (bar)	15	
Steam velocity (m/s)	15	
Average ambient temperature (°C)	15	
Minimum pipe diameter (mm)	20	
Maximum pipe diameter (mm)	300	
Installation costs + material (pipe costs) (€/m)	1,063	
Civil works costs (€/m)	Paved path: 76	Unpaved path: 106
Heat losses (kWh/year)	**Diameter (mm)**	**Heat losses**
	200	1,825
	250	2,114
	300	2,530
Pumping cost (%)	Not considered	

Table 5-12. Steam heat distribution conditions

Delivery option	Fluid	Price x capacity (€/kW)	Energy price (€/kWh)
Option 1	Steam	N/A	0.0375
Option 2	Hot water	N/A	0.0375
Option 3	Decentralized	N/A	0.0437

Table 5-13. Heat delivery costs of the three different delivery options considered

6 Kyivska – Pereiaslav, Ukraine

6.1 Introduction

6.1.1 City/area energy background

In frame of Dena's project "Municipal heat transition in Ukraine", which is financed by the German Ministry of Economic Affairs and Energy, various selected Ukrainian municipalities have been supported to help integrate energy efficiency and low-carbon heat supply into their local heating networks. In order to analyse the heating network options with the THERMOS tool, the city of Pereiaslav has been selected.

Figure 6-1 - Pereislav - Ukraine (Source: Антон Петрусь, Wikipedia)

Pereiaslav is an ancient city in the Kyiv Oblast (province) of central Ukraine, located near the confluence of Alta and Trubizh rivers, some 95 km south of the national capital, Kyiv. It has a population of around 26,900 (as of November 2019).

The Ukrainian heating market is mainly dominated by natural gas; renewable energy sources such as biomass or solar energy are only slowly gaining importance. The district heating grid in cities is well established, but in an outdated state with low energy efficiency, with leakages in the pipes and lump sum settlement for consumer tariffs. The heating market is traditionally not attractive for investors and dominated by a strong market monopoly. Around 75 % of the heating market is owned by the state company DTEK, and the rest is in the hands of regional or municipal companies. District heating grids are generally in a critical economic situation, which increases the need for increasing their efficiency.

In summary, there is great potential in the Ukrainian heating market for cost and greenhouse gas emission savings through the modernisation and restructuring of the DH network. An overall nationwide strategy or local strategies regarding heat supply are still missing, but necessary for achieving Ukraine's climate targets. DH grid operators have been requested to elaborate 5-year-plans for strategic development of their grids, however, energy efficiency and renewable energy targets haven't been included into these requirements yet.

Pereiaslav has a district heating network consisting of 9 sub-grids. These heating networks are supplying most of the municipal buildings as well as 23 % of the 26,900 inhabitants with heat for space heating. The heat production is based primarily on natural gas boilers supported by wood boilers, which currently hold 18.6% of the share in heat supply, and usually used for transitional periods during spring and autumn.

For a deeper analysis with the THERMOS tool, the sub-grid Kyivska has been selected. The Kyivska network is currently supplied with 2.2 MW of gas boiler capacity and 0.6 MW of biomass (log wood) capacity. The network includes 13 consumers, all of them residential buildings with an annual heat demand of around 3,170 MWh.

The analysis was implemented in cooperation with Tilia GmbH, who have supported the analytical work and technical recommendation of the "Municipal heat transition in Ukraine" Dena's project.

6.1.2 THERMOS involvement set up

The simulation of the district heating situation and optimisation options in the THERMOS tool was aimed at evaluating the state of the art and finding new pathways for the integration of more renewable energy sources and increase in energy efficiency into the heating network.

The findings were analysed by the district heating experts of Tilia GmbH, who technically supported the whole process to find the best options for modernising the heating system in the city in accordance to Dena's project framework.

Finally, on 11 December 2020 the results and findings were presented and discussed with representatives of the city of Pereiaslav, who are direct counterparts of the Dena's project. At the moment, the district heating grid is owned and operated by the regional supply company. Within the next years, it is likely that the city of Pereiaslav will take over the ownership and operation of the DH grids, leading to more opportunities for their modernisation and strategic development.

6.2 Overview of the case study analysed with THERMOS

6.2.1 Introduction

Description of the situation and design of the network

The initial analysis showed that the data basis for the local Kyivska heating network was good enough to examine it more closely by means of the computer-aided simulation in the THERMOS tool.

In addition, the Thermos tool can be used to simulate an increase in the use of biomass as fuel, which is currently being pursued. Such a simulation enables efficient preliminary planning and makes it easier to decide in which parameters a heating network should be sustainably optimised. This makes the planning process much simpler and can accelerate the cost-effective construction and/or expansion of low-carbon heating and cooling systems in the long term.

The overall aim of the case study is to examine how to integrate a larger share of renewable energy sources into Kyivska's existing heating grid. The overall analyses of the city's DH grid started in 2019, with detailed involvement and evaluation in the THERMOS tool from August to December 2020. During this period, several discussions and exchanges have taken place with the city representatives regarding data collection, interpretation, case study targets and the sub-grid to choose and concluded with a final web-meeting on 11 December 2020.

In order to be able to introduce the buildings already connected to the DH network in THERMOS, the route plan of the existing network was first inserted as an image overlay in Google Earth and compared with the satellite image (see Figure 6-2).

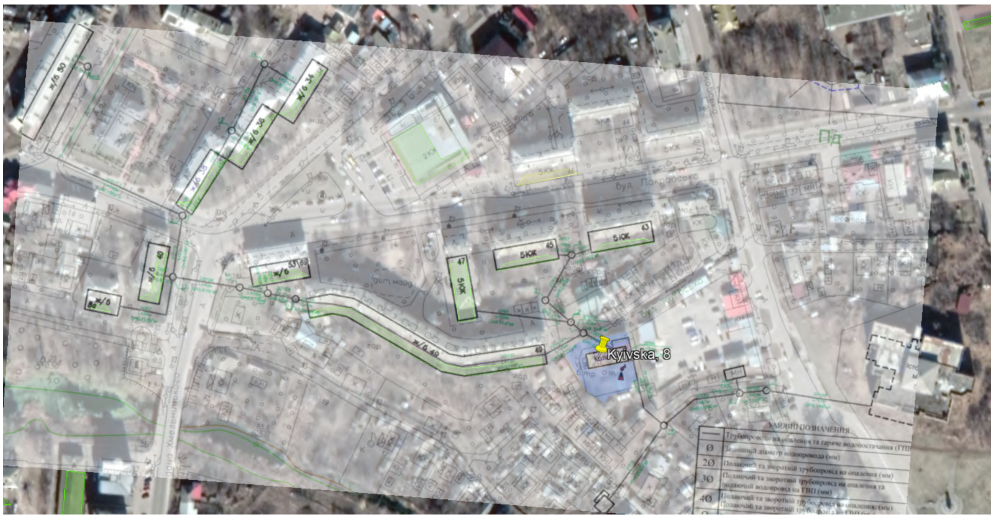


Figure 6-2. View of Pereiaslav in Google Earth with network plan as overlay image, the figure was created by Tilia GmbH on the basis of Google Earth.

In the THERMOS tool, each building was then assigned an individual annual heat demand and heat load, and the supply location - from where heat is supplied to the network - was defined (see the pinhead in Figure 6-2).

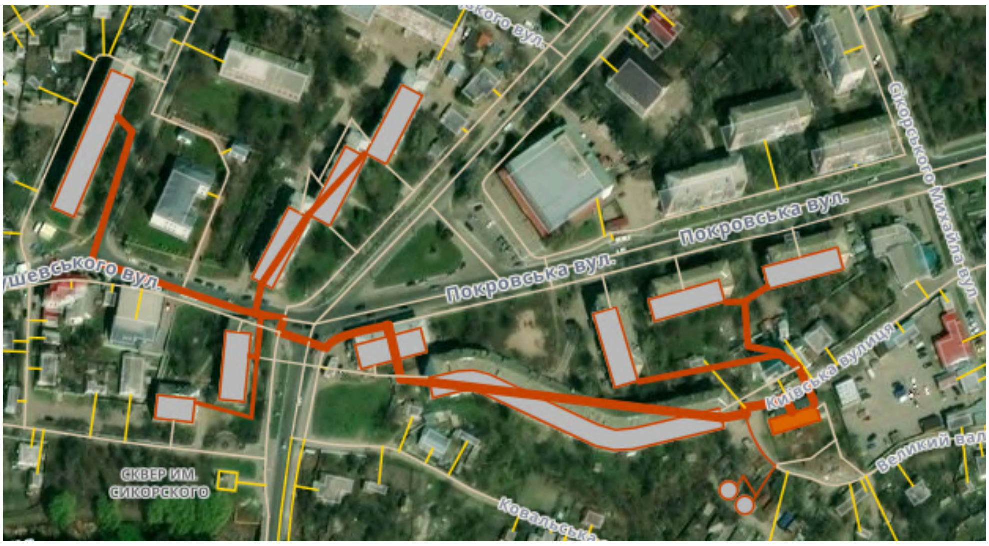


Figure 6-3. Course and dimension of the heating network after simulation with THERMOS

Using the automated optimisation function, the tool then simulates the path and dimensioning of the heating network (see Figure 6-3). The red lines represent the network, and the line thickness represents the dimension of the pipes. In order to reproduce the existing network as realistically as possible, new roads were created in the tool that correspond to the real course of the heating network, leading to a result close to reality.

6.2.2 Case study definition

The objective of this case study is to examine options to integrate more renewable energy sources into the existing heating network (whole system optimisation), based on the technical potential to use the existing biomass boiler and install and use geothermal energy in the premises of the existing boiler house in the Kyivska district. The default settings have been considered for the seasonal load and demand profiles (see data preparation in 6.3.1). The total demand to be satisfied is 3,170 MWh per year including 13 residential/apartment buildings, corresponding to a total capacity of 1.59 MW, as illustrated in Table 3-1.

	Demand
# of buildings involved	
- Residential	13
Tot. energy demand	
- Residential	3,170 MWh/year, (1.59 MW capacity)

Table 6-1. Main characteristics of the demand

The supply consists of an existing construction which includes 3 gas boilers and 1 logwood boiler that use natural gas from the gas grid and logwood from the regional forests.

To simulate the integration of more renewable energy sources, a fuel portfolio of 2.0 MW gas, 0.6 MW wood and 0.1 geothermal energy has been applied. For using more peak load capacities, a thermal storage with 0.6 MW capacity is considered. The main characteristics of the supply are presented in Table 3-2.

	Supply
Current Technology	Gas and logwood boiler
Capacities considered in RES integration scenario	2.0 MW natural gas, 0.6 MW wood, 0.1 MW geothermal energy, 0.6 MW storage
Maximum capacity	2.9 MW
Fixed costs	0 (existing boilers depreciated, new RES applications depending on availability of funds)
Capacity costs	60 €/kWp for gas boiler, 500 €/kWp technology costs for all renewable applications – assuming relevant subsidies are available (see Figure 6-4)
Annual O&M costs	1 – 60 €/kW operating costs (see Figure 6-4)
Supply costs	3.0 cent/kWh
CO_2 emissions	204 g/kWh
PM_{25} emissions	n.a. g/kWh
NO_x emissions	n.a. g/kWh

Table 6-2. Main characteristics of the supply

6.3 Case Study development and results

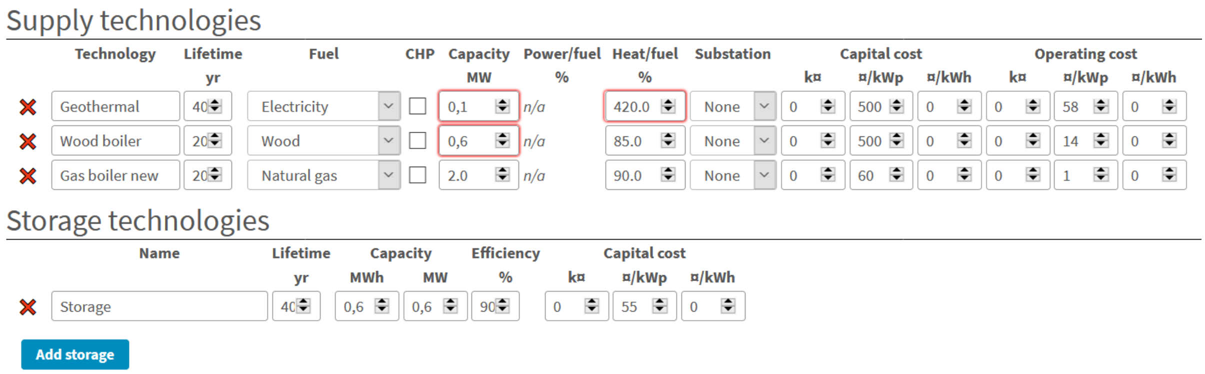
6.3.1 Data preparation

Description of the situation and design of the network

For mapping a realistic situation of the DH grid, the case study analysis began by setting the parameters to represent the supply situation and the integration of geothermal energy.

The energy supply as well as demand data are based on real data obtained from the DH operator. The data has been translated from Ukrainian into English language and calculated into common specific energy units. Since real data was used, no LiDAR data has been integrated into the tool.

In addition to the base load heat generators fired by wood and gas, there is the possibility of using small scale near-surface geothermal energy on the site of the boiler house. The use of these renewable energy sources to supply the connected buildings has been investigated further using the tool. Figure 6-4 shows the heat generators considered based on their merit order. The efficiency of the considered technologies and their conversion factors are estimated based on reference values from real operation.



Supply technologies

Technology	Lifetime (yr)	Fuel	CHP	Capacity (MW)	Power/fuel (%)	Heat/fuel (%)	Substation	Capital cost k¤	Capital cost ¤/kWp	Capital cost ¤/kWh	Operating cost k¤	Operating cost ¤/kWp	Operating cost ¤/kWh
Geothermal	40	Electricity		0,1	n/a	420.0	None	0	500	0	0	58	0
Wood boiler	20	Wood		0,6	n/a	85.0	None	0	500	0	0	14	0
Gas boiler new	20	Natural gas		2.0	n/a	90.0	None	0	60	0	0	1	0

Storage technologies

Name	Lifetime (yr)	Capacity MWh	Capacity MW	Efficiency (%)	Capital cost k¤	Capital cost ¤/kWp	Capital cost ¤/kWh
Storage	40	0,6	0,6	90	0	55	0

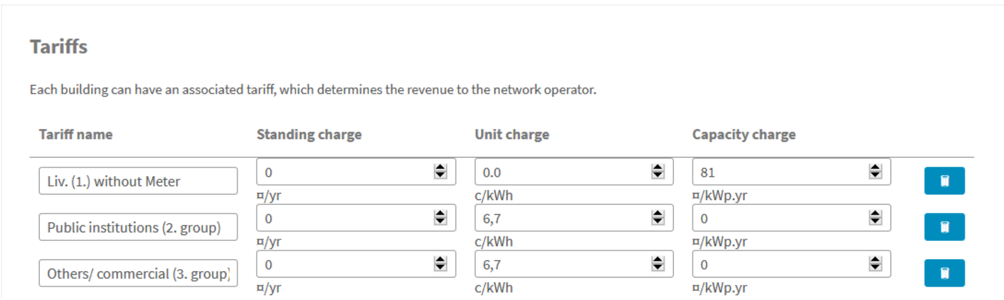
Add storage

Figure 6-4. Parameter overview of the supply technologies.

The efficiency of the geothermal energy corresponds to the annual performance factor of the heat pump and is about 4.2 (or 420%). The efficiency of the gas and logwood boiler was assumed to be 90% and 85%. In addition, a 600 kWh storage tank, which can hold two hours of runtime from the geothermal thermal sources, was considered.

The capital and operational costs used for the wood and gas boiler (see Figure 6-4) were taken from empirical values of other projects performed by the company Tilia GmbH. The capital costs for geothermal energy are usually around 1,200 €/kWp. For favouring an integration of these technologies, it is assumed these technologies are subsidised, which result in capital costs of 500 €/kWp for each renewable energy technology.

For simplicity reasons, only one real tariff, which is most relevant for the network, Tariff *"Liv.(1.) without meter*", was applied in THERMOS (cf. Figure 6-5).



Tariffs

Each building can have an associated tariff, which determines the revenue to the network operator.

Tariff name	Standing charge (¤/yr)	Unit charge (c/kWh)	Capacity charge (¤/kWp.yr)
Liv. (1.) without Meter	0	0.0	81
Public institutions (2. group)	0	6,7	0
Others/ commercial (3. group)	0	6,7	0

Figure 6-5. Overview of THERMOS tariff settings

Before the calculation to optimise the generators was carried out, the following preliminary steps were taken:

- The load profiles are based on the following settings, based on assumptions for an operation from October to April:

  - 107 normal weekdays (spring and autumn days, no summer time);
  - 42 normal weekends (spring and autumn days);
  - 62 winter weekdays;
  - 27 winter weekend days;
  - 1 day with maximum heat output;
  - For 126 days (May to September), it is assumed that there is no demand.
- The CO_2 price was set at 24.75 €/t CO_2 according to EU Emission Allowances (average value from February 2021);
- Prices for fuels were chosen as follows:
  - Electricity 5.0 ct/kWh;
  - Gas 3.0 ct/kWh.

6.3.2 Results

Network Optimisation

The DH network obtained in THERMOS is illustrated in Figure 6-6. The original pipe route has been partly corrected by hand. For buildings connected to the network through the cellar, pipe routes have been drawn manually through the building geometries, which better represents the real pipe configuration.

Figure 6-6. Solution presentation of Kyivska DH grid

Doing so, the solution presentation gives a good picture of the real situation of the Kyivska grid, considering the above-mentioned supply technologies including renewables.

The overall results of the network solution are listed in Table 6-3. The DH grid comprises 875 m of pipework. The pipework has yearly losses of 173 MWh (potential pipe leakages not included here). For the supply, no capital or operating cost could be considered. On the demand side, no connection costs are included, which might reflect the local situation. For better economies, relevant connection costs and heat consumption measurements at each individual building are required.

Pipework solution	
Length	0.88 km
Total Cost	N/A (already built)
Linear Cost	N/A
Losses	172,93 MWh/year, 22,55 W/m
Capacity	791,27 kW
Demand solution	
Total Undiversified Peak Demand [11]	1.59 MW
Demand	3.17 GWh/year
Connection Costs	Not considered
Revenues	128,390 €/year
Supplies solution	
Total Capacity Required	1.03 MWp
Output	3.34 GWh/year
Capital cost	-
Operating cost: O&M	-
Operating cost: heat production	100,280 M€/year

Table 6-3. Network solutionNetwork Solution: Economic Analysis

The financial results obtained from the THERMOS tool are presented in Table 6-4. As the network is already existing, we are focusing on operational costs and revenues. We are assuming a discount rate of 4% and a period of 20 years.

[11] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

	Capital cost	Operating costs	Operating revenue	NPV
Pipework	0 €			0
Heat supply		-100,280 €/year		-1,420,000 €
Demands			128,390 €/year	1,810,000 €
Emissions	Not included at this stage			
Network	**0 €**	**-100,280 €/year**	**128,390 €/year**	**390,000 €**

Table 6-4. Economic analysis of network solution

In the future, the financial analysis should be evaluated in depth, considering the existing infrastructure and wood boiler, which might be partly amortised. Furthermore, available subsidies for renewable technology capital investments should be integrated based on currently available funds. Finally, a different heat sale tariff scheme could also be considered.The THERMOS tool then offers the possibility to export the results obtained to Excel. A selection of these is briefly presented in Table 6-5 below.

Category	**Address**	**Annual demand (kWh)**	**Peak demand (kW)**	**Revenue (€/yr)**	**Revenue (NPV, €)**	**Revenue (total, €)**
Apartments	vul. B. Khmel'nyts'koho 38 (zh.bud)	215.000	108	8.748	123.644	174.960
Apartments	Shevchenka, 50 (2: zh.bud.; perukarnya)	459.000	229	18.549	262.170	370.980
Residential	Verkh.val 3 kv 3 zh.b.Fesenko	8.000	4	324	4.579	6.480
Residential	vul. Pokrovska, 53/69 (2: TOV "CFK"; zh.bud.)	162.000	81	6.561	92.733	131.220
Residential	vul. B. Khmel'nyts'koho 40 (zh.bud)	151.000	75	6.075	85.864	121.500
Residential	vul. Pokrovska, 45 (zh.bud)	290.000	145	11.745	166.003	234.900
Residential	Koval's, 8A (zh.bud.)	78.000	39	3.159	44.649	63.180
Residential	vul. Pokrovska, 43 (2: ZhBK"Druzhba; zh/kv.)	236.000	118	9.558	135.092	191.160
Residential	vul. Pokrovska, 47 (2: zh.bud; Privatbank)	267.000	133	10.773	152.265	215.460
Apartments	vul. B. Khmel'nyts'koho 34 (zh.bud)	236.000	118	9.558	135.092	191.160
Residential	vul. Pokrovska, 49 (3: zh.bud; oshchadkasa; HO Instytut pidtrymky) 819 M 410 k 0 building Residential ✓	819.000	410	33.210	469.388	664.200
Residential	Verkh.val 3 kv2 zh.b.Mazur	7.000	4	324	4.579	6.480
Apartments	vul. B. Khmel'nyts'koho 36 (zh.bud)	242.000	121	9.801	138.527	196.020

Table 6-5. Overview of consumers and associated revenues of the tariff Liv.(1.) without meter

Table 6-5 clearly shows the 13 connected buildings, their heating requirements, and the revenue that can be achieved per building with the current tariff.

Supply Optimisation

Figure 6-7 presents an overview of the automated optimisation of the supply generators performed by THERMOS. As shown, the logwood boiler and the geothermal heat pump, to a smaller extent, feed into the heating network the whole year, providing a "base load" for the heat supply. In this scenario, the gas boiler is only used in wintertime for "peak load demand".

Total cost summary

Supply technologies							
Item	**Capex** ¤TOTAL	**Opex** ¤TOTAL	**Fuel** ¤TOTAL	**Export** ¤TOTAL	**Emissions** ¤TOTAL	**Total** ¤TOTAL	**PC** ¤PV
Geothermal	50 k	116 k	208,57 k		61,95 k	436,52 k	323,15 k
Wood boiler	213,87 k	119,77 k	1,9 M		0	2,23 M	1,64 M
Gas boiler new	22,34 k	7,45 k	385,67 k		63,64 k	479,1 k	345,13 k
Storage	7,95 k					7,95 k	7,95 k
Total	294,17 k	243,21 k	2,49 M	0	125,58 k	3,16 M	2,32 M

Heat production for all days		
Source	**Wh/yr**	**Wh total**
Geothermal	876 M	17,52 G
Wood boiler	3,67 G	73,4 G
Gas boiler new	578,51 M	11,57 G
Storage	167,39 M	3,35 G
Curtailment	-0	-0
Total	5,29 G	105,84 G

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

Plant	**Peak** W	**Output** Wh/yr	**Capex** ¤TOTAL	**Opex** ¤TOTAL	**Fuel** ¤TOTAL	**Export** ¤TOTAL	**Emissions** ¤TOTAL
Geothermal	100 k	876 M	50 k	116 k	208,57 k	0	61,95 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

Store type	**Store size** Wh	**Peak flow** Wp	**Capital cost** ¤TOTAL
Storage	600 kWh	144,6 kWp	7,95 k¤

Figure 6-7. Summary of the economic efficiency of the generators.

Figure 6-8 illustrates the heat output over time for a 24-hour period in different typical days over the year. The wood boiler (blue) and the geothermal plant (turquoise) are used by the tool as base load provider, and the gas boiler (red) is only used in the peak times. The storage tank (green) is also used during peak load periods.

For further analysis with the availability of more local data, the possible (future) costs of emissions and building insulation measures should be considered. With increasing CO_2 and gas prices and decreasing renewable energy costs in the future, a complete heat supply with more renewable energies and a positive financial outlook could be achieved.

Figure 6-8. Heat production timeline of generation technologies.

6.4 Conclusions

6.4.1 *Status quo* of the case study

This case study provides a very good visual solution, which attracts users and decision makers to further consider DH optimisation steps, such as:

- Integration of new heat sources (renewables, excess heat);

- Better utilisation of existing (wood) heat capacities by connecting neighbouring consumers, using DH grid for hot water supply, and possible year-round operation of boilers;
- Potential reduction of used capacities when technologies installed are oversized (e.g. by switching off peak/reserve boilers or prioritising wood boilers over gas boilers) visualizing the potential connection of neighbouring buildings (demand loads) for better network efficiency.

The implementation of the results of this case study, meaning the integration of geothermal energy, depends on several aspects. On one hand, the ownership of the DH grids in Pereiaslav (and with it the economic operation) is currently not defined or is in a state of transition. The potential takeover of the DH grids by the city council could secure the operation and facilitate strategic measures.

Currently, the integration of renewables is not economically feasible, but could become realistic when applying for international investment subsidies and when renewable heat experiences decreasing costs in future. As soon as more capacities for strategic actions are available, the integration of renewables could be a real added value and support the country's future local climate and energy targets and SECAP processes. Besides technical support, building a clear ownership perspective for DH grids, and improving capacity and knowledge for grid operators is necessary.

6.4.2 General reflections on using THERMOS in developing the case study

Based on the testing of the tool and the simulation of results, the use of the THERMOS tool demonstrates remarkable results for the integration of renewable energy sources in the existing heat grid. The further use of the tool is seen also useful for the planning of new heat networks and considerations towards expansion of existing ones.

For the representation of existing networks (as is the case in the city of Pereislav), the first mapping result in the tool had to be adjusted manually to reflect a realistic routing of the pipes.

It took approximately 2-3 full weeks worktime by DH experts to illustrate the network and integrate a realistic set of input data for this network. For a quick and clear potential estimation of the spatial heat density, however, the heatmap function of the tool is particularly suitable. This visual presentation of the network and solutions is a real added value which is not available in other tools or models.

6.4.3 Challenges

The selection of the right parameters, such as the estimation of the costs of different generation technologies requires deep knowledge in the field of energy technology. This knowledge would have to be ensured in the application case in Ukraine, for instance, by a mentor who accompanies Ukrainian colleagues on site when using the tool.

The tool is suitable for simulating all heat technologies. If renewable energies are to be considered, however, it becomes more difficult, as there are often temporal or seasonal restrictions (e.g., solar thermal at night), which require specific settings in the demand and supply problem. It would be helpful to have the ability to use or generate load profiles with 8760 points in time in the tool (e.g. for each hour of each day in the year). This would also facilitate a realistic simulation of the operating times of the energy generation plants (currently from October to April).

In the Pereislav case, small heat outputs for renewable energy generators in the range of 20-180 kW have been identified as technically feasible. However, these cannot be ideally represented in the model since a minimum power of 0.1 MW must be selected. The tool therefore seems to be more suitable for larger scales.

6.4.4 Future outlook

In summary, the tool provides a good simulation of district heating options for the integration of renewable energy sources. The following optimisations are suggested to further improve the tool:

- Better integration of renewable energy generators by adding a higher spectrum of fuel options, more renewable energy technology default values, smaller generation capacities, and more options for the preference of low-carbon energy generators;
- Easy selection of buildings to be supplied by selecting building addresses in the tool;
- Short explanations and interpretations of results would provide an extra value of optimisation results in the tool.

6.4.5 Scope for replication

In summary, the use of the tool in the investigated environment is recommended to obtain an initial spatial potential assessment of the heat density, possible pipe runs and favoured heat supply solutions. Especially in the case of integrating renewable heat sources, new construction projects or network expansion, this can be advantageous and provide decision-makers with a clear, spatial picture of the demand-supply situation and advantageous supply solutions.

The integration of renewable energy sources into a heating network can be represented in the tool provided that expert knowledge or a good data set is available, and the user has basic knowledge of English language.

The use of the THERMOS tool is currently free of charge and available worldwide for all areas shown in OpenStreetMap. This means that the tool is also available to users in Ukraine for the representation and further development of their heating network projects. For a further detailed analysis and to obtain more realistic results when using the THERMOS tool, a good data set, time for data preparation and practical experience in thermal energy technologies is recommended.

7 Madrid Nuevo Norte - Madrid, Spain

7.1 Introduction

Madrid Nuevo Norte (MNN) is a public initiative to regenerate 300 hectares of land in the North of the Spanish Capital. The project was approved in July 2020 with the modification of the Madrid City area masterplan with the most innovative, citizen oriented and sustainable urban standards. MNN is the largest urban development in Europe for the next decade.

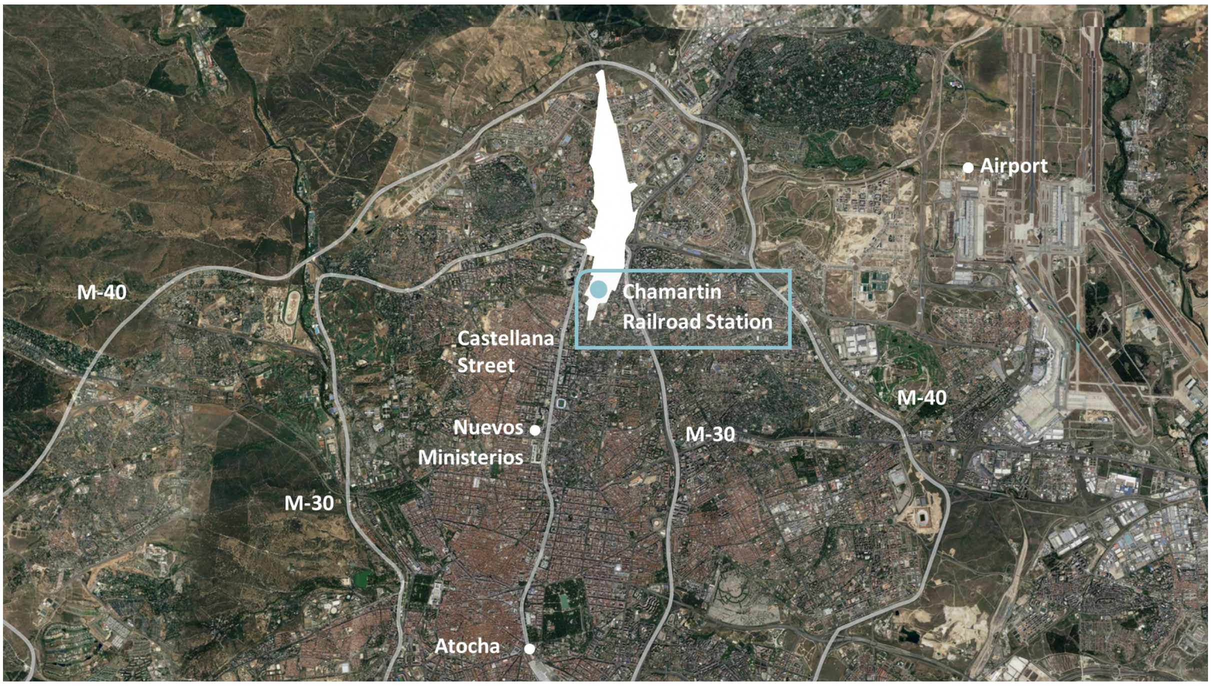


Figure 7-1. Madrid Nuevo Norte - location.

7.1.1 City/area energy background

Madrid municipality is a signatory of the Covenant of Mayors since 2008, submitting its action plan in January 2010. At this point the city already had policies set regarding renewable energy sources and sustainable development. A tangible example of this policy might be the development of the first sustainable neighbourhood or "EcoBarrio" in 2008, which incorporated a district heating system.

Even though the Autonomic Community of Madrid has promoted DHC systems for quite a long time, it has not yet achieved the full potential of these solutions. As published in their latest census by the Spanish Association of District Heating and Cooling (ADHAC), 33 DHC networks are currently operating in Madrid, accounting for 7% of the nation's total. These systems represent nearly 24% of the national installed capacity, depicting a region characterised by few and large DHC systems. These values contrast with the ones of the autonomic community of Cataluña, which gathers 171 (37%) of the country´s DHC networks, corresponding to 32% of the national installed capacity, implying smaller and more distributed DHC systems.

Anyhow, the long-term perspective for DHC development is positive, not only because of future projects such as the one presents in this case study, but also because in 2020 the Spanish Government submitted to the EC their national energy and climate plan (NECP). This document contemplates DHC systems as a key mechanism in both the decarbonisation and the energy efficiency dimensions. This plan is binding, which means that the country has made a commitment to develop measures aimed to the promotion DHC technology and the development of local energetic communities.

The Madrid Nuevo Norte master plan is a Madrid City Council initiative. However, most of the investment will be done by private developers, and the project is underpinned by an exemplary public-private collaboration. MNN follows the General Urban Development Plan of Madrid and the regulations established in Specific Planning Areas (APEs) 05.31, 08.20 and 08.21. The latest modification of the General Urban Development Plan of Madid of 1997, requested and approved for the urban operation of MNN, includes and promotes new standards concerning building characteristics and energy supply technologies in line with relevant European Directives. Some of the innovative regulations include among others:

- The consumption of non-renewable primary energy of the spaces contained within the thermal envelope of a building will not exceed 70% of the limit value set in the Technical Building Code (CTE) in force at the time or regulations that replace it;
- The total primary energy consumption of the spaces contained within the thermal envelope of a building, or, where appropriate, of a part of the building considered, will not exceed 85% of the limit value fixed in the Technical Building Code (CTE) in force at the time or regulations that replace it;
- The urbanization projects shall include a viability study of the implementation of DHC System.

The project will be structured and developed according to four different areas:

- Chamartin Station (APR. 05.10);
- Chamartin Business District (APE.05.30);
- Malmea-San Roque- Tres Olivos (APE.08.20);
- Las Tablas Oeste (APE.08.21).

In 1993, Distrito Castellana Norte (DCN) earned the right to buy more than 50% of the MNN area to the national railway company, becoming the development's largest shareholder amongst a large pool of smaller landowners.

7.1.2 THERMOS involvement set up

In the midst of the regional government´s new promotion approach to energy efficiency and according to MNN legal framework, DCN developed a study to assess the implementation of different DHC system solutions which could upgrade the sustainability of the urban development. This study highlighted very promising results for a distributed energy network solution based on geothermal technology.

With this in mind, Creara and the THERMOS consortium were contacted to find out how the THERMOS tool may support the assessment of district energy solutions from a different perspective, adding knowledge and value to the process.

7.2 Overview of the case study analysed with THERMOS

7.2.1 Introduction

As already mentioned, the project is set to be the largest urban development of the next decade. It will cover an area of 5,6 km in length and up to 1 km in the widest section.

MNN comprises 2,357,443 m^2 of land, leading to 1,048,535 m^2 of residential and 1,608,778 m^2 tertiary gross buildable floor area. The project will close the significant gap separating local areas in the north and create a new sustainable city model, structured around green areas and an extensive public transport network, including the total renovation of the Chamartín railway station.

The following illustration presents the current and the expected state of the area after the development.

Figure 7-2. Madrid Nuevo Norte - current state and future development

Given the project's innovative character, a general inclination towards electrification of the demand and the results of the aforementioned preliminary study, DCN was interested in the development of a case study encompassing the implementation of a DHC system featuring geothermal heat pumps as the main thermal energy supply.

From this point forward, the project's objectives were two: from an energetic standpoint, assessing if it would be viable to cover these demands using only geothermal energy and, from an economic one, identifying the areas where would it be more profitable to implement such system.

Figure 7-3. Madrid Nuevo Norte. Credit: ROGERS, STIRK, HARBOUR + PARTNERS

Initial THERMOS analysis confirmed that heating and cooling demand could be covered in a profitable way with a network solution. Once these results were presented and following MNN legal framework, DCN decided to conduct an external study to assess the feasibility of the solution. This report would also allow to compare THERMOS results with an in-depth technical study carried by field experts. The results presented in the study confirmed most of the ones already obtained using the tool, like the minimal heat transfer surface needed for thermal power's absorption and dissipation or the unfeasibility of dimensioning a single supply to cover the whole network.

As the report concluded that it would not be possible to support the whole network with a single plant, an alternative was considered. The proposed alternative envisioned the design of 19 independent networks which would go around the served buildings creating loops. These networks, powered by 11 different supplies, would deliver the necessary surface for heat absorption, allowing to use only geothermal energy as the heating source.

DCN decided to carry out further case studies in order to identify the most profitable areas and present them to the rest of stakeholders so that they can choose whether to invest in such solutions. Examples of stakeholders for this project may go from public entities, such as the municipality, which is supervising the project, to private landowners, not forgetting energy providers that may be interested in the exploitation of the energy network.

Even though there are several stakeholders involved, it is DCN as the majoritarian private partner who has been leading this case study. Nevertheless, it has been done as a non-binding exercise, with the only goal of presenting this information to their partners just in case they want to consider it. DCN does not have any compromise to carry over the project or even take part in it.

7.2.2 Case study definition

The defined THERMOS case study encompasses 11 individual energy supplies, all with the same characteristics, located around the development area. The objective was to identify the most profitable areas for network implementation. To do so, all buildings and network paths were set as optional, allowing the program to choose the more suitable demands to be connected.

The only spatial constraint set was to forbid the network from crossing the railway tracks or the city's ring road. This limitation had to be introduced due to the different distribution among landowners, as a shared network could end up leading to governance issues.

Due to its characteristics, this case study could be considered as a "new network" THERMOS use case. The initial project distribution, including location of supplies and proposed pathway, can be shown in Figure 7-2.

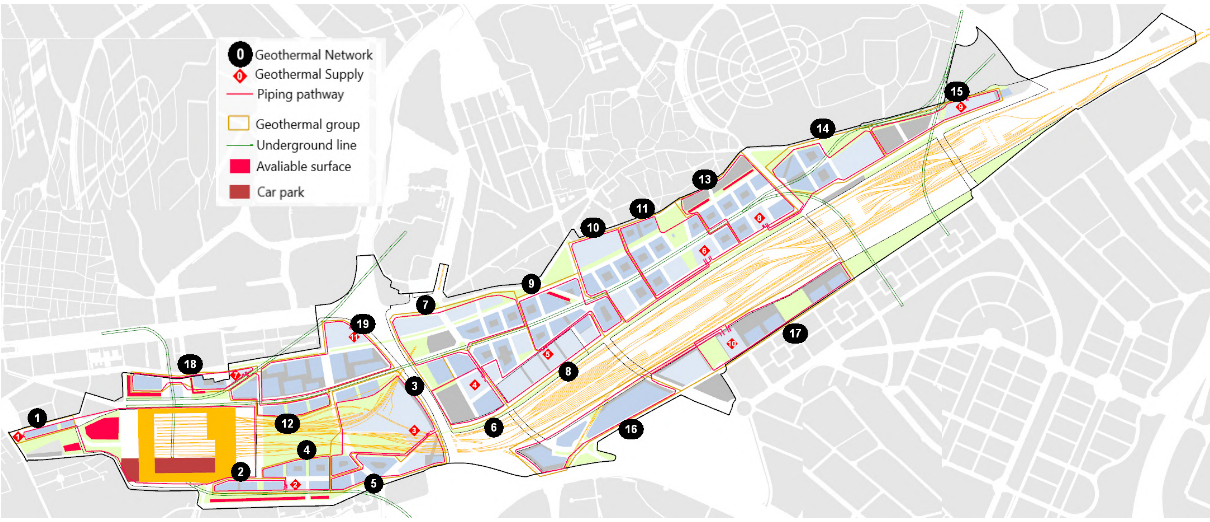


Figure 7-2. Initial project distribution. Source: DCN

The total heating demand to be satisfied is 90,9 GWh including residential, tertiary and other uses, such as educational, and cultural.

The main characteristics of the demand are illustrated in Table 3-1.

	Demand
# of buildings involved	
- Residential	45
- Commercial	21
- Other	28
Tot. energy demand	
- Residential	40,580 MWh/year
- Commercial	41,530 MWh/year
- Other	8,800 MWh/year

Table 7-1. Main characteristics of the demand

The supplies are new constructions that share the same technical and economical characteristics. All are set as optional in order to allow the THERMOS tool to select which of them would be better to include. The main characteristics of the supplies are presented in Table 3-2.

	Supply
Technology	Geothermal
Fuel used	Electricity
Maximum capacity	5 MW
Fixed costs	240,000 €
Capacity costs	650 €/kW
Annual O&M costs	31.5 €/kW
Supply costs	1.4 c€/kWh

Table 7-2. Main characteristics of the supply

7.3 Case Study development and results

7.3.1 Data preparation

For the analysis and results presented in this report, most of the data was provided by DCN, either from their own sources or extracted from the external study. In particular:

- The GIS shape files were prepared based on CAD files provided by DCN, including useful information such as the plot's code or its maximum built surface;

- Thermal energy demand estimations were calculated multiplying demand ratios (kWh/m^2) and expected total floor areas. These ratios were elaborated from demand curves provided by DCN and differentiated depending on the buildings use (residential, commercial, offices, health);
- The network and supply costs were also taken from the external study provided by DCN, and were elaborated and harmonised as needed.

Some of the economic parameters were adjusted by Creara based on expert interviews and the experience of other similar case studies developed in THERMOS.

7.3.2 Results

The results presented in this section are the outcome of an iterative process that allowed to fine tune the key assumptions behind the case study.

Initially, based on the external study performed by DCN, the project's time horizon was set to 20 years, considering a discount value of 5%. With these initial assumptions, a first solution was identified, and then the time horizon was extended in order to appreciate the effect on the results in terms of both topology and economics.

Further, one of the objectives of the THERMOS case study was the desire to study the energy sale tariff.

Spain's current market values are in the 3-4 c€/KWh range. Considering other THERMOS case studies and the market tariffs proposed by DHC operators in Spain, a capacity charge of 19 €/kW/yr was set, which allowed to reduce the unit charge to 3,6 c€/kWh.

Network topology

The initial solution elaborated by THERMOS, presented in this section, does not cover the majority of the MNN area, but it efficiently highlights the most profitable areas for the project's development, which was one of the objectives of the case study.

Figure 7-3. Initial solution - network layout

This result identifies two separate networks, one in the southern part of the project, the business area of the planned urban development, and another in the southernmost end of the North-Western section, called Malmea, planned as a mostly residential and commercial area. Both of these locations have been identified as the most profitable ones throughout multiple performed iterations. Each of the two networks is supplied by a single energy supply of 5 MW.

The majority of buildings were not connected: the identified solution only connects 22 out of the 94 possible candidates. Even though this accounts for less than 25% of the buildings, it represents nearly a third of the annual demand, reaching almost 30 GWh per year.

Rather than extending the network to include more demands, it is more profitable to only include the ones closer to the chosen heat supplies. This has also been tested by designing alternative scenarios and forcing the tool to include all demands, which leads to worse economic results. Anyhow, if the already built supplies could have more capacity, more demands could be connected.

Analysing the network solution, it can be observed that more than half of the connected demands (14) correspond to residential buildings, while only 8 are dedicated to tertiary use, mostly office buildings. Even though this seems odd from a financial standpoint, it is explained through the analysis of the annual demand, which shows that tertiary buildings represent more than 50% of demand (14,7 GWh/year). Furthermore, after performing an in-depth analysis of the residential buildings, it has been noticed that none of the 14 connected ones are purely residential buildings, as they all merge both residential and commercial destinations.

Pipework solution	
Length	2,54 km
Total Cost	0,784 M€
Linear Cost	309,08 €/m
Losses	347,37 MWh/year
Capacity	4,97 MW
Demand solution	
Total Undiversified Peak Demand [12]	30,44 MW
Demand	29,37 GWh/year
Connection costs	Not considered
Revenues	1,34 M€/year

Table 7-3. Network solution

From the eleven available supplies, the optimisation has only included two of them. The first one is the one located in the South-East end of the project, while the other is located in the North-West end. Both supplies have nearly the same power, as well as the same output, which could be assumed as the plant's maximum working capacity. All data related to supplies is displayed in Table 7-4 and an additional detail of the included supplies' location can be found in Figure 7-4.

[12] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

Supplies solution		
Supply number	**2**	**4**
Total Capacity Required	4.97 MWp	4.96 MWp
Output	14.59 GWh/year	15.13 GWh/year
Capital cost	3.47 M€	3.46 M€
Operating cost: O&M	0.16 M€/year	0.16 M€/year
Operating cost: heat production	0.20 M€/year	0.21 M€/year

Table 7-4. Initial solution – Supplies

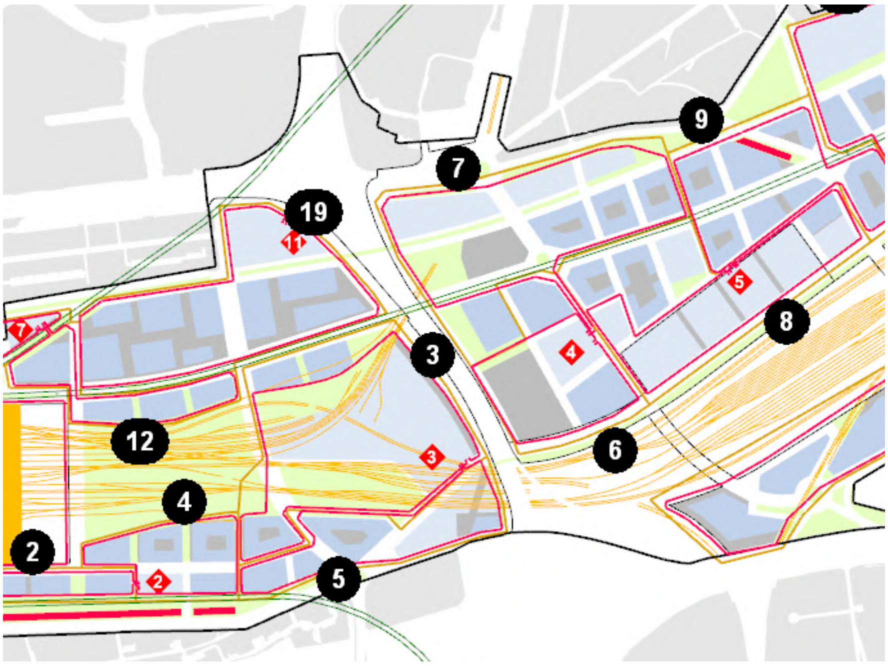


Figure 7-4. location

Financial analysis

For this initial solution, the overall profitability is quite low. One of the main justifications for this result is the high capital expenditure associated with geothermal energy. This is mainly due to the necessity of drilling geothermal wells, which increases civil costs significantly (representing up to 40% of the overall supply cost) and limits the network's size.

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	-0.78 M€			-0.78M€
Heat supply	-6.93 M€	-0.73 M€/yr		-16.47 M€
Demands			1.34 M€/yr	17.58 M€
Emissions	Not included at this stage			
Network	**-7.72 M€**	**-0.73 M€/yr**	**1.34 M€/yr**	**2.08 M€**

Table 7-5. Initial solution – Economics for 20 years' time horizon

Even though results are not as promising as it could be expected for a project of this magnitude, they are not completely discouraging as this should be considered a first iteration and there still are several measures that can be taken to improve the economics of the project.

In fact, by modifying simple parameters which have a direct impact on the project's financial results, such as tariffs or project extension, the optimised solution becomes more comprehensive from the topology point of view and more profitable from the economic point of view. The first action taken was extending the problem's time horizon; 20 years is a significantly low period for evaluating the operation of a geothermal DHC system. Values between 40 and 50 years can be considered as a more appropriate, but still conservative, estimation.

Further simulations were performed, assessing the feasibility of the project with timespans of 30 and 40 years, respectively. The energy sale tariff was also updated as previously mentioned. The 30-years solution connects 73 buildings and covers up to 95% of the demand, with an NPV of 5,97 M€. To do so, the tool estimates that 7 heat supplies are needed, with capacities ranging from 2,5 MW to 5 MW.

The 40 years solution didn't change much compared to the last one, especially energy-wise. In this case, 79 buildings were connected, accounting for nearly 98% of the demand and using the same supplies as the first test. The NPV accounts for 9,43 M€ at the end of the period.

A depiction of the network's evolution over the three different time horizons can be observed in Figure 7-5.

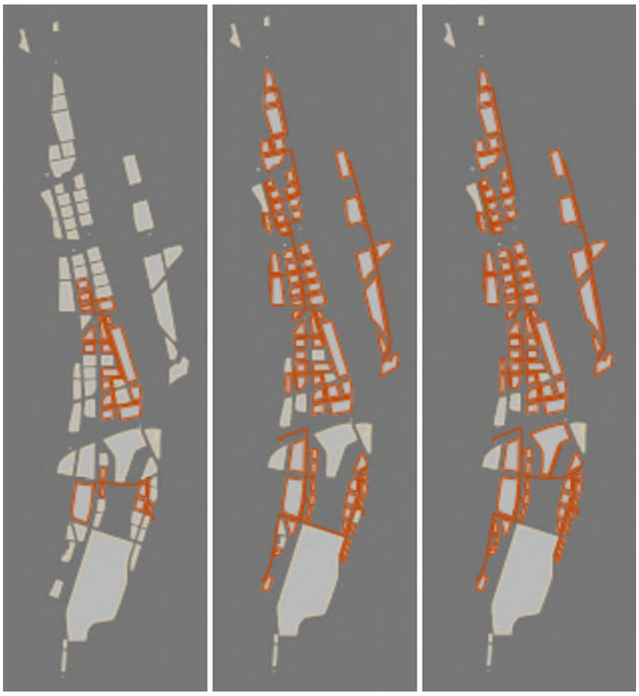


Figure 7-5. Topology comparison of 20, 30 and 40-years time horizon solutions

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	- 2.31M€			-2.31 M€
Heat supply	-21.54 M€	-2.23 M€/yr		-61.66 M€
Demands			4.07 M€/yr	73.4 M€
Emissions	Not included at this stage			
Network	**-23.85 M€**	**-2.23 M€/yr**	**4.07 M€/yr**	**9.43 M€**

Table 7-6. Economics – 40-years time horizon

Also, there are more hypothesis that can be made to evaluate their impact on the profitability of the case study. An example could be setting a limit for high demands, assuming they would be covered with an alternative individual heat supply solution, and assessing the impact of providing the saved energy to additional consumers. Some tests were run in this regard, obtaining better economic results and allowing to develop a further energy supply.

Another important aspect to be accounted for is the choice of using geothermal energy, which is not taken only from an economic perspective, but also aims to provide environmental and social benefits. Even before developing the case study, DCN knew geothermal energy would not be the cheapest solution, nor the easiest to implement, but it was chosen anyway due to their motivation to set an achievable example for future developments.

7.4 Conclusions

7.4.1 *Status quo* of the case study

The case study developed with THERMOS has proven that using geothermal energy to cover the Madrid Nuevo Norte project's thermal demand, or a part of it, would be feasible. As of right now, this solution is starting to be considered, but it is still in early stages of development. The project's schedule, yet to start construction work, allows for valuable time that can be used to better develop the case study.

The objective would be obtaining a solution consistent enough so DCN or any other interested stakeholder could develop a business plan around it and start looking for investors interested in funding the energy network development.

7.4.2 General reflections on using THERMOS in developing the case study

Specifically, this case study took a considerable amount of time to be developed. This could be attributed to two main reasons: the technical knowledge required to develop a geothermal study and the need to perform tests to create an accurate and consistent network. Due to the project's magnitude, creating different scenarios was quite complex, mostly because of the amount of combinations that could be considered.

As it has been mentioned before, this case study required a deeper technical knowledge on top of GIS or THERMOS skills, as demonstrated by the need of hiring an external consultant agency to validate the initial THERMOS results. DCN has also manifested that, had THERMOS not been available, this would have been their initial option.

7.4.3 Challenges

Regarding the project itself, the most important challenge to overcome would be the financing aspects. It is considered necessary to resort to first-tier specialised private partners, experienced in this type of energy network and who have the know-how and the legal and financial structure necessary to develop the technical challenges in an excellent and economically profitable way. Due to the social and environmental impact associated with this technology implementation, new sources of financing could emerge in the following years, as Spain is currently developing their 2030 strategy, which includes both geothermal energy and DHC networks. At present, DCN plans to present the results to MNN project partners or potential investors that could be interested in carrying out the network. As THERMOS Ambassadors, DCN will showcase both the case study and its development methodology, which might encourage other stakeholders to get involved with the tool.

7.4.4 Future outlook

Currently, the focus is on performing more simulations to improve the results, as well as detecting the most relevant parameters and setting a suitable range for them. This will allow to define tariffs, revenues, supply parameters, and potential connected buildings, leading to the generation of new, more accurate and specific case studies. As a long-term goal, it could be interesting to evaluate the network using the supply optimisation tool integrated in THERMOS, allowing to optimise a supply incorporating different technologies such as PV generation and thermally activated structures, that are yet to be considered.

DCN would like to keep developing the case study even after the end of the Horizon 2020 project. They have identified the possibility of not only implementing the technology in a profitable way, but also adding value to it by setting an example of sustainable heating and cooling.

7.4.5 Scope for replication

From a replication standpoint, this project should be considered by other urban development agents planning a large-scale development. It could be interesting to analyse the overall profitability of the project, but also other factors like best locations for implementation, possible network topology or techno-economic parameter's impact on the final solution.

Also, this case study could prove valuable for other entities interested in developing a geothermal DHC network. In this case, it was used to evaluate the feasibility of two different scenarios: a single network encompassing the whole development area or the combination of several independent networks. Also, it was useful to evaluate the pipework's length, as it has a direct impact on the number of geothermal drillings that could be carried out.

An interesting conclusion drawn from this case study could be the tool's versatility regarding users. This case study was not developed by a technical office or a DHC company, but by the project's main developers. This means that, even though the tool has a vast technical potential, other less-experienced users can also obtain useful information by adopting it.

8 Parc De l’Alba – Cerdanyola del Valles, Spain

8.1 Introduction

Parc de l’Alba is the name of a public park located in the city of Cerdanyola del Vallès, north of the metropolitan area of Barcelona, Catalonia, Spain. The name is referred to the emblematic element of this park, which is the Alba synchrotron.

Parc de l’ Alba is included in the urban master plan for the delimitation and ordinance of the Directional Centre of Cerdanyola del Vallés. The Urban Development Consortium of the Directional Centre of Cerdanyola del Vallés, Parc de l’ Alba, hereinafter the Consortium, is a public entity, constituted by the Catalan Institute for Land Development (INCASOL) of the Government of Catalonia and the Cerdanyola del Vallés City Council and attached to the former. The purpose of this entity is to serve as an acting administration for the execution of the Alba Park.

8.1.1 City/area energy background

Cerdanyola del Vallés is strongly committed to technology and knowledge, which gives the city its own identity and makes it a central hub within the metropolitan area of Barcelona. For some years now, Cerdanyola del Vallès has committed to improving the energy management of its municipal buildings and its public lighting. It has also joined various European projects to incorporate energy efficiency criteria in new urban developments. In this context, Cerdanyola del Vallès has been one of the first municipalities in Catalonia to draft its Sustainable Energy Action Plan (SEAP).

One of the central elements of the innovative Cerdanyola del Vallès is the Alba Synchrotron. It is a unique scientific facility in Spain that works as a large ring-shaped particle accelerator. Measuring around 250 meters in perimeter (equivalent to two football fields), the Alba synchrotron offers incredible opportunities for scientists around the world investigating microscopic materials and components.

Around the Alba Synchrotron stand out facilities such as Parc de l’Alba, better known internationally as the Barcelona Synchrotron Park, well suitable to host technology companies.

Figure 8-1. Synchrotron. Parc de l'Alba. Cerdanyola del Vallés.
Source: Catalan society for spatial planning

The objective of this new urban development with a total surface area of 408 hectares is to promote scientific innovation, citizen cohesion and the sustainability of the natural environment. The 65% of the surface is for public use and 50% is reserved for green areas. Within *Parc de l'Alba*, a high efficiency energy system is to be gradually implemented in order to produce electricity, heat and cold. This trigeneration system will comprise up to 4 natural gas cogeneration plants (the first one in operation since 2010) with thermal cooling facilities (single and double effect absorption chillers) and a district heating and cooling network to feed the buildings of the Science and Technology Park.

The particularity of this case study lays on the fact that the DH&C was originally designed to cover only an industrial and tertiary development and, at first, the option of extending the network to the residential part was not considered. The main goal of this THERMOS case study is to determine the feasibility of extending the district energy network to the residential and other buildings that will be built in the area.

8.1.2 THERMOS involvement set up

This case study has been developed by Creara in cooperation with Parc de l'Alba. The municipality of Granollers, one of the partners of the THERMOS project, was also instrumental to identify the case study and to engage Parc de l'Alba.

In early 2020, Creara and Parc de l'Alba staff started working together. Creara received from Parc de l'Alba a vast amount of data on the current situation of the network, the already connected buildings, thermal energy demand estimations for each land plot under development, as well as information on the approved future development steps and the ones currently under study. The information was organised in CAD files, spreadsheets and other documents.

Creara with such information started preparing the GIS and other data files necessary to prepare the case study in the tool, in order to provide to Parc de l'Alba an idea of the viable district energy development alternatives.

8.2 Overview of the case study analysed with THERMOS

8.2.1 Introduction

The motivation of Parc de l'Alba to get involved with the THERMOS projects lays on the fact that they already have a profitable district energy network, and they would like to extend it to the rest of the park with a progressive and phased approach that follows its urban development.

Apart from connecting the commercial and education-oriented buildings that will be part of the park, the current position of the park's stakeholders is that extending the network to the residential parts could also be interesting, but it could complicate its management, having to deal with many additional individual customers. Therefore, this option hast to be carefully evaluated.

An alternative that is being evaluated is to supply the residential part by building blocks, in a way that the customer is the whole block, and the administrator of the property is the one that distributes the costs based on community rules. Another possibility to deal with the management is the integration of a new stakeholder that does have the infrastructure to supply a considerable number of individual customers.

*Stake*holders

The temporary association of companies behind the development of the Park, apart from Parc de l'Alba and the Synchrotron consortium, also involves the construction group San José and the engineering company *Lonjastec Energia.*

It is possible that, in the future, new stakeholders grow interest on getting involved in the project, such as residential landowners, energy companies that are interested to provide services, or even the city council, that could become interested in replicating the case in another area of the municipality.

Development schedule

While a part of the DHC network has already been realised, there is not yet a fixed schedule for the land development. In Figure 8-2 the different phases in which the project has been divided can be seen.

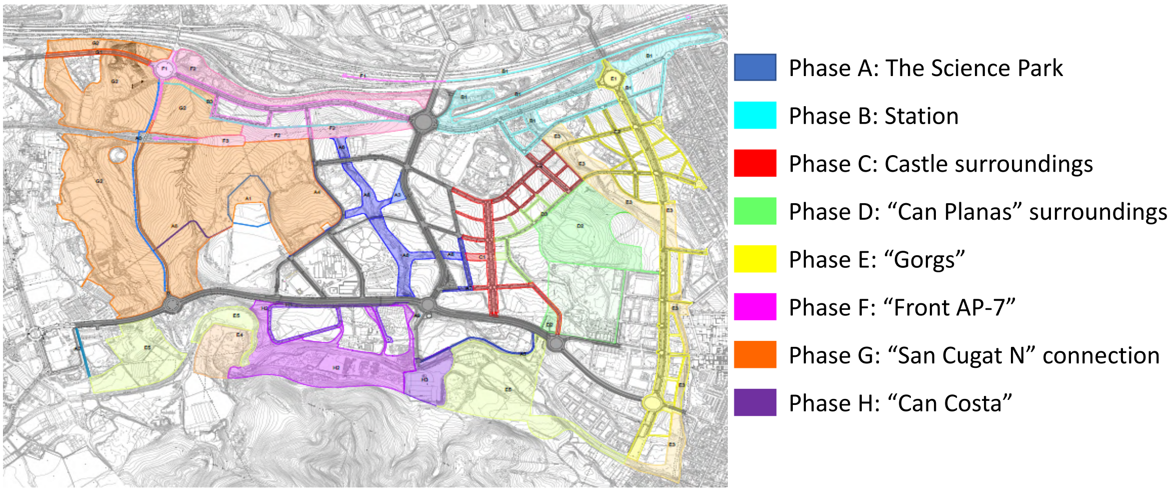


Figure 8-2. Development phases

The areas that are planned to be built first are the commercial and the residential areas, which are represented in the figure by blue and yellow parts, respectively, as well as some of the plots intended for public use, such as parks and schools, among others. This is a long-term project and its whole development is expected to last more than 30 years, being the offices area the last one planned to be constructed.

8.2.2 Case study definition

For this case study, three different scenarios are going to be considered. The main characteristics of the demand are summarised in Table 3-1.

Base scenario

This scenario includes only the buildings that are already included in the construction plans and the plots for public facilities placed in their way.

- Heat demand: 63 GWh/year;
- Cold demand: 165 GWh/year.

Alternative scenario 1

This scenario includes, in addition to what has been included in the base scenario, all the additional public facilities and the residential plots. Only a part of the base scenario buildings are considered as required, while the others are considered optional.

- Heat demand: 77 GWh/year;
- Cold demand: 170 GWh/year.

All these buildings will be considered as optional in the THERMOS tool, so that they are part of the network solution only if it makes economic sense.

Alternative scenario 2

This scenario includes the same buildings of Alternative scenario 1. In this case, all the plots for public facilities will be included as required, thus forcing their connection to the network, and the residential buildings will remain as optional.

	Demand			
	Base scenario		Alternative scenarios 1 and 2	
# of buildings	105		157	
- Residential	-		44	
- Commercial	8		8	
- Offices	93		95	
- Public use	4		10	
Total Energy demand (GWh/year)	**Cold**	**Heat**	**Cold**	**Heat**
- Residential	0	0	3	13
- Commercial	43	12	43	12
- Offices	102	51	102	51
- Public use	20	1	22	2
Total	**165**	**64**	**170**	**79**

Table 8-1. Main characteristics of the demand

The supply considered for this case study includes four different energy centres named ST00, ST04, ST05 and ST09, with the particularity that the ST00 is located within a commercial plot. Currently, only ST04 exists, and it serves 4 buildings including the Alba Synchrotron.

The main characteristics of the supply, as entered in THERMOS, are the same for all the scenarios considered in this document and they are presented in Table 3-2.

The fixed and O&M costs presented in Table 3-2 were calculated by attributing a share of the energy supply construction and operation costs to the generation of heat and cold based on the current distribution of revenues. As most of the revenues are generated by the electricity sale, only 2% and 13% of these costs can be attributed to heat generation and, respectively, to cold generation. Further, in the case of ST04, the costs only consider the upgrade from its current 10 MWe capacity to the planned capacity.

	Supply							
	ST00		ST04		ST05		ST09	
	Heat	Cold	Heat	Cold	Heat	Cold	Heat	Cold
Technology	Combined heat and power (CHP)							
Fuel used	Natural gas							
Max Capacity (MW)	8.9	6.5	17.9	18.0	16.7	18.0	16.7	18.0
Fixed costs (kEUR)	329	2,364	161	1,980	599	6,897	599	6,897
Capacity costs	0							
Annual O&M costs (EUR/kW)	0.66	4.10	0.66	4.10	0.66	4.10	0.66	4.10
Supply costs	2.53 c€/kWh							
CO_2 Emissions	202 g/kWh							

Table 8-2. Main characteristics of the supply as modelled in THERMOS

8.3 Case study development and results

8.3.1 Data preparation

Demand estimation

In order to build the case study on the THERMOS application, Parc de l'Alba provided:

- A spreadsheet containing a list of all the planned plots and their characteristics such as their heat and cold demand as well as their heat and cold capacity;
- A CAD file with all the plots together with their identification number and some of their characteristics, such as the buildable floor area and other information.

The starting hypothesis for the thermal demand is presented in Table 8-3. For the residential part, the demand was estimated by Creara considering the surface of the plot and multiplying it by the ratios (kWh/m^2) proposed by the Long-term Strategy for Energy Rehabilitation in the Building Sector in Spain (ERESEE 2020), the category considered in this case is the one for blocks since the residential buildings of the area have a base floor and between 3 and 6 additional floors. For the rest of the buildings the demand estimation was provided by the park.

	Cold	Heat
PC plots (kWh/m^{2}t)	85	44
Data centre plot (kWh/m^{2}t)	240	-
Residential plots (kWh/m^{2}t)	5	23

Table 8-3. Ratios for the demand estimation [kWh/m^{2}t]

Using this material, the objective was to develop a Geojson file that would include all the information necessary to represent the case study and that could be easily uploaded to the

THERMOS application in a single step. For this, it was necessary to open the CAD file with QGIS and start working from there.

Firstly, the file was cleaned, in order to keep only the desired plots and their identification number, which was the only data desired from the CAD file. At the same time, a spreadsheet was developed with all the useful information about the plots. Once the two files were ready, the spreadsheet was attached to the Geojson file, this was performed having the identification number of the plots as a common field so all the information on the spreadsheet related to a specific identification number was attached to the same number of the Geojson file. Figure 8-3 presents the resulting file opened in QGIS.

Figure 8-3. Plots layer in the GIS Geojson file

All the mentioned information was included into the attributes table of the shapefile so when the Geojson file is uploaded to the THERMOS application, all this data can be considered. The fields contained on the final Geojson file for each of the plots are:

- Identification number;
- Buildable floor area;
- Peak cold demand;
- Peak heat demand;
- Annual cold demand;
- Annual heat demand;
- Category (such as offices, residential…);
- Demand profile;
- Network status (explains if they are already connected to the network, near to it or not);
- Constraint (corresponding THERMOS application constraint: optional, required or forbidden);
- Residential (a binary variable to rapidly identify if a plot is for residential use or not).

Network topology

For the network, the park provided the map shown in Figure 8-4 with all the paths included in the construction design.

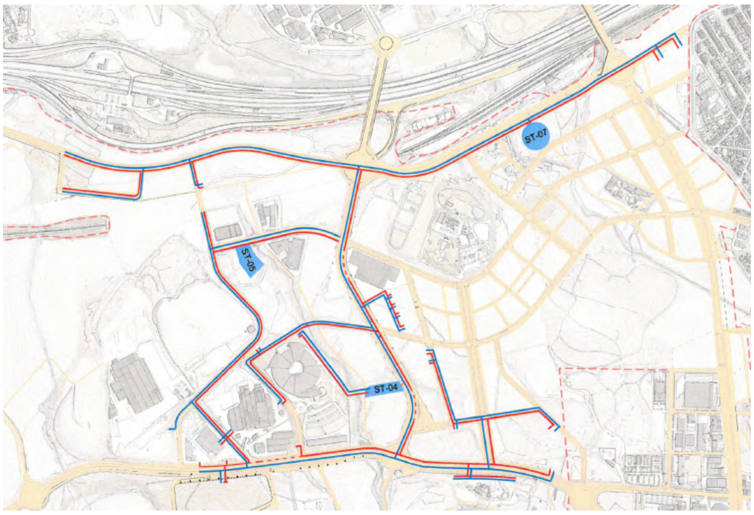


Figure 8-4. Current and planned network topology.

From the represented paths, it was necessary to distinguish three different possibilities:

- Already existing paths;
- Construction approved paths;
- Planned paths.

Taking into account this classification and the instructions provided by Parc de l'Alba, the information was introduced in a Geojson file by creating a shapefile in which the paths of Figure 8-4 were draw. For each of the paths, their construction status was included into the attributes table so when the file is uploaded to THERMOS application this information can be considered.

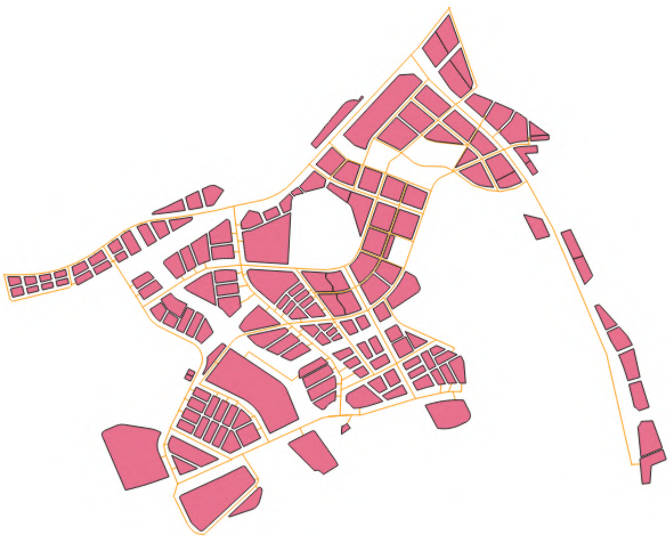


Figure 8-5. Outlook of plots and paths in the Geojson file

Once these two Geojson files were created, uploading them to THERMOS is an easy process and all the information introduced in their tables of attributes can be related to categories in the application, this made the process of entering the data less time consuming since only some values needed to be adjusted or introduced manually.

Emissions

The emissions considered in this case study were provided:

- CO_2 emissions: 0.202 kg/kWh;
- Emissions cost: 40 €/tCO_2.

DH network costs and tariffs

Network construction costs and energy sale tariffs have been elaborated and validated through conversations with Parc de l'Alba. The following tariffs have been used for the study:

- Unit charge: 3.3 €c/kWh;
- Capacity charge: 28 €/kWp/year;

In the capacity charge, the one-off connection costs of 152 EUR/kW have also been merged and spread over the time horizon considered for the project.

8.3.2 Results

In this section, we shall only consider the production and distribution of cold.

Network topology

As previously explained in Section 8.2.2, Parc de l' Alba is willing to consider three different scenarios. To achieve this goal, a sequential process has been carried out starting from the currently existing network which includes only the ST04 supply, expanding it until reaching the base scenario which will be further analysed in this document.

Current network

To begin with, the already existing installation was simulated in THERMOS . Figure 8-6 presents this first design of the case, where the ST04 supply and four currently connected buildings are considered: the biggest one is the synchrotron, and the others are offices. All the buildings were set as required and, as it can be seen, all of them are included in the solution.

Figure 8-6. Current network.

ST04 upgrade

The first expansion performed has the intention of analysing how many more buildings could be satisfied by the planned upgrade of the ST04 supply. With this aim and with the previous network as the starting point, the surrounding buildings were included as optional, the solution returned by the application is displayed in Figure 8-7. This expansion revealed that, indeed, is possible to cover the demand of several more buildings with an upgraded ST04.

Figure 8-7. First network expansion: upgrade of ST04

Addition of the ST05 supply

In this case, the ST05 and its characteristics were defined in the application. Starting from the current network, the rest of buildings were set as optional to see how many of them could be covered by the 2 supplies. The solution of this scenario is presented in Figure 8-8.

Figure 8-8. Second network expansion: ST04 & ST05

Addition of the ST09 supply

For the third network expansion, the ST09 as the third supply station was added to the problem and the optimisation was performed to see how many and which buildings could be included in the network. The solution can be seen in Figure 8-9.

Figure 8-9. Third network expansion: ST04, ST05 and ST09

Base scenario

The fourth expansion includes, in addition to the third one, the supply station ST00. This case corresponds to the base scenario and all the results presented below are referred to it. As described in section 8.2.2, the base scenario includes all supplies ST04 (required), ST05, ST09 and ST00 (optional), the four buildings presented in Figure 8-6 set as required and the rest of the planned park buildings set as optional;

Figure 8-10. Base scenario network

Considering all the sequential scenarios presented so far, Table 8-4 presents a summary of the main representative figures of each of them with the aim of having a comparative outlook. From the interpretation of the results, it can be seen that the base scenario is the one with more buildings connected to the network and so a higher demand satisfied.

	Supply stations	Total Supply capacity exploited [MW]	Connected buildings	Demand served [GWh/yr]	Total Network length
Current network	ST04	8.3	4	28.2	1.3 km
1st expansion	ST04	18	18	55.7	3.9 km
2nd expansion	ST04, ST05	36	35	92.2	4.9 km
3rd expansion	ST04, ST05, ST09	54	67	133,9	7.6 km
Base scenario	ST04, ST05, ST09, ST00	60,5	82	140,9	8.9 km

Table 8-4. Comparative of the sequential scenarios

However, it can be noted that the THERMOS optimisation of base scenario only connects 82 of the 105 buildings, so it appears that the total foreseen cold capacity may be insufficient to cover all the foreseen demand. Further analysis needs to be undertaken before confirming this result.

From now on, the results presented are referred to the base scenario. Figure 8-10 shows the optimal path THERMOS has identified for the implementation of the DH network considering the base scenario, highlighted in dark orange. The optional paths which were not chosen can be appreciated in a lighter orange colour and the ones in yellow are classified by the application as peripheral. Table 8-5 compiles the network solution for the base scenario. The pipework solution is considering the non-existing paths that have to be added to the network.

Pipework solution				
Length (Additional network)	4.6 km			
Total Cost	9.73 M€			
Average Linear Cost	2,115 €/m			
Losses	0.27 GWh/year			
Capacity	19.89 MW			
Demand solution				
Total Undiversified Peak Demand [13]	95.57 MW			
Demand	148.52 GWh/year			
Revenues	7.58 M€/year			
Supplies solution				
	ST00	**ST04**	**ST05**	**ST09**
Total Capacity Required (MWp)	6.5	18	18	18
Output (GWh/year)	10.38	62.84	31.77	43.8
Capital cost (M€)[14]	1.92	1.98	6.90	6.90
Operating cost: O&M (M€/year)	-	-	-	-
Operating cost: heat production (M€/year)	0.26	1.59	0.80	1.11

Table 8-5. Base scenario network solution

Financial analysis

Table 8-6 shows the economic solution provided by THERMOS considering a time horizon of 25 years and a discount rate of 3%. The NPV for the network is positive and therefore its installation is economically viable. The operating revenues exceed the operating costs by approximately 2.38 M€ per year.

[13] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

14 This value is referred to the share of supply costs that can be attributed to cold production and sales.

	Capital cost	Yearly operating cost	Yearly operating revenue	NPV
Pipework	-9.73 M€	--	--	**- 9.73 M€**
Cold supply	-17.69 M€	-4.01 M€	--	**- 89.66 M€**
Demands	0	--	7.58 M€	**135.90 M€**
Emissions	--	- 1.20 M€	--	**-21.56 M€**
Network	**-27.42 M€**	**5.21 M€**	**7.58 M€**	**14.95 M€**

Table 8-6. Economic solution

Alternative scenarios

Even though the results of the optimisation have been provided for the base scenario, it is interesting also to provide a summary of the possible alternatives that have been also considered for this case study. The following points cover the approach of these alternative scenarios and give a first outlook of their THERMOS solution.

Alternative scenario 1

This first alternative for the base scenario includes:

- Supply stations: ST04, as required and ST05, ST09 and ST00 as optional;
- The builidings included in the base scenario;
- The addition of the public plots and the residential buildings as optional.

Figure 8-11 displays the map view of the optimised solution returned by THERMOS for the alternative 1 of the base scenario. While more bulidings are connected wit respect to the base scenario, no residential buildings are connected.

Figure 8-11. Solution map view for the base scenario alternative 1

Alternative scenario 2:

The second alternative to the base scenario includes:

- Supply stations: ST04, as required and ST05, ST09 and ST00 as optional;
- The buildings included in the base scenario, this time all of them as required;
- The public areas and the residential buildings with the difference that in this case the public areas will be included as required and the residential buildings will still be optional.

Figure 8-12 shows the solution of this scenario. Also in this case, more buildings are connected, but no residential buildings.

Figure 8-12. Solution map view for the base scenario alternative 2

For further analysis and comparison of the base scenario and its two alternatives, Table 8-7 has been developed.

	Total Supply capacity [MW]	Connected buildings	Demand satisfied [GWh/yr]	Total Network length	Capital costs [M€]	NPV [M€]
Base scenario	60,5	82	140.88	8.9 km	27.42	14.95
Alternative 1	60,5	97	140.87	10.34 km	28.76	13.61
Alternative 2	60,5	102	141,43	12.89 km	31.01	11.50

Table 8-7. Comparison between the base scenario and its two alternatives

The alternative scenarios allow to connect a higher number of buildings, while requiring a slightly higher investment and a presenting a marginally inferior economic performance after 25 years.

8.4 Conclusions

8.4.1 *Status quo* of the case study

In general, from THERMOS results it appears that the total planned cold generation capacity of the supplies may not be sufficient to cover the demand of all the buildings, even not considering the residential plots, which anyway appear to represent a less profitable demand.

After verifying if demand estimations as well as other assumptions such as losses are correct, an expansion of the capacity of some of the supply stations could be studied , if the objective is to cover all the buildings and also a part of the residential ones.

8.4.2 General reflections on using THERMOS in developing the case study

The THERMOS tool has proved to be useful developing this case study and appears sound for its use in future case studies. After the necessary preliminary discussion of objectives and the data identification and preparation phases, it was possible to develop several different scenarios proposed by Parc de l'Alba that will be instrumental to study the possibility of extending the scope of the network to the residential and other planned areas contemplated in the development of the park.

Since the concession contract was already in place, if the THERMOS tool was not available the consortium would have had to develop the study internally with the consequent time and resources expenditure.

8.4.3 Challenges

The consortium has to deal a number of challenges in developing the project. A significant one is the lack of knowledge of the clients, and the consequent uncertainties. This barrier can be overcome little by little as the number of clients on the network increases. In this sense, the Synchrotron was very helpful to fight against the initial mistrust.

Another barrier that can be overcome in the future is the fact that the project could benefit a lot from a more significant political support. If the Parc de l'Alba consortium gets more involved on the initiatives this would mean an important push for the project.

Among all the benefits that the development of this project can bring, one of the most attractive ones nowadays is how its implementation can contribute to sustainability objectives. Preliminary calculations developed by Parc de l'Alba state that greenhouse gas emissions to the atmosphere could decrease up to 35% with the implementation of the district energy network to cover most of the park's thermal energy demand, compared to conventional individual production systems.

8.4.4 Future outlook

On the previously presented section of results, it has been summarised all the data concerning the solution given by the tool for the base scenario and it has also been provided a preliminary outlook of the solutions for the alternatives 1 and 2 of the base scenario.

To support a possible improvement for the future, it has been considered and introduced in THERMOS a trial example considering the expansion of the capacity of the supply station ST05 up to 22 MW. The solution map view is shown in Figure 8-13. In this case, some residential buildings are connected.

Figure 8-13. Expansion of the supply capacity

Since the future demand will depend on the actual use of the buildings, and the district energy system will be implemented gradually, the capacity of the plants can be adapted to match that demand. It is also possible that the technologies used in future plants will be different – it is very likely that all the plants will incorporate photovoltaic panels, and perhaps they will shift from natural gas CHP to biomass boiler to reduce the cost of CO_2 emissions rights - thus modifying the cost structure of the project. As a result, in the following years, other scenarios should be considered.

8.4.5 Scope for replication

Parc de l'Alba is one of the most strategic urban development projects in Spain and has the objective of becoming a powerful engine of scientific, technological and business competitiveness in southern Europe. The application of the THERMOS tool in this case study and the results achieved can be used for other projects taking place throughout Europe.

The replicability of this project is very interesting for the transition towards a more sustainable economy, since Parc de l'Alba is located in an area that is being transformed in a high quality urban and environmental space. Moreover, the case study incorporates state-of-the-art urban services, a wide range of facilities and services, an extensive network of green areas and natural ecosystems and will also include a sustainable residential neighbourhood. All these elements make this case study very interesting for its replication by urban and technologic areas that want to achieve the same sustainable results as Parc de l'Alba.

Parc de l'Alba is member of the of the network of Spanish science and technology parks and it is expected that this network will be interested in replicating the benefits of this system.

9 Salaspils Siltums – Salaspils, Latvia

9.1 Introduction

9.1.1 City/area energy background

In Salaspils city (about 18.000 inhabitants on a total area of 12 km^2), most multi-apartment and commercial buildings are heated by a district heating system provided by *Salaspils Siltums* (Salaspils Heat company). The network which covers 85% of the city's heating demand, which is about 60 GWh per year, through a pipeline infrastructure with a total length of 21.3km.

Salaspils Siltums is fully owned by the Salaspils municipality. Historically, the district heating company has helped the city that joined the Covenant of Mayors to develop its energy planning targets. *Salaspils Siltums* is the first district heating company in Latvia that integrated solar collectors into their heating systems to reduce emissions and to increase renewable energy share in the energy mix. *Salaspils Siltums* is supporting the implementation of the zoning method[15] in areas near the district heating network where new constructions or refurbishment of existing buildings will be planned. These buildings will be able to choose to use zero emission heating solutions or to connect to the district heating network.

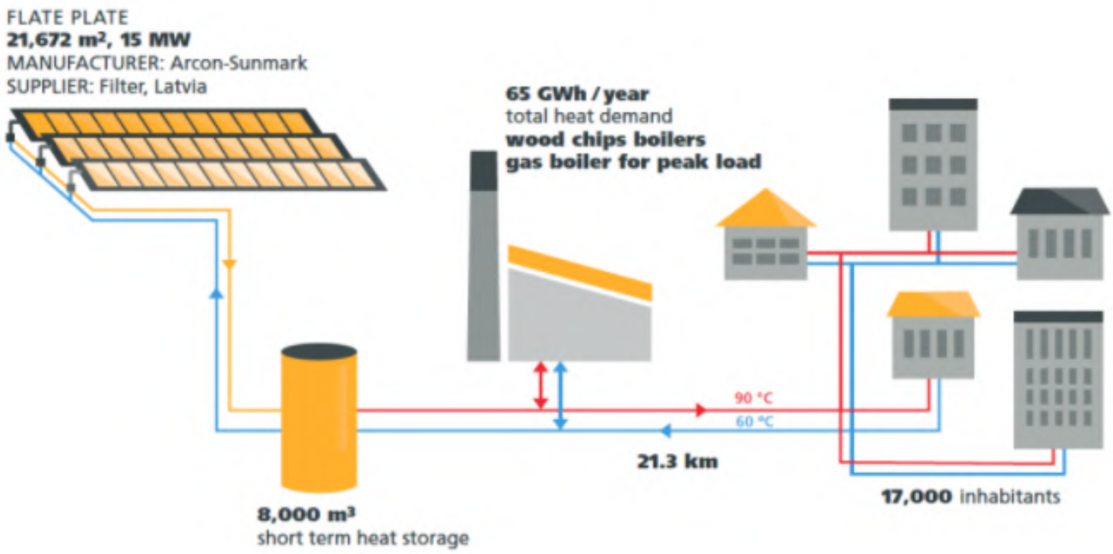


Figure 9-1. Salaspils District Heating network architecture

Between 2010 and 2020 there has been a significant transition of investments towards the renovation of the district heating network and large investments in new supply capacities

[15] Zoning is a method of urban planning in which a municipality or other tier of government divides land into areas called zones, each of which has a set of regulations for new development that differs from other zones. See https://en.wikipedia.org/wiki/Zoning

replacing old fossil fuel boilers. The most significant activities started with investments in more efficient heat only boilers (HOB) natural gas boilers.

The following investments in 2012 were mostly focused on the increase of renewable energy sources (RES), as a result 7 MW biomass HOB capacity were installed. Comparing CO_2 emissions in 2011 to 2016, a reduction of 80% was achieved. In 2019, the most significant investment was a solar collector park with an active area of 21,672 m^2, an 8,000 m^3 storage tank and a 3 MW biomass boiler. Solar energy will provide about 20% of the total heat demand of the city.

After improvements and investments have been performed in the supply side and the network, the current focus is to intensify the reduction of fossil fuels on the demand side by connecting more customers to the district heating network.

9.1.2 THERMOS involvement set up

Currently, the use of existing GIS databases and limited staff resources and skills within an organization are limiting the speed of the decision-making process for the design or expansion of new and existing district heating networks. In fact, planning and modelling of different network layouts as well as taking into consideration different scenarios of possible demand connections within a specific area of the city are time and resource consuming activities.

The THERMOS tool can make the heat network planning faster, more efficient, and more cost effective. Within this specific case study, the use of the THERMOS tool has been tested and compared with existing processes.

9.2 Overview of the case study analysed with THERMOS

Figure 9-2. Salaspils supply power plant

9.2.1 Introduction

The existing supply capacity is 35.18 MW. This exceeds the maximum heat load demand of Salaspils city. Many multi-apartment buildings have reduced their heat consumption and demand after complex renovations have increased their energy efficiency. There are also more energy efficiency projects being proposed that will be implemented in the coming years, which will reduce the demand even more.

In order to use the existing supply infrastructure more effectively and to maintain the heat tariff at a competitive level, new demands must be connected. There is a plan to set specific zones in the city where only district heating or zero emission heat supply is allowed. With the tools the district heating company currently uses, the analysis of each potential zone requires significant time and human resources, which in turn enquire larger costs. In this case study, a specific zone has been evaluated using the THERMOS tool to understand the costs, optimal network layout and estimated demand. Engineers, project managers and technical specialists have been involved in the study to provide the necessary inputs and validate the outputs. At this stage the analysis will focus on NPV, emission factors, and further steps can be included if necessary when comparing the results of this case study with fossil solutions.

There are areas in the city which are near to the existing network for which there is no need to perform calculations to conclude that it is reasonable to connect them with the network. In this case study, an area that is quite far from the network will be analysed since it has a significant heat demand and their existing gas boilers are coming to the end of their lifecycle. The preliminary evaluation to determine whether this area can be included in the near-future plans to expand the existing network will be performed using the THERMOS tool.

Figure 9-3. Multi-apartment housing included in case study

9.2.2 Case study definition

In this case study, a specific area will be analysed focusing on the NPV of expanding the existing network. The supply capacity will be limited by the size of the existing magistral pipeline. The total annual demand to be satisfied is 2,480 MWh for 10 residential buildings.

The supply is provided via connection with one of the main pipelines. The main characteristics of the supply are presented in the Table 3-2 where the main energy sources are listed. The existing supply capacity is enough to supply up to 10 MW heat demand for the new additions to the network. For this specific area the main limitation is the size of pipes. The most important factor to consider is the increase of variable supply costs when modelling the connection to new customers. The fixed costs of the existing supply capacities have not been included in the calculation.

	Supply
Technology	Biomass and natural gas HOB, solar collectors
Energy source	Woodchips, Solar, Natural gas
Maximum capacity	5 MW
Supply costs	2 c€/kWh

Table 9-1. Main characteristics of the supply

9.3 Case Study development and results

9.3.1 Data preparation

Building and network layers were taken from the Open street maps data. GIS files provided by *Salaspils Siltums* mostly contain data regarding buildings which are already connected and existing networks, excluding objects outside the network scope. If in the future the THERMOS tool is to be used daily, the GIS files from the Construction Department of the city could be adopted for Thermos needs.

Currently there is no free LIDAR data available for the city of Salapils. Demand data has been adjusted in line with the internal consumption and capacity data available from similar buildings already connected to the existing network. Supply costs and tariff information is taken from *Salaspils Siltums'* internal data.

Pipeline costs have been adjusted according to actual costs from internal existing data. To have more accurate investment estimates, prices would have to be updated to match the 2021 price level.

9.3.2 Results

Network topology

Figure 9-4. THERMOS solution network layout overview

In the map a long pipeline, represented by an orange line, can be appreciated. This pipeline connects the existing main pipeline to 10 residential buildings. Other existing pipelines, represented by thinner purple lines, that are closer to the buildings have a diameter which is too small to satisfy the necessary demand capacity of all the buildings. Therefore, the only option would be to construct a new pipeline that is more than 1km long.

Financial analysis

The NPV analysis, considering a 40-year perspective and a 3% discount rate is offered below and can be considered positive. The NPV is at a level that could be considered acceptable for an investment decision.

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	-387,270			-387,270
Heat supply		-1,320,000		-1,320,000
Demands			2,830,000	2,830,000
Emissions	Not included at this stage			
Network	**-387,270**	**-1,320,000**	**2,830,000**	**1,120,000**

Table 9-3. Economic solution

Pipework solution	
Length	1.29 km
Total Cost	0.39 M€
Linear Cost	301 €/m
Losses	0.30 GWh/year
Capacity	1.11 MW
Demand solution	
Total Undiversified Peak Demand[16]	1.68 MW
Demand	2.48 GWh/year
Connection Costs	included in network costs MW
Revenues	118,830 €/year
Supplies solution	
Total Capacity Required	1.09 MWp
Output	2.78 GWh/year
Capital cost	-
Operating cost: O&M	-
Operating cost: heat production	55,540 EUR/year

Table 9-2. Network solution

9.4 Conclusions

9.4.1 *Status quo* of the case study

The initial modelling of the analysed area has been done and will be presented to *Salaspils Siltums'* management. Engineers will validate the accuracy of the outputs and will adjust some of the inputs if needed.

9.4.2 General reflections on using THERMOS in developing the case study

The tool is, in general, simple to use. The main advantage when compared to the existing planning processes is that the tool can save many hours of engineering work regarding

[16] This value represents the sum of the peak thermal energy demand of each building in the solution. However, since the peak demands of a set of buildings are unlikely to occur at exactly the same time, the total capacity required by the supply is considerably less that this value.

technical drawings and investment calculations. Alternative scenarios can be created within a very short time span compared to manual engineers' work.

As the THERMOS tool is simple to use, it can also be used by staff which do not have an engineering degree. Since the case study was developed with the support of a THERMOS certified trainer, the time needed to understand the tool was one full working day. Without this support, the learning curve to understand the tool functionalities would require more time. Nevertheless, the design of new and existing networks requires much less time using THERMOS compared to previous conventional methods.

9.4.3 Challenges

In order to implement the THERMOS tool into the daily planning processes of the network development zones, a deeper validation of the provided results would have to be performed. Building trust on the accuracy of inputs and outputs provided by the tool is key to integrate its use into network planning processes.

9.4.4 Future outlook

If considered for further development, more accurate pipeline and civil work costs should be entered in the THERMOS tool in order to produce a more accurate result. The demand side can still be adjusted manually for each building since the territories under analysis are small scale and only have a few buildings. After adjustments and detailed investigation, the tool could be used to analyse selected areas in the vicinity of the existing network. It can also be used for the planification of areas in the city which may be prioritized as zero emission areas.

9.4.5 Scope for replication

Salaspils Siltums' team believes that a similar approach for planning areas and zones for network expansion using the THERMOS tool could be applicable to other district heating companies and municipalities.

10 Żywiec – Żywiec, Poland

10.1 Introduction

The city of Żywiec is actively looking to improve its air quality. One of the main areas for improvement is the heating sector. Development of the district heating network owned by the city-owned company EKOTERM is considered to be a good long-term solution that could support achievement of the sustainable development goals for the city.

Currently the heating network supplies around 200 TJ (roughly 56 GWh) of heat a year to final consumers. The total length of the network is around 28 km. The main sources for heat production are 5 coal boilers. The facility also uses 60 kWp photovoltaic panels to cover part of its own electricity demand.

Figure 10-1. Żywiec city view. Source: https://www.ekoterm.ig.pl/

10.1.1 City/area energy background

The city's current goals consist of decreasing its energy consumption by 22,069 MWh (4.6% reduction compared to business as usual (BAU) scenario), reducing GHG emissions by 8,024 $MgCO_2$ (5.9% reduction compared to BAU scenario), and increasing the energy production from RES to 3,437 MWh by 2030 (increase from 0.34% of total consumption estimated in BAU to 0.76%). The BAU scenario[17] for 2030 estimates the energy consumption to reach 476,982 MWh, the GHG emissions to reach 136,536 $MgCO_2$ and the production from RES to be 1,615 MWh

[17] Plan Gospodarki Niskoemisyjnej dla Miasta Żywiec AKTUALIZACJA.

No large-scale wind or solar farms are planned to be built due to protection of the cities' outstanding natural features, high urbanization, and arrangements in its spatial development plan. The development of RES is planned to cover small scale prosumer installations (Żywiec, 2019).

The majority of the city's heating needs are covered with individual heating sources – mostly coal boilers.

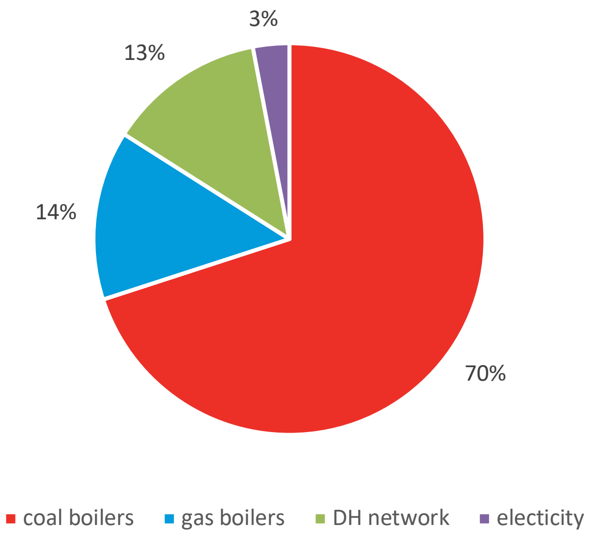


Figure 10-2. Energy consumption for heating purposes in Żywiec

The DH network already covers most high-density areas on the eastern side of river Soła.

The areas with low-rise buildings outside the gas network could be considered for further development of the DH network to limit air pollution. However, since there is currently no obligation to connect to the DH network to these buildings, the economy of those solutions is difficult to evaluate. Usually, the individual coal boilers are the least expensive source of heat but the decision to connect to the network could be based on other factors such as comfort or air quality. From the network perspective, connecting the areas with scattered low-rise buildings could also impact the price of heat discouraging consumers to connect to the network and through that limiting the possibilities for further development.

10.1.2 THERMOS involvement set up

Żywiec was introduced to the tool by KAPE – THERMOS project partner – during the preparation of "Antysmogowa mapa drogowa dla Żywca" (Anti-smog roadmap for Żywiec). The roadmap provided the overall outlook on the directions that the city could take to limit smog. An expansion of the existing district heating network was one of the proposed solutions along with the replacement of individual heating sources. The city representatives were interested in trying out the tool to analyse specific areas that were identified for the possible expansion of DH network.

THERMOS as a tool could be very useful to evaluate the possibilities for the DH network expansion in Żywiec. The possibility to consider both the financial and emissions side of different solutions could bring a better understanding of the costs and benefits of the DH solutions.

After introducing the tool to the cities' media representative, a meeting was held with the city's Mayor and management of EKOTERM - the city owned DH network operator. The value added from using the tool was presented during the meeting. The city decided to try out the tool and learn how to use it and chose EKOTERM to work with the tool on their behalf. Since EKOTERM is already using other tools to analyse the possibilities for the expansion of the network, an additional goal for them was to compare the different options. Free access to the THERMOS tool was considered as an important factor that could decide whether to change from the standard solution.

Two EKOTERM employees worked on the preparation of the case with the tool cooperating with other employees to collect the necessary data. The English language was a barrier in the process since the automatic translation was inaccurate and frequent consultations with KAPE were required to allow for a better understanding of the tool's options.

10.2 Overview of the case study analysed with THERMOS

10.2.1 Introduction

The city of Żywiec was interested in the opportunity to use the THERMOS tool to support the goals of increasing its air quality by developing its DH network. EKOTERM was chosen to work on the case due to its expert knowledge in the field.

One of the areas with low-rise buildings that use individual coal boilers as heat sources near the DH network was chosen for the analysis using THERMOS. The area was suggested by EKOTERM - DH network operators since this area is one of the locations where the expansion of the network was planned. The aim of the analysis was to evaluate if building the network in the area would be economically viable considering current heating tariffs.

The willingness of the consumers to connect to the network was one of the key aspects to be considered in this case study. Typically, in the first years after the construction of the network not all consumers decide to connect to the network, which can lower the economic viability of the project.

The area is currently not covered by the gas network, however the expansion of a gas network and switching the individual coal boilers to gas sources could also be considered as one of the ways to limit air pollution, and therefore an analysis on that topic has also been covered in this report.

10.2.2 Case study definition

The THERMOS tool was used to analyse the possibilities to expand the network in the southern part of the DH network in Żywiec. Buildings on the streets: Klonowa, Mikołaja Kopernika, Marii Skłodowskiej-Curie, Jana Kilińskiego and Mikołaja Reja were considered. This area is planned to be connected to the existing DH pipeline near Grunwaldzka Street. This pipeline is currently oversized, and the additional power was assigned as a limit in the source.

	Demand
# of buildings involved	61
- Residential	60
- Commercial	1
Tot. energy demand	2,2 GWh/year
- Residential	2,08 GWh/year
- Commercial	121 MWh/year

Table 10-1. Main characteristics of the demand

All buildings were set as required when performing the initial optimisation in the tool. To account for the possibility that some customers would not want to be connected to the network, other maps with less buildings connected were prepared as well. The network NPV optimisation was used to evaluate all cases, which should not impact the result as all buildings were set as required. The total demand to be satisfied in the area is estimated for 2,2 GWh/year including 60 residential and 1 commercial building. The main characteristics of the demand are illustrated in Table 10-1.

	Supply
Technology	Boilers
Fuel used	Coal
Maximum capacity	1.5 MW
Fixed costs	N/A
Annual O&M costs	N/A
Supply costs	21 gr[18]/kWh (including O&M costs)

Table 10-2. Main characteristics of the supply

[18] Gr stand for polish Grosz, which represents 0.01 of a Zloty (PLN)

The supply is an existing construction that uses coal boilers. For the purpose of evaluation, a theoretical source was assigned where the maximum capacity was reflecting the capacity of the already existing pipeline near the area. The emissions were not considered in the case study. It is also worth mentioning that the annual O&M costs have been considered within the supply costs. The main characteristics of the supply are presented in Table 10-2.

10.3 Case Study development and results

10.3.1 Data preparation

At the start of the case study the OpenStreetMap was used with 2D inputs. The accuracy of the heat demand estimation based on that input was considered to be too low. Individual estimations performed by EKOTERM for each building in the area were used. The heat demand and peak power demand estimation was based on the standard methodology used by the DH network operators. The total heat demand estimated was over two times higher than the estimation provided with the OpenStreetMap map and the peak heat power estimation was 30% lower than from the OpenStreetMap estimation for the chosen area.

For the pipeline costs the capex values were provided by EKOTERM. A simplified approach combining the pipe costs with the civil costs was used to create one simplified cost parameter based on the experience of the operators. For the tariffs, the current A3 type tariff[19] for individual customers was used in the area for the unit charge and the capacity charge. The distribution and heat prices were summed up to create a unit charge and a capacity charge. In addition, the change of units was required as GJ instead of kWh since these units are typically used in the heating sector. An additional standing charge was added which represents the costs of the meter's maintenance.

For the individual decentralized sources two types were assigned in the analysis – gas and coal boilers. For the coal boilers only the heat cost value was used as this was the counterfactual source in the analysis. The estimation was provided by EKOTERM. For gas boilers the heat cost per kWh was estimated based on gas tariffs in Poland. The capital cost and operating costs were estimated based on a market analysis. Additional fixed capital costs were added to each boiler to account for the costs of connecting the buildings to the gas network in the studied area.

To include the influence of dynamic cost parameters impacting the NPV of the solution external calculations had to be done. For the case study the dynamic costs included:

- Additional yearly 2% tax of the investment costs for the pipes;
- 4.5% depreciation over 22 years;
- Investment loan for 10 years (8%).

[19] https://www.ekoterm.ig.pl/index.php/oferta/taryfa

For each 100 PLN of the investment, the cost for the investor is around 302.5 PLN within the 25-year period due to the additional dynamic cost factors. If the discount rate of 4% is considered the value reaches 227.7 PLN over the 25-year period for each 100 PLN of the investment costs.

Figure 10-3. Starting Open Street Map input – Żywiec

The option to give the pipework capital costs annually, which is available in the "objectives" tab, was used to reach similar results with the tool. The period was set to 16 years and the rate to 17.3%. Those values were reached through iteration and checking how different combination of options (annualization and reoccurrence) will impact the result. For that iteration, the goal seek option in Excel was used to reach the solution faster. With the 16-year period and 17.3% rate, the final costs for each 100 PLN of the investment are around 300.7 PLN over the analysis period and applying the discounted rate - 227.77 PLN, which are close to the expected original results.

Figure 10-4. Adjusted paths - Żywiec

Paths representing the expected pipework roots were drawn on the map in addition to the standard input from Open Street Map.

Further insight from building owners regarding current building energy consumption could be useful to make the demand estimation more accurate. Furthermore, additional information about the current costs for the existing heat sources could show which buildings are more likely to be connected to the network. Estimation of the costs for the expansion of the gas network would also be useful to compare them to the DH solution.

10.3.2 Results

Network topology

The network topology was forced as all paths were set to required. Three maps were prepared to evaluate the risk of some clients deciding not to connect to the network. The buildings not connected to the network were chosen randomly, more or less evenly spread out between network paths. The network maps showing the connection paths for the three considered scenarios are shown in Figure 10-5, Figure 10-6 and Figure 10-7.

Figure 10-5. Map with 61 buildings connected to the network

Figure 10-6. Map with 41 buildings connected to the network

Figure 10-7. Map with 33 buildings connected to the network

25 years were used as the analysis period with a 4% discount rate. The details of the network solution for the three scenarios are presented in in

Pipework solution			
	61 buildings	**41 buildings**	**33 buildings**
Length	2020 m	1850 m	1780 m
Total Cost	3.54 M PLN	3.16 M PLN	2.95 M PLN
Linear Cost	1750 PLN/m	1710 PLN/m	1660 PLN/m
Losses	401.19 MWh/year	355.44 MWh/year	333.93 MWh/year
Capacity	734.64 kW	508.47 kW	425.31 kW
Demand solution			
Total Peak Demand	1.26 MW	0.90 MW	0.76 MW
Demand	2.2 GWh/year	1.57 GWh/year	1.34 GWh/year
Revenues	0.56 MPLN/year	0.37 MPLN/year	0.31 MPLN/year
Supplies solution			
Total Capacity Required	0.79MWp	0.57 MWp	0.48 MWp
Output	2.6 GWh/year	1.93 GWh/year	1.68 GWh/year
Capital cost	-	-	-
Operating cost: O&M	-	-	-
Operating cost: heat	21 cPLN/kWh	21 cPLN /kWh	21 cPLN /kWh

Table 10-3.

Pipework solution			

	61 buildings	41 buildings	33 buildings
Length	2020 m	1850 m	1780 m
Total Cost	3.54 M PLN	3.16 M PLN	2.95 M PLN
Linear Cost	1750 PLN/m	1710 PLN/m	1660 PLN/m
Losses	401.19 MWh/year	355.44 MWh/year	333.93 MWh/year
Capacity	734.64 kW	508.47 kW	425.31 kW
Demand solution			
Total Peak Demand	1.26 MW	0.90 MW	0.76 MW
Demand	2.2 GWh/year	1.57 GWh/year	1.34 GWh/year
Revenues	0.56 MPLN/year	0.37 MPLN/year	0.31 MPLN/year
Supplies solution			
Total Capacity Required	0.79MWp	0.57 MWp	0.48 MWp
Output	2.6 GWh/year	1.93 GWh/year	1.68 GWh/year
Capital cost	-	-	-
Operating cost: O&M	-	-	-
Operating cost: heat	21 cPLN/kWh	21 cPLN /kWh	21 cPLN /kWh

Table 10-3. Network solution

Small differences in pipework costs and parameters between cases are a result of a change in the structure of the demands. The length of the pipework is different because along with the buildings the last connection pipeline was set to forbidden as well. The impact of having less buildings connected to the network is more visible for demand and supplies solution.

For the analysis of the gas network expansion, as a first step all buildings were set to optional and the optimised network NPV was searched for.

Figure 10-8. Results of the optimisation with all buildings set to optional.

In this solution network, a positive NPV of 860 000 PLN is obtained. Some buildings should not be connected to the network in order to reach a positive NPV. This result was used as a reference for the comparison with the gas network expansion case.

The fixed capital cost of the individual gas boilers was increased until the solution was similar to the reference result. For such a network the DH solution would cost less than the gas solution. The total costs of the gas network should be higher than roughly 2.5 million PLN for the DH solution to be less expensive when maximising the whole system NPV.

Financial analysis

Current values were used for the calculation of the production costs and the tariffs. The future tariffs and production costs are difficult to estimate as the CO_2 emission cost influences both. Tariffs are regulated and cost based, so the future equilibrium between costs and revenues should be similar to the current state.

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	-3.54 MPLN	--	--	-2.68 MPLN
Heat supply	0	-13.67 MPLN	--	-8.88 MPLN
Demands	0	--	13.15 MPLN	8.55 MPLN
Emissions	Not included at this stage			
Network	-3.54 MPLN	-13.67 MPLN	13.15 MPLN	-3.01 MPLN
Whole system	-3.54 MPLN	-13.67 MPLN	n/a	-11.56 MPLN

Table 10-4. Economic solution (61 buildings connected to the network)

	Capital cost	Operating cost	Operating revenue	NPV

Pipework	-3.16 MPLN	--	--	-2.39 MPLN
Heat supply	0	-10.13 MPLN	--	-6.58 MPLN
Demands	0	--	9.17 MPLN	5.96 MPLN
Emissions	Not included at this stage			
Network	-3.16 MPLN	-10.13 MPLN	9.17 MPLN	-3.02 MPLN
Whole system	-3.16 MPLN	-10.13 MPLN	n/a	-8.92 MPLN

Table 10-5. Economic solution (41 buildings connected to the network)

	Capital cost	Operating cost	Operating revenue	NPV
Pipework	-2.95 MPLN	--	--	-2.23 MPLN
Heat supply	0	-8.79 MPLN	--	-5.72 MPLN
Demands	0	--	7.69 MPLN	5 MPLN
Emissions	Not included at this stage			
Network	-2.95 MPLN	-8.79 MPLN	7.69 MPLN	-2.95 MPLN
Whole system	-2.95 MPLN	-8.79 MPLN	n/a	-7.95 MPLN

Table 10-6. Economic solution (33 buildings connected to the network)

In all 3 cases the operating costs were higher than the operating revenue. Two main factors contribute to this result: relatively small benefit margin from the tariff and low density of the demand in this area, which results in relatively high losses in comparison to the demands. The gap between operating costs and revenues becomes more significant the less buildings are connected to the network, ranging between 0.5 to 1 million PLN (around 110 to 240 thousand EUR). Together with the additional capital costs linked to the pipework installation, this results in a negative NPV for the total network in all 3 cases.

To reach a positive NPV, the tariff costs should be 36% higher for the case which has the most buildings connected, 52% for the case with 41 buildings, and 60% for the case with 33 buildings.

10.4 Conclusions

10.4.1 *Status quo* of the case study

The results of this case study show that in the current conditions, developing the network in the chosen area for all buildings is not financially viable without additional support. Other optimisation options should be considered in this area. A similar analysis could also be conducted using the THERMOS tool for other expansion options in different areas of the city. Other development options such as changing or adding different sources in the network could also be analysed.

For the expansion of a gas network, if the costs of the expansion are higher than 2.5 mln PLN, the DH network solution would only cost less if the space heating and domestic hot water purposes are considered. Further insight into the plans and costs of the gas network expansion would be needed to be able to compare both solutions in more detail. In addition, the CO_2 or NO_X emissions could be considered for that comparison.

10.4.2 General reflections on using THERMOS in developing the case study

The use of the tool requires some basic knowledge in multiple areas. A cooperation of experts is usually needed. The most time-consuming part of the process in this case study has been the preparation of the data to be introduced into the tool. The understanding and relevance of the chosen parameters are usually not clear for newcomers using the tool, especially those with less experience in a particular field or those which might find the English language as a barrier.

The main works regarding the data gathering process and its input into the tool, as well as creating different scenarios lasted approximately 2 weeks. For most of the users this was the first time getting to know the tool and looking into the different possibilities it offers.

The alternative process for investment planning which is a current standard practice covers following steps:

- Analysis of the gas network reach in the area;
- Evaluation of the interest of the building owners to connect;
- Obtaining the maps and extract from the land register;
- Defining the path and owners of the land for the pipeline;
- Analysis of the costs for pipework and the revenues from the heat supply in Excel;
- Obtaining the permits;
- Final decision for the investment;
- Realisation.

10.4.3 Challenges

A low profit margin for the DH network is the main barrier for the expansion of the network in the areas with less heat demand. Moreover, the increasing impact of the CO_2 emission costs from the EU ETS mechanism on the heat production costs and tariffs for network sources makes the network solutions less competitive to individual heating sources, which do not bare direct additional costs for the emission of CO_2 or negative impact on air quality. Mechanisms levelling the field for network solutions and acknowledging the benefits in comparison to the individual solutions are needed to support the uptake of network solutions.

In the Region, there are ongoing programmes that could support the investments in the DH network:

- The „*Ciepłownictwo powiatowe*" ("County heating") programme by National Fund for Environmental Protection and Water Management (NFOŚiGW) offers grants (up to 50% of the qualified costs) and loans for new heat or electricity sources, modernisation of the DH network or existing sources;
- The Priority programme „*Racjonalna gospodarka odpadami*" ("rational waste management") by NFOŚiGW offers grants (up to 50% of the qualified costs) and loans for new buildings or extending existing sources for thermal utilisation of waste using CHP technology for energy production;
- The „*Ochrona atmosfery i ochrona przed hałasem*" ("Air quality and noise protection") dedicated axis by Regional Fund for Environmental Protection and Water Management (WFOŚiGW) in Katowice which organises calls for the implementation of innovative and environmentally friendly energy generation distribution projects. The support offered could cover up to 90% of the qualified costs with a loan with partial remission (10% or 30% if the funds will be used for another environmental investment).

Moreover, there are programmes that are expected to offer support in the future which are the Infrastructure and the Environment (https://www.pois.gov.pl/en/) Regional Operational Programmes for Silesian voivodship and from modernisation Fund established based on the 2% of the revenues from CO_2 emission allowances auctions.

10.4.4 Future outlook

For the chosen area other solutions could also be considered including different optimisation options or changing the scope of the study. This could be evaluated with a different approach - setting the buildings and paths as optional and allowing the tool to optimise the connections.

To limit the impact of the individual coal boilers used in the chosen area on the air quality other heating solutions could be considered. Further insight into the costs of the gas network expansion, possibilities, and costs for the use of renewable sources would be helpful for the comparison with the network solution. A more advanced case could be built with THERMOS with this additional information, also considering the emission factors.

10.4.5 Scope for replication

The case study prepared presents an approach for analysing the expansion of an existing network in a chosen area. This could be replicated by other network operators on a similar scale. The data inputs required by the tool will likely not be challenging for the operators to obtain as most of them could be taken from their standard practice. Some parameters like costs included in the tariff will depend on the groups targeted or how the tariff is defined. The production costs may be difficult to estimate for the whole period of the analysis. Some additional assumptions have to be made in that regard in the early stage (for example, how the fuel/electricity costs are estimated to change over time or how the CO_2 price will impact the solution within the analysis period). In some cases, it can also be beneficial to make a sensitivity analysis by recalculating the case based on different costs. It should be noted that in most cases the tariffs and production costs should be analysed together as the costs strongly impact the tariffs.

The common problem for the expansion of the existing network is the uncertainty of whether the clients will be willing to connect to the network. The case of Żywiec presents how to account for such a situation using the tool. It could be done by setting part of the consumers as forbidden in the tool simulating the lack of will to connect to the network. The results obtained could be used to estimate the risk of this factor on the success of the project.

In the case study the way of accounting for different less typical dynamic parameters was used, which could be followed in other cases. This approach could be very flexible and used in many different use cases. The presented solution required a recalculation of the dynamic inputs through an iterative process to receive theoretical parameters that could be input in the tool that would result in similar outcomes as the use of all dynamic parameters together.

11 Annex – Working on Case Studies with THERMOS

The development of the case studies presented in this report lasted more than six months and involved staff from several organisations across Europe. It was an exciting experience that allowed all people involved to learn about real world district heating and cooling solutions and their deployment. Also, this experience has further allowed us both to improve the THERMOS tool and to further explore and understand its capabilities.

In the following sections we offer an overview of the common problems that may be encountered while using the tool to identify and assess DHC opportunities, with the aim to provide support to its users.

11.1 Common problems faced in the development of the case studies

The problems identified have been divided in three different categories, depending in whether they are related with the use of GIS tools, with the availability and preparation of the data, or with the THERMOS tool.

GIS tools and data

During the development of the case studies presented in this document, the free open source QGIS[20] software has been used and has proven to be a very useful tool to manage and prepare the data for uploading it to THERMOS. In some of the cases, the users did not have any previous experience using GIS, and for this reason developing the files in the specific format was a little time consuming. Also due to the same reason, in some of the case studies, there were some issues with the final location of the elements, which was easily fixed by changing the project's spatial reference system to a more specific one. Even when the users did have experience using GIS, sometimes the original information came in CAD format and there is not a rapid and direct tool to convert this data, so this process can be tedious and time-consuming.

Also, the limited experience of some modellers with GIS techniques required technical support to import shape files into THERMOS.

The spreadsheet download and upload facility in THERMOS proved very useful to enable further manipulation and assessment of data outside of the model. However, there was some difficulty in cross-referencing specific pipes ID from the spreadsheet with those in the model, so accurate identification of pipes was not always possible.

[20] https://qgis.org/en/site/

Availability and treatment of the data

In some of the case studies not all the data was available from the beginning and, with the benefit of hindsight, the approach to the analysis may have been improved if all the information were available from the start. Unfortunately, this was not the case for all the projects, and time constraints prevented a replication analysis using the additional data.

The EcoCongost case study revealed a set of challenges regarding the information and data collection process from the different stakeholders involved in the ecosystem. When obtaining information regarding energy demands, a variety of problems were encountered:

- **Industrial heating demand benchmarking**: business activities are registered under various CNAE (National Classification of Economic Activities) rendering the task laborious. Furthermore, the real demand of certain industrial activities may not involve a thermal demand despite having a CNAE which does have an associated consumption, leading to inaccurate results and important deviations in industries that have surface areas within their buildings which are used for purposes other than the industrial production process itself (e.g., warehouses, labs, etc.);
- **Sanitary hot water benchmarking**: there is scarce information regarding worker data, and the consumption forecast is very oversized for small and micro-companies or for non-industrial activities;
- **Ambient heating demand**: all the available surface areas do not always correspond to areas which require ambient heating, which has a significant impact on the global demand;
- **Peak demand definition**: the calculations of the tool in order to define the peak demand of the space heating is not useful when considering the industrial demand, which is usually smaller.

When collecting real data for industrial users, the number of companies who have accurate information is limited, and those who do have the information are sometimes hesitant to share this data, as it usually is proprietary. The same is true for sanitary hot water and ambient heating demand since many companies do not monitor this parameter.

Also, for industrial modelling, the freely available Open Street Map information may not be accurate since the geometry of most industrial buildings is currently missing and other public facilities are not well defined either. Therefore, it is recommended to develop the local geometry in GIS and upload it to the THERMOS tool.

During the development of the Kyivska case study it was noticed that when integrating volatile and seasonally varying renewable generation such as solar thermal energy, a simulation of supply (and demand) data on an hourly basis is necessary. Load curves for supply and demand usually exist in the form of MS Excel data. The integration of these can increase the precision of the input data and would improve the value of the results for renewable technology integration. Also, the integration of default values for renewable fuels and energy technologies (technology and cost data) can help to make quick and realistic assumptions for a fast mapping of renewable energy solutions. The integration of small capacity sizes normally applied for renewable technologies and in local grids would facilitate renewable integration scenarios.

In other projects, the most tangible issue found was related to the lack of awareness regarding technical areas of the problem. An example of a related field that would need expert knowledge could be networks using geothermal energy, as geothermal heat pumps expertise was needed on top of the DHC networks one. For this type of projects, it could be interesting obtain an external study, performed by a technical expert, that could be used to confirm the obtained results, which usually are pretty accurate.

Moreover, sometimes accounting for different dynamic cost parameters related to the investment was quite time consuming. This was the case with Żywiec project, the process required additional calculations to convert the dynamic values to fit the tools' input. This process was followed to input the pipework costs. In this part the annual tax of 2% of the initial value of the pipework, the costs of the loan and depreciation were considered. The annualization of the costs in the objective section was used for that purpose. A theoretical period and rate were calculated outside the tool, so the final values considered in the case study (total costs and present value) are similar to the ones obtained from the original dynamic parameters.

Another significant issue would be that there is no obligation for the consumers to connect to the network and the decision could be made based on factors other than financial ones. More insight as to what decisions the customers will take regarding their connection to the network could be useful for a better evaluation. In order to estimate the costs and benefits when not all buildings are connected, additional maps with different restrictions can be created. In some case studies, such as the Zywiec project, the analysis showed that the decision whether to connect buildings or not was made randomly.

In some cases, it could be useful to evaluate expanding the gas network and connecting the buildings to it (to use individual gas boilers to limit the emissions) as an alternative to connecting them to the DH network. The direct costs of such a solution are difficult to estimate. To account for that, additional costs must be assigned to the individual solutions.

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For certain types of projects, such as the one related to Barrio La Pinada case study, which does not aim for maximum profitability but for an affordable tariff, an iterative process is needed. First, the tariff must be established and then, once the project is deemed profitable, it can be gradually reduced until it matches the development's minimum profit.

In the case of Ecocongost, one of the first challenges faced during this case study was the fact that an industrial steam network could not be optimized and evaluated by the THERMOS tool.

However, thanks to the development of this case study the THERMOS tool has been adapted and improved, rendering the option of adding a steam network available.

Also, the THERMOS tool has been designed to be as versatile as possible, but sometimes this creates an issue of its own. When trying to model specific technologies which have peculiarities, such as the geothermal one, it might be difficult to correctly assign some of the parameters to the variables used by the tool.

Finally, it has been noticed that the ratio between peak and annual energy demand of a building can have a great impact on its inclusion in the network. This occurs because the tool identifies that a considerable amount of supply capacity must be saved in order to satisfy peak demands, and the annual demand, and the associated revenue, may not justify its inclusion.

Applying THERMOS in areas which do not include LIDAR data results in quite inaccurate demand estimates. For a case study analysing the validity of the THERMOS tool in a relatively small area of the city, this is not a problem, as demand information can be adjusted manually for each building. Nevertheless, the lack of LIDAR data among other demand estimation methods, could prove to be an issue for larger projects, for this reason THERMOS offers the possibility to the user of adding LIDAR information.

11.2 Recommendations and solutions

GIS tools and data

As mentioned before, QGIS has been widely used for the development of the case studies and it is a recommended software to use for these purposes.

For new developments, GIS files for buildings can be easily created by importing the CAD files and using the "lines to polygons" tool in QGIS. This changes for paths, as the imported depiction shows more than one line per road, so it is easier to create a new layer and draw them from the beginning. In this way it is fair to say that THERMOS users can benefit from learning some basic GIS skills, or alternatively arranging for accessible technical support in this area. This can help considerably in supplementing and manipulating data within THERMOS, particularly where data could only be inputted in GIS format.

A good practice applicable when working with the THERMOS tool is to check the files format to match the required one: polygons or multipolygons for buildings; lines or multilines for paths. In case the user is having issues to upload the GIS files in a certain format, changing it from Geojson to shapefile or vice versa may help to solve the issue.

Availability and treatment of the data

Regarding data preparation for specific technologies, it is recommended to spend some time designing a methodology or thinking about how to input the data. It is useful to bring all your economic parameters in an excel spreadsheet where you can modify them easily and then, once the results are consistent, input them into the tool.

For entering cost data in the tool, it is recommended to separate costs related to supply power, such as boilers, heat pumps, pumping stations, from the ones that are not, like civil costs. Once this classification is made fixed costs are obtained, while power related costs can be divided by the total installed power, thus establishing the capacity costs.

When having your economic data on an excel spreadsheet, it tends to be useful to assign an ID to buildings on QGIS similar to the one used in the project. This ID should also be entered on the spreadsheet, enabling the use of QGIS functionality "Links" to quickly match the values on excel with the polygons from the GIS files.

Another useful recommendation is that, when planning the expansion of the network in a specific area, the people responsible for the design might want to make calculations taking into regard possible future scenarios: for instance, to understand whether it is feasible to include bigger pipe diameters for some parts of the network for future potential in nearby areas.

Lastly, regarding the replicability of the projects and to improve it for future case studies considering ambient heat demand, it is important to fully understand and have concrete data regarding the building's climate control energy needs. For example, some buildings (such as warehouses) may not require heating or cooling demand. If all buildings are assumed to need an ambient heating and cooling demand, erroneous conclusions regarding total demand may be reached. In addition, having an efficient monitoring of sanitary hot water demand and availability of real data regarding industrial demand can be very helpful to simplify the design of the district heating network.

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When performing an iterative process is required, it is recommended to first develop a general project and develop the iterations by modifying the desired parameters and then changing the project's name. An alternative way to set general parameters (found in the left side menu) is to download the excel data spreadsheet to then upload it to a new map. The difference between these two methods is that, while the first keeps both the parameter and the map constraints, the second one does not, forcing the user to input supply data and map constraints every time a new map is created.

Also, when developing multiple tests, it is recommended to note the changes in the projectname, instead of "Test 1" a more appropriate way to name it would be "Test 1 – Reduced tariff". In case we are modifying a specific parameter, it is better to input the value for it, so that it will be easier to identify each case. Using the last example, the proposed name for the project would be "Test 1 – Reduced tariff (3,3)".