SET HEAT

Supporting Energy Transition
and Decarbonisation
in District Heating Sector

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Publishable report from sensitive deliverables of Work Package 3

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1

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Summary

This document presents the results of the activities carried out within WP3 of the LIFE22-CET-SET_HEAT Project, tasks 3.1, 3.2, 3.3 and 3.4. All activities in those tasks resulted in sensitive deliverables, which are summarised in this document. In particular, the sensitive deliverables are:

- D3.1 (D17) Report on technical options for investment projects
- D3.2 (D18) Report on definition of model investment projects
- D3.3 (D19) 6 technical prefeasibility studies of model investment projects
- D3.4 (D20) Report on DH network performance, recommendations and guidelines for network technical interventions
- D3.5 (D21) Technical risk assessment report.

The work package was titled *Definition of potential investment projects and technical feasibility assessment*. Its specific objectives were:

- To pre-design technological solutions for the integration of low-grade renewable energy and waste heat sources;
- To perform necessary pre-feasibility studies in order to prove technical performance and to identify technical risks;
- To generate qualitative data, which are necessary for further financial, economic, environmental and other studies;
- To formulate technical guidelines to be used for replication and dissemination activities.

The results of WP 3 consist of technical documentation of model investment projects, that make the basis for the replication and development of investment plans for district heating companies participating in the SET_HEAT initiative.

All work package activities took place from March 2024 to December 2025, which was 4 months longer than initially planned. The long duration resulted from the number of activities and their overall complexity.

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Nomenclature

AHP	Absorption heat pumps
ASHP	Air source heat pumps
CSTT	Concentrated solar thermal technologies
DGS	Deep geothermal systems
DH	District heating
ETSC	Evacuated tube solar collectors
FSC	Flat solar collectors
GSHP	Ground source heat pumps
HTTES	High temperature thermal energy storage
LWWHS-G	Low-temperature waste heat recovery from gasses (including H_2O condensing systems)
LWWHS-L	Low-temperature direct waste heat recovery from liquids
MCDA	Multi-criteria decision analysis
PTSC	Parabolic trough solar collectors
PVT	Photovoltaic thermal panels
SHS	Large scale heat storage - seasonal storage
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TTES	Heat storage tanks - short-term storage
WSHP	Water and wastewater source heat pumps

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1. Introduction

The ambitious EU climate and energy policy, which is setting targets and pushing towards decarbonization and climate neutrality in 2050, has placed DH systems at the forefront of urban, green energy transition. These systems play a pivotal role in mitigating climate change, ensuring energy security and affordability for citizens. This is because DH offers a unique opportunity to integrate local renewable and waste energy sources and improve energy efficiency at the city level.

On the other hand, since DH is deeply embedded in the socio-economic system and built environment, the energy transition and decarbonisation of DH assets at the local level trigger serious technical, economic and social challenges. Considering the scale of the required change, relatively short timeline, state of play, technological and infrastructural constraints, socio-cultural factors, and scarce capital and other resources, it can be concluded that in many EU member states, the goals may be difficult to achieve.

In the SET_HEAT Project countries Croatia, Lithuania, Poland, and Romania the transition progresses relatively slowly, and since the European strategy for district heating and cooling (DHC) was announced in 2016, no major change has happened in the sector. Although many DH companies have recently initiated investment projects focused on renewables and waste heat, the decarbonisation potential is largely untapped, and the share of clean technologies in heat production is still relatively small. The main reasons for this are the complexity and multidimensionality of the energy system planning process. It is also important that the tactics to achieve the strategic targets, the EU policymakers have left to individual decision-makers at the company and municipality levels, who must overcome existing barriers, look for opportunities and address threats to devise future-proof solutions under uncertain boundary conditions.

An effective energy transition and decarbonisation of DH systems requires a significant shift from fossil fuels to local resources. Depending on local conditions, the structure of the primary energy mix of a given DH system can vary greatly. The announced strategies of such cities as Berlin, Amsterdam, Copenhagen, Vienna and several others revealed that the future primary energy mixes will be highly diversified and DH systems will become very complex structures. This is mainly due to the scarcity of resources such as renewable and waste heat and land or other space, such as suitable parcels or building rooftops, in dense built urban environments. In general, an energy harvesting strategy must be implemented in each case. On the other hand, the number of potential types of heat sources are relatively small, and projects of individual types are usually multiplied by implementing them in various locations.

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Examples include the implementation of solar collectors, air source heat pumps, heat recovery from supermarkets or shallow geothermal systems.

Current projects tend to focus on large sources such as waste-to-energy plants, sewage treatment facilities, solar thermal installations, and large industrial sites. Smaller, distributed heat sources, especially low-temperature ones, receive less attention. These sources are often used onsite, reducing consumers' reliance on DH systems. However, integrating small-capacity sources may be essential to achieve and maintain the status of an efficient DH company, as defined by the revised Energy Efficiency Directive. Large-scale heat storage, including seasonal storage, will also play a vital role.

Despite similarities among systems and projects, new strategies and investments are often planned as unique, tailor-made solutions. This siloed approach demands considerable time and financial resources, which many municipalities and DH companies lack. A coordinated approach to large-scale DH energy transition planning is needed. Such an approach should prioritise collaboration, knowledge exchange, and implementation of replicable technical and non-technical solutions. Replication and standardisation can streamline planning, reduce costs, improve quality, facilitate communication, and ultimately accelerate investment and transition processes.

The replicability of a project, process or approach is defined as the ability to reproduce it across different contexts. It ensures that proven solutions can be adapted and implemented in various locations with minimal modifications. Standardisation entails the establishment and execution of consistent procedures and criteria. In principle, a wide range of elements within the domain of DH are conducive to standardisation and replication.

In the SET_HEAT Project, replication and standardisation are pivotal to the strategy for achieving large-scale real change. For instance, the project's tasks included the development of a standardised approach and methodology, which resulted in the framework document, Handbook for planning and development of investment projects. The central concept of the SET_HEAT Project is to develop a set of replicable model investment projects. To define such projects, a multi-criteria parametric assessment was carried out within the group of preselected technologies. Then, the preselected projects were addressed with detailed pre-feasibility studies to identify their complexity and provide district heating companies with guidelines for further development.

The development of these models aims to overcome the barrier of limited access to specific technical information and guidelines that make it difficult for district heating companies to plan the implementation of particular technological solutions. It is expected that they will form the basis for internal replication within the DH systems directly targeted by the project and the development of investment plans. In this way, a real change is supposed to be triggered.

2. Technical options for investment projects

The integration of low-grade and waste heat sources into district heating (DH) networks is crucial for advancing energy efficiency and decarbonization. In this work, various technology options have been explored for replicable projects across different regions, focusing on low-temperature district heating technologies such as solar collectors, heat pumps, and thermal storage systems. These technologies, including water and wastewater heat pumps (WSHP), air source heat pumps (ASHP), flat solar collectors (FSC), and others, are analysed from different perspectives to determine their suitability for different DH systems.

Within the report, based on the outputs of SET_HEAT project work package WP1, technical options are defined for the considered DH systems. The work focuses on matching the characteristics of systems, distributed sources of heat, and available technologies. The analysis focuses on replicable projects that could be implemented in different regions by different DH companies. In order to make the assessment as comprehensive as possible, taking into account both the scientific and innovation potential of the technology and the actual conditions in DH companies, the assessment is carried out at three levels:

- Applying the TOPSIS multi-criteria assessment
- Analysis of technologies vs local heat maps, which have been compiled for the WP1 phase
- Analysis of suitability of technologies vs investment projects.

This allows a comprehensive assessment of the technologies and reveals the most suitable projects for replication.

2.1. Technology options

Technical options are defined for considered DH systems, and model (typical) investment projects dedicated to the integration of low-grade and waste heat sources in DH networks. These technology options focus on replicable projects that could be implemented in different regions by different DH companies.

Such low-temperature district heating technologies are further analyzed:

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- **FSC (Flat Solar Collector)**: Solar panels that absorb sunlight to heat water, used in residential and commercial heating.
- **ETSC (Evacuated Tube Solar Collectors)**: Vacuum-sealed tubes that capture solar heat more efficiently, especially in colder climates.
- **PTSC (Parabolic Trough Solar Collectors)**: Curved mirrors that focus sunlight onto a tube to generate heat, commonly used in industrial processes.
- **CSTT (Concentrated Solar Thermal Technologies)**: Systems that use mirrors to concentrate sunlight and generate electricity or heat.
- **PVT (PV-Thermal Panels)**: Panels that generate both electricity and heat from sunlight, maximizing energy output.
- **WSHP (Water and Wastewater Source Heat Pumps)**: Extract heat from water sources for heating and cooling.
- **GSHP (Ground Source Heat Pumps)**: Extract heat from the ground, providing efficient heating and cooling.
- **ASHP (Air Source Heat Pumps)**: Extract heat from outside air for indoor heating and cooling.
- **AHP (Absorption Heat Pumps)**: Use heat instead of electricity to drive cooling or heating processes, often using waste heat.
- **DGS (Deep Geothermal Systems)**: Tap deep underground heat for electricity and direct heating.
- **LWWHS-L (Low-Temperature Waste Heat Recovery from Liquids)**: Captures heat from cooled liquids in industrial processes.
- **LWWHS-G (Low-Temperature Waste Heat Recovery from Gases)**: Captures heat from exhaust gases by condensing water vapor.
- **TTES (Heat Storage Tanks - Short-Term Storage)**: Stores thermal energy for short periods, typically in hot water tanks.
- **SHS (Large Scale Heat Storage - Seasonal Storage)**: Stores heat for months, balancing seasonal supply and demand.
- **HTTES (High Temperature Thermal Energy Storage)**: Stores high-temperature heat for industrial uses or energy production.

All technologies have been analysed in detailed in the SET_HEAT project's **Catalogue of technologies and vendors (D1.7)**.

2.2. Methodology

The technology assessment considers three approaches:

- scientific - using the multi-criteria analysis method TOPSIS,
- theoretical - by assessing the heat maps of the areas concerned, and
- practical - by assessing the planned investment plans and interest in specific technologies of DH companies.

This results in the final ranking list. The whole process can be divided into few main steps:

- Definition of assessment criteria,

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- Survey of indicators: expert assessment is used,
- A list of indicators and weights,
- Finding criteria values of the technologies,
- Implementing MCDA using TOPSIS method and making a ranking list using MCDA,
- Survey among DH companies on interest in specific technologies (ranking of interests),
- Assessment of potential impact resulted from heat maps (ranking of impact potential),
- Building final ranking list.

A flowchart for identifying the final list of selected technologies is presented in Fig. 4.1.

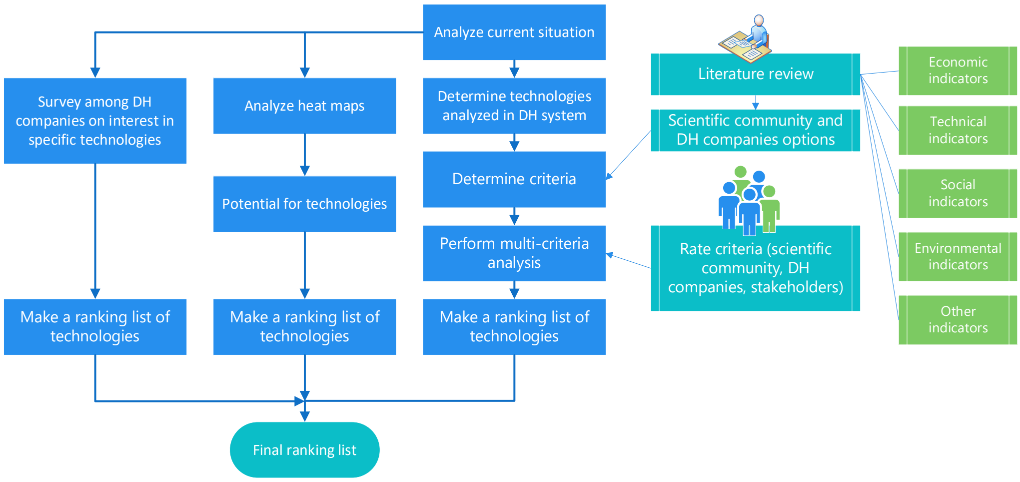

Fig. 4.1. A flowchart for identifying technical options for investment projects

This then allows the most appropriate technologies to be selected for development, analysed and appropriate investment plans to be drawn up.

2.2.1. Assessment criteria

Selecting the right criteria is crucial for conducting a proper analysis. The chosen criteria should be pertinent to the specific area of study and include technical, economic, and social indicators to effectively assess the efficiency, cost, and appropriateness of each district heating (DH) system. Additionally, the criteria should be independent of one another to reduce redundancy and streamline the model [2].

As a starting point, a review of the evaluation criteria used in the energy sector was carried out. They were grouped into the following categories:

- Technical indicators, process quality and implementation related indicators

- Financial and economic indicators
- Social indicators

Technical, process quality and implementation related indicators are presented in Table 2.1.

Financial and economic indicators are presented in Table 2.2. In addition, one of them includes avoided CO_2 emissions costs.

Several social indicators were also identified and are listed in Table 2.3.

Table 2.1. Technical, process quality and implementation related assessment indicators

No	Proposed assessment indicator	Symbol	Unit	Description
1.	Maximum size	S_{max}	MW	How big the installation can be. Maximum size limitation
2.	Minimum size	S_{min}	MW	How small the installation can be. Minimum size limitation
3.	Share of electric energy in heat production	*SEE*	%	The percentage of electric energy in the final product (heat)
4.	Share of renewable energy sources	*SRES*	%	0-100%, 0 - no renewable technology used, 100 - only renewable energy used
5.	Operational reliability	*R*	%	Typical time of operation / expected time of operation; indicated the number of unexpected outages
6.	Maximum supply water temperature	T_{max}	°C	The maximum temperature the technology in question may provide
7.	Maturity of the technology/	*TRL*	[-]	Technology indicator from TRL 1 (conceptual) to TRL9 (commercial)

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	Technology readiness level			
8.	Lifespan/ Economic lifetime	*Lf*	years	Overall expected period of exploitation
9.	Suitability for base load coverage	*BLCC*	[-]	Yes/No; If the technology in question can run all over the year
10.	Suitability for peak load coverage	*PLCC*	[-]	Yes/No; If the technology in question can run under severe winter conditions and high heating loads
11.	Land use area	*LU*	m^2/kW	This criterion quantifies the area occupied [3,4]
12.	Dependence on ambient conditions	*ACD*	[-]	Yes/No; Shows if achievable output in MW drops with ambient temperature
13.	Service requirement	*SR*	[-]	0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high
14.	Degree of automation	*DA*	[-]	Very low - human operator is required/Low/Medium/ High / Very high - fully automatic
15.	Replicability	*RP*	[-]	Very low - special conditions required, cannot be installed everywhere/Low/Medium/ High / Very high - no special conditions required (e.g. geology) and can be installed anywhere
16.	Complexity of installation	*CP*	[-]	Very low - simple technology easy to install/Low/Medium/ High / Very high - complex technology with many components of the system
17.	Flexibility	*F*	[-]	Ability of part load operation and ability to work

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				under variable ambient and grid temperatures. 0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high
18.	Safety	*Sf*	[-]	Very low - requires special supplementary installations to provide safety/Low/Medium/ High / Very high - fully safe, no additional equipment is required
19.	Expected working time /Availability	*A*	Hours/a	The expected annual time of technology use

Table 2.2. Proposed financial and economic indicators

No	Proposed assessment indicator	Symbol	Unit	Description
1.	Specific capital expenditures	*CAPEX*	€/kW, €/GJ	Specific investment expenditure related to process performance. For storage regarded as per GJ
2.	Specific fixed operational expenditures	*OPEXf*	€/GJ	Sum of fixed operating costs per total heat production of the technology in GJ
3.	Specific variable operational expenditures	*OPEXv*	€/GJ	Sum of variable operating costs per total heat production of the technology in GJ
4.	Levelized cost of heat	*LCOH*	€/GJ	This indicator determines the product's costs (heat in this case) resulting from CAPEX, OPEX and the annual production
5.	Avoided CO2 emissions costs	*CCO2,av*	€/GJ	Avoided cost of CO2 that results from replacement

				of CO_2 production technologies and compensation that is needed fo deliver the same amount of heat to the networks.
6.	Number of competing suppliers/vendors	*NCP*	[-]	0- Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high

Table 2.3. Proposed social indicators

No	Proposed assessment indicator	Symbol	Unit	Description
1.	Level of social acceptance	*SA*	[-]	Very low - protests expected/Low/Medium/ High / Very high - easily acceptable
2.	Occurrence of social costs	*SC*	[-]	Very low - no external social costs/Low/Medium/ High / Very high - social costs can be identified (e.g. increase of electricity prices)
3.	Popularity /number of references	*P*	[-]	0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high

2.2.2. Survey of indicators

A survey (see Fig. 2.2) for the project partners was formulated, covering 28 different indicators. The survey required first selecting whether an indicator was relevant and then giving it a weight, which could vary within 0-1. Meaning of weights for selected indicator:

- 0.01 - indicator of little or no relevance to the decarbonisation of fossil-fuel-fired district heating systems;
- 1.00 - indicator of high (key) importance in the context of the decarbonisation of the district heating systems.

The survey was attended by DH company representatives, researchers and members of the Project Advisory Board.

The number of respondents who rated the indicator as important at all was measured by selecting only the "Yes" or "No" option. It should be noted that there was no indicator that did not receive a "No" from all respondents. In addition, one indicator - Maximum supply water temperature - was rated by all respondents as one to be considered. The distribution of all proposed indicators in the 1-0 range, under the "Yes" and "No" options, is shown in Fig. 2.3.

As can be seen, 10 indicators were chosen by most of the experts interviewed (Fig. 2.3). These have included most of the financial, technical and implementation related indicators. In descending order, the list would be:

1. Maximum supply water temperature
2. Share of electric energy in heat production
3. Share of renewable energy sources
4. Lifespan
5. Specific capital expenditures
6. Specific operational expenditures (fixed and variable)
7. Land use area
8. Levelized cost of heat
9. Suitability for peak load coverage and
10. Flexibility.

This survey is intended to select indicators and their importance (weights) for a ranking list of technologies for the decarbonisation of district heating technologies. In addition, it is proposed to introduce indicator weights ranging from 0 to 1.

Meaning of weights for selected indicators (cannot be 0)
0.01 - indicator of little or no relevance to the decarbonisation of fossil-fuel-fired district heating systems
1 - indicator of high (key) importance in the context of the decarbonisation of the district heating systems

No.	Proposed assessment indicator	Symbol	Unit	Decription	Please select if you think it should be used	Specify the value of weight (0.01 - 1)	Your comments
	Technical indicators						
1	**Maximum size**	S_{max}	MW	How big the installation can be. Maximum size limitation	Yes		
2	**Minimum size**	S_{min}	MW	How small the installation can be. Minimum size limitation	Yes		
3	**Share of electric energy in heat production**	SEE	%	The percentage of electric energy in the final product (heat)	Yes		
4	**Share of renewable energy sources**	SRES	%	0-100%, 0 - no renewable technology used, 100 - only renewable energy used	Yes		
5	**Operational reliability**	*R*	%	Typical time of operation / expected time of operation; indicated the number of unexpected outages	No		
6	**Maximum supply water temperature**	T_{max}	°C	The maximum temperature the technology in question may provide	Yes		
7	**Maturity of the technology/ Technology readiness level**	*TRL*	[-]	Technology indicator from TRL 1 (conceptual) to TRL9 (commercial)	Yes		
8	**Lifespan/ Economic lifetime**	*Lf*	years	Overal expected period of exploitation	Yes		
	Financial indicators						
9	**Specific capital expenditures**	CAPEX	€/kW, €/GJ	Specific investment expenditure related to process performance. For storage regarded as per GJ.	Yes		
10	**Specific fixed operational expenditures**	OPEXf	€/GJ	Sum of fixed operating costs per total heat production of the technology in GJ	Yes		
11	**Specific variable operational expenditures**	OPEXf	€/GJ	Sum of variable operating costs per total heat production of the technology in GJ	Yes		
12	**Levelized Cost Of Heat**	LCOH	€/GJ	This indicator determines the product's costs (heat in this case) resulting from CAPEX, OPEX and the annual production	Yes		
	Economic indicators						
13	**Avoided CO2 emissions costs**	$CCO_{2,av}$	€/GJ	Avoided cost of CO2 that results from replacement of CO2 production technologies and compensation that is needed fo deiver the same amount of heat to the networks.	Yes		
14	**Expected working time /Availability**	A	hours/year	The expected annual time of technology use	Yes		
	Process quality and implementation related indicators						
15	**Suitability for base load coverage**	BLCC	[-]	Yes/no; If the technology in question can run all over the year	Yes		
16	**Suitability for peak load coverage**	PLCC	[-]	Yes/no; If the technology in question can run under severe winter conditions and high heating loads	Yes		
17	**Land use area**	LU	m^2/kW		Yes		
18	**Dependence on ambient conditions**	ACD	[-]	Yes/no; Shows if achievable output in MW drops with ambient temperature.	No		
19	**Service requirement**	SR	[-]	0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high	No		
20	**Popularity /number of references**	P	[-]	0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high	No		
21	**Number of competing suppliers/vendors**	NCP	[-]	0- Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high	No		
22	**Degree of automation**	DA	[-]	Very low - human operator is required/Low/Medium/ High / Very high - fully automatic	No		
23	**Replicability**	RP	[-]	Very low - special conditions required, cannot be instaled everywhere/Low/Medium/ High / Very high - no special conditions required (e.g. geology) and can be installed anywhere	No		
24	**Complexity of installation**	CP		Very low - simple technology easy to install/Low/Medium/ High / Very high - compex technology with many components of the system	No		
25	**Flexibility**	F	[-]	Ability of part load operation and ability to work under variable ambient and grid temperatures. 0 - Very low/0.25 - Low/0.5 - Medium/ 0.75 - High / 1 - Very high	Yes		
26	**Safety**	Sf	[-]	Very low - requires special supplementary installations to provide safety/Low/Medium/ High / Very high - fully safe, no additional equipment is required	No		
	Social indicators						
27	**Level of social acceptance**	SA	[-]	Very low - protests expected/Low/Medium/ High / Very high - easily acceptable	No		
28	**Occurance of social costs**	S.C.	[-]	Very low - no external social costs/Low/Medium/ High / Very high - social costs can be identified (e.g. increase of electricity prices)	No		

Fig. 2.2. Example of the survey

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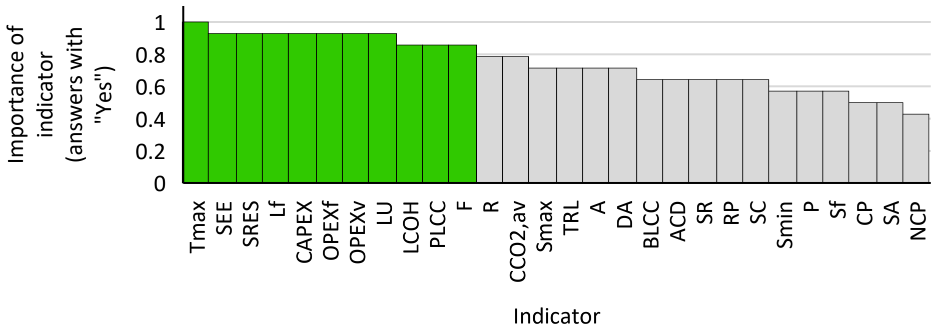

Fig. 2.3. Indicator weighting by selecting Yes and No options (blue >0.8, grey <0.8)

2.1. Key indicators and their weights

The survey also asked respondents to rate the importance of the selected indicators. The average importance of the 10 key indicators in the 0-1 range is given below.

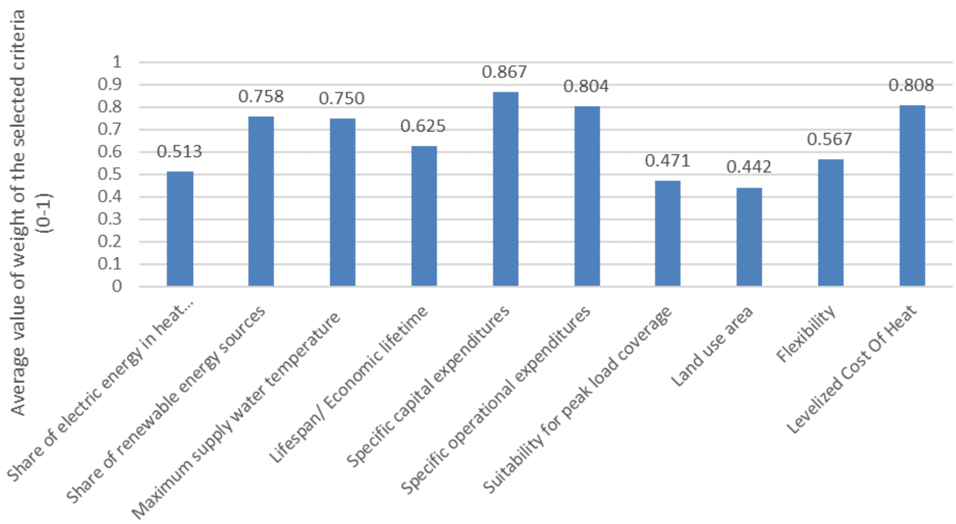

Fig. 2.4. The average importance of the key indicators/criteria

The weights of these criteria were normalised to prepare them for further use in multicriteria analysis. Their percentage distribution is shown in Fig. 2.5 (the sum of the importance of all the criteria adds up to 100 percentage).

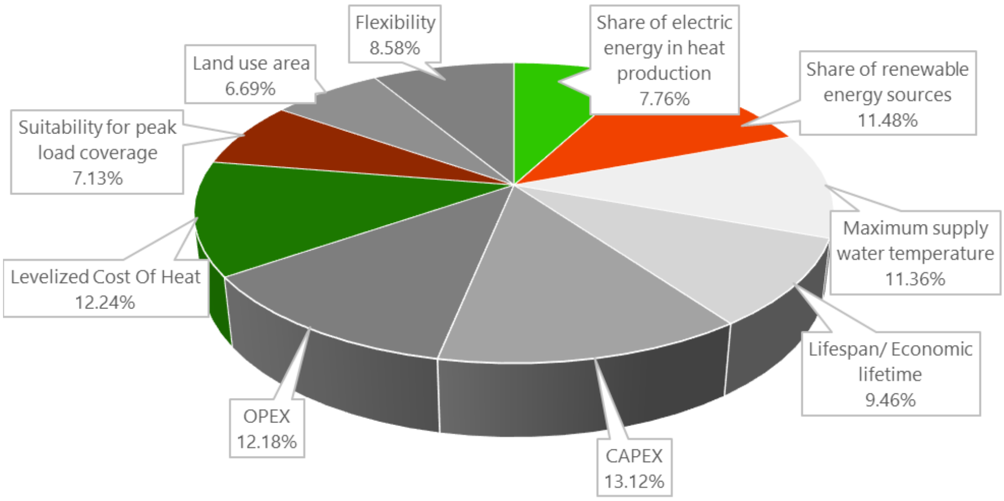

Fig. 2.5. Assessment of the importance of the criteria

CAPEX, OPEX and levelized cost of heat represent 37.54% of the total valuation. The criterion with the lowest weight was Land use area (6.69%) and the criterion with the highest weight was CAPEX (13.12%).

2.3. Analysis of criteria values of the technologies

Given the importance of the criteria, it is necessary to collect the actual values of the relevant technologies. This is done on the basis of both scientific references, various catalogues, project reports, etc.

In many cases, individual technology indicators can vary considerably depending on the specific technology chosen, the scope of implementation, the specificity of the location, etc. For example, criteria such as CAPEX and OPEX depend on

- Specific type of technology chosen,
- Project scale (smaller projects may face higher per-unit costs due to the lack of bulk purchasing and other efficiencies),
- Characteristics of geographic location (resources availability, infrastructure in region, local labour costs),
- Regulatory and policy environment (incentives, subsidies, costs associated with obtaining permits),
- Financing conditions (e.g. investors' expectations),
- Operational efficiency (maintenance practices, different schedules),
- Market conditions (supply chain variability, competition in market),
- Specific requirements.

A lot of data on this is provided in the Project report **D1.7. Catalogue of technologies and vendors.** There was also use in the work the Catalogues of Technologies developed by the Danish Energy Agency (available at: https://ens.dk/en/our-services/technology-catalogues).

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Below is a table summarising the matrix of values for the 15 technologies and the 10 evaluation criteria, showing the variation of the respective criteria. The references for the respective technologies are also given.

Table 2.4. Technologies and the limits of their evaluation criteria

No	Technology short name	SEE	SRES	T_{max}	Lf	CAPEX	OPEX	LCOH	PLCC	LU	F	Ref.
		%	%	°C	years	€/kW, €/GJ	€/GJ	€/GJ	Yes/No	m2/kW	0-1	
1	FSC	0	100	60-120	20-25	300-550	1.11-1.75	6.95-14.13	No	2.2-2.7	0.25	[5,6], [7], [8], [9]
2	ETSC	0	100	250	20-25	556-1667	1.27-2.00	10.28-20.8	No	3.0-8.0	0.25	[7], [8], [9]
3	PTSC	0	100	450	25-30	2000-5000	2.50-3.00	20.00-50.00	No	5.0-20.0	0.25	[7], [8], [9,10]
4	CSTT	10	100	450	25-30	4000-15000	1.41-4.28	10.59-32.14	No	10.0-30.0	0.25	[7], [8], [9]
5	PVT	50	100	80	25-30	2200-4200	6.85-11.66	51.42-87.56	No	4.0-12.0	0.25	[7], [8], [9]
6	WSHP	20-30	70-80	60	20-25	800-1500	4.00-10.00	20.00-40.00	Partially	1.0-3.0	0.50	[11–14]
7	GSHP	20-30	70-80	65	20-25	1000-2500	3.00-12.00	10.00-30.00	Partially	0.2-1.7	0.50-0.75	[11–13]
8	ASHP	30-40	60-70	55-60	15-20	800-1500	5.00-10.00	20.00-50.00	Partially	0.1-0.5	0.50-0.75	[11–13]
9	AHP	5-10	5-100	90	15-25	1000-2500	5.00-15.00	15.00-50.00	Partially	0.1-0.7	0.50	[11–13,15]
10	DGS	1	100	90-150	30-50	1500-4000	4.07	10.00-30.00	Yes	0.2-0.5	0.50	[16–18]
11	LWWHS-L	5-10	0-100	90	15-20	600-1200	1.50-6.00	15.00-40.00	Yes	1.0-2.0	0.5-0.75	[19,20]
12	LWWHS-G	5-15	0-100	90	15-25	800-1500	2.00-10.00	20.00-50.00	Yes	1.0-3.0	0.5-0.75	[20–22]
13	TTES	0-15	100	95-100	20-30	100-300	0.10-2.00	10.00-50.00	Yes	0.5-2.0	1.00	[23–26]
14	SHS	0-15	100	90-95	20-40	50-300	0.10-1.50	10.00-50.00	Yes	0.3-3.0	1.00	[27,28]
15	HTTES	5-15	100	100-500	20-30	100-500	1.00-3.00	30.00-150.00	Yes	0.2-1.5	1.00	[24,29]

The multi-criteria evaluation of a project's technology requires the selection of only one criterion value, so below is a table of the values used in the calculations.

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Table 2.5. Technologies considered and numerical values for their indicators in TOPSIS method

No	Technology short name	*SEE*	*SRES*	T_{max}	*Lf*	CAPEX	OPEX	LCOH	PLCC	LU	F
		%	%	°C	years	€/kW, €/GJ	€/GJ	€/GJ	Yes/No	m2/kW	0-1
1	FSC	0.00	100.00	100.00	20.00	430.00	1.43	10.00	0.00	2.50	0.25
2	ETSC	0.00	100.00	150.00	20.00	1000.00	1.50	15.00	0.00	5.00	0.25
3	PTSC	0.00	100.00	400.00	25.00	4000.00	3.00	25.00	0.00	14.00	0.25
4	CSTT	10.00	100.00	450.00	25.00	9500.00	3.00	20.00	0.00	20.00	0.25
5	PVT	50.00	100.00	80.00	25.00	3200.00	8.00	65.00	0.00	8.00	0.25
6	WSHP	30.00	75.00	60.00	20.00	1000.00	8.00	40.00	0.50	1.00	0.50
7	GSHP	30.00	75.00	65.00	20.00	1500.00	10.00	25.00	0.50	1.50	0.75
8	ASHP	30.00	65.00	60.00	15.00	900.00	10.00	30.00	0.50	0.50	0.75
9	AHP	10.00	75.00	90.00	20.00	2000.00	5.00	35.00	0.50	0.50	0.50
10	DGS	1.00	100.00	120.00	30.00	3500.00	4.00	25.00	1.50	5.00	0.50
11	LWWHS-L	10.00	90.00	90.00	18.00	1000.00	4.00	35.00	2.00	2.00	0.75
12	LWWHS-G	10.00	90.00	90.00	20.00	1200.00	6.00	25.00	1.00	2.00	0.75
13	TTES	5.00	100.00	100.00	20.00	100.00	1.00	15.00	1.00	1.00	1.00
14	SHS	10.00	100.00	95.00	40.00	130.00	0.50	20.00	1.00	1.00	1.00
15	HTTES	10.00	100.00	300.00	30.00	180.00	7.00	50.00	1.00	1.00	1.00

Here: FSC – Flat solar collector; ETSC - Evacuated tube solar collectors; PTSC - Parabolic trough solar collectors; CSTT - Concentrated solar thermal technologies; PVT - PV-thermal panels; WSHP - Water and wastewater source heat pumps; GSHP - Ground source heat pumps; ASHP - Air source heat pumps; AHP - Absorption heat pumps; DGS - Deep geothermal systems; LWWHS-L- Low-temperature waste heat recovery from liquids; LWWHS-G - Low-temperature waste heat recovery from gasses (H_2O condensing systems); TTES - Heat storage tanks - short-term storage; SHS - Large scale heat storage - seasonal storage; HTTES - High temperature thermal energy storage.

2.4. Assessment tool - TOPSIS

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was proposed by Hwang and Yoon [30]. The method allows decision makers to find the optimal alternative that is closest to the ideal solution and as far away from the negative ideal solution as possible. The ideal solution represents a set of the highest achievable attribute values, while the negative ideal solution reflects a set of the lowest attribute values [3]. The TOPSIS method is an appropriate multi-criteria analysis method for analysis of DH systems as it is easy of use and provides comparable results to other more complex methods [2]. In addition, it should mention this method has efficient computation and ability to measure the relative performance of the alternative decisions. Taking into account the use of the TOPSIS method in engineering and energy in the scientific community, it can be seen (Fig. 2.6) that the use of this method is growing in popularity, indicating its suitability for solving the relevant problems in the DH field.

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The main advantages of the TOPSIS method are:

– **Simplicity and ease of use**
  - Straghtforward process: the steps of the method are simple, involving the normalization of data, weight assigment, and distance calculation.
  - Clear ranking: it provides a clear and interpretable ranking of alternatives based on their closeness to the ideal solution, making decision-making more transparent.

– **Consideration of positive and negative ideal solutions**
  - Dual focus: TOPSIS evaluates alternatives by simultaneously considering both the best (positive ideal) and worst (negative ideal) solutions. This ensures that the method accounts for how far each elternative/technology solution is from both extremes, giving a balanced assessment.

– **Ability to handle multiple criteria:**
  - Multi-dimensional decision making: it is essential when decision-makers need to evaluate alternatives based on several conflicting or complementary factors.
  - Flexibility in criteria types: the method can handle both qualitative and quantitative criteria.

– **Realistic Comparison**
  - Closeness to reality.

– **Flexibility in weighting**
  - Customizable weight assignment: it accomodate the preferences of stakeholders.

– **Efficient for large-scale problems**
  - Scalability: TOPSIS can efficiently handle large-scale problems with numerous alternatives and criteria. It is suitable for complex-making situations in engineering, business etc.

The TOPSIS multicriteria analysis method was therefore chosen for further analysis, allowing the evaluation of the different technologies according to the weights given by the experts and the corresponding indicator values.

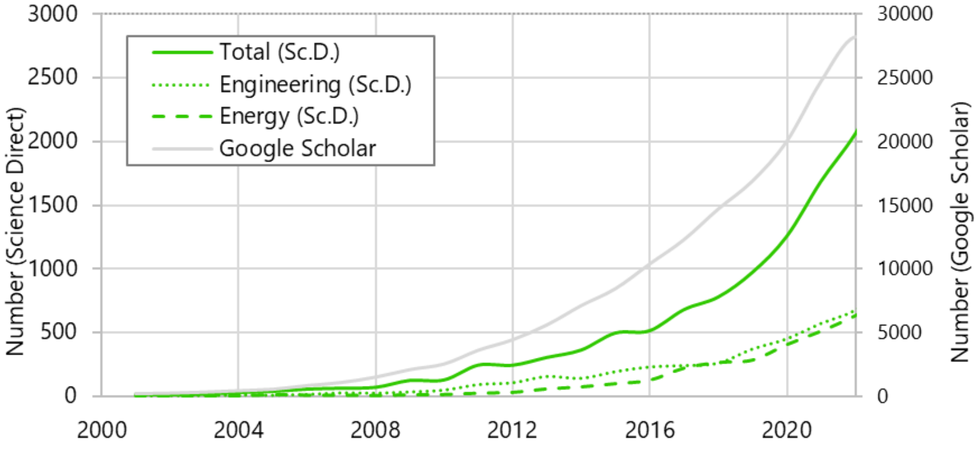

Fig. 2.6. Popularity of the TOPSIS method

The classical TOPSIS method steps:

- Create a decision matrix and determine the weight of criteria.
    - Criteria can be: cost functions (less is better) and/or benefit functions (more is better)
- Normalize the decision matrix
    - Various attribute dimensions are transformed into non-dimensional attributes which allows comparison across criteria. The scores in the evaluation matrix must be transformed to a normalized scale.
- Calculate the weighted normalized decision matrix
- Determine the positive and negative ideal solutions
    - Identify the positive ideal alternative, which represents the best possible performance on each criterion, and the negative ideal alternative, which reflects the worst possible performance. The positive ideal solution aims to maximize benefit criteria while minimizing cost criteria, whereas the negative ideal solution seeks to maximize costs and minimize benefits.
- Calculate the separation measures
- Determine the relative closeness to the positive ideal solution
- Rank or select the alternative closest to 1
    - A set of technologies now can be ranked by the descending order.

A flowchart of the method is shown in the Fig. 2.7 below.

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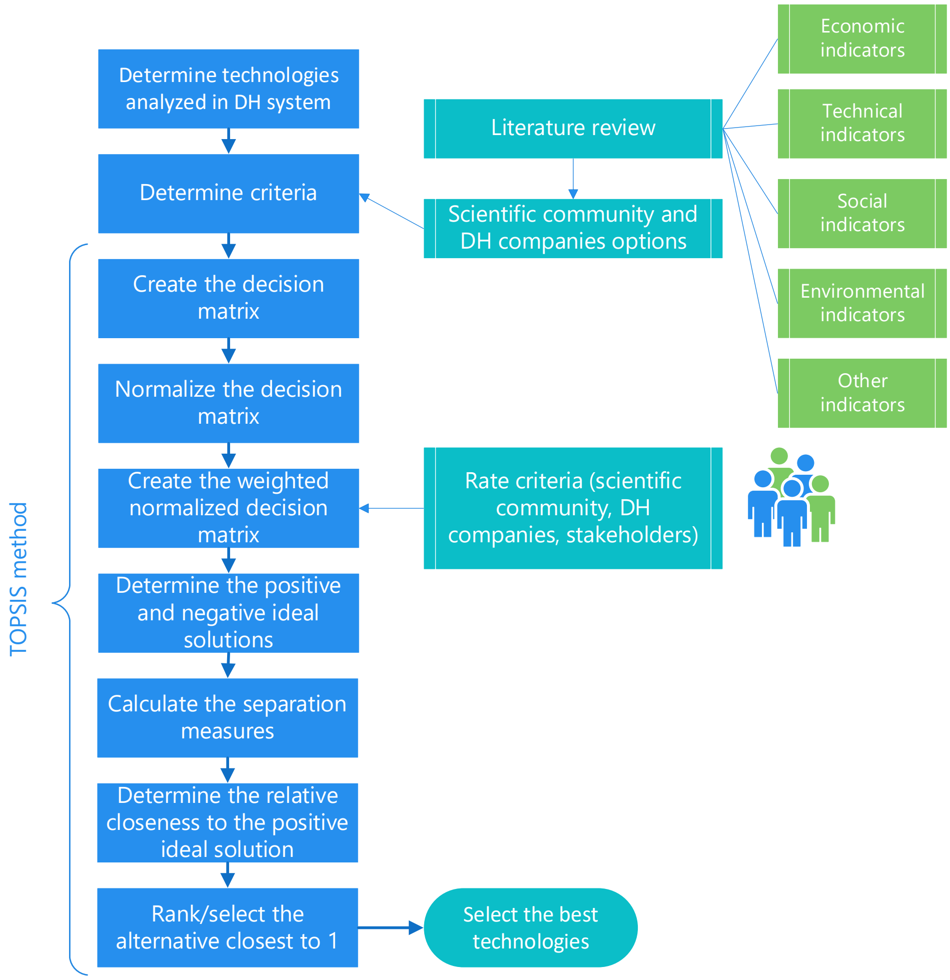

Fig. 2.7. Main steps of the TOPSIS method

In this approach, all the above technologies were evaluated and a value close to 1 was obtained for each technology. Tables for the calculation of the intermediate stages of TOPSIS are given in the annexes and the final Ranking List using the scientific approach (TOPSIS) is presented in the following chapter.

2.5. Ranking list

The performance score (the closest to 1) of the technologies using the TOPSIS method is given in the Fig. 2.8. These results are then normalised and presented from the lowest-value technology to the highest value (Fig. 2.9).

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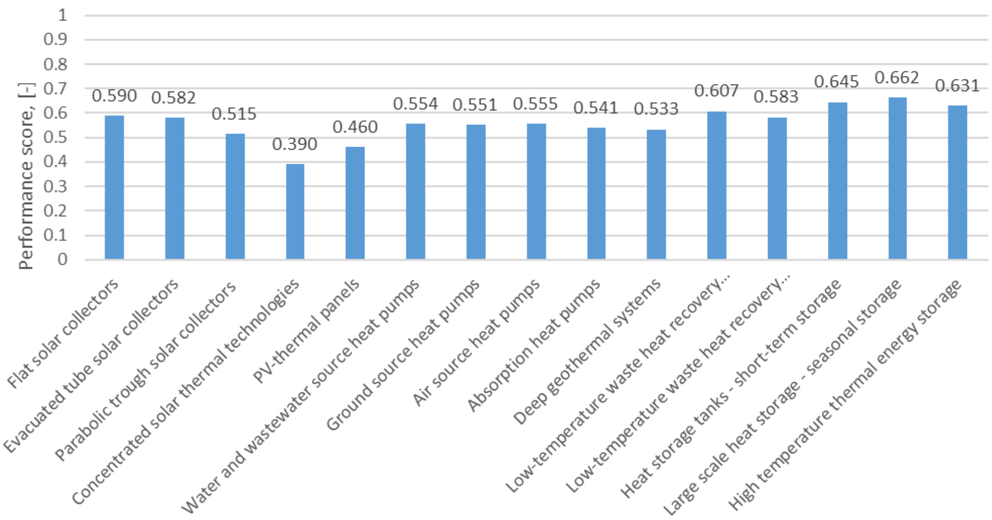

Fig. 2.8. Performance factor of technologies evaluated in SET_HEAT using the TOPSIS method

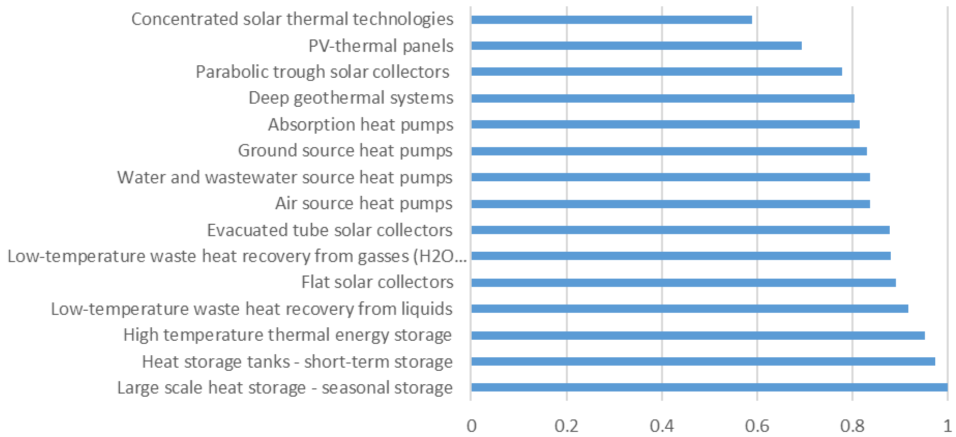

Fig. 2.9. Ranking of technologies from 0 to 1 using the TOPSIS method

As we can see, the highest positions were taken by heat storage technologies (large-scale heat storage and short-term storage tanks), which are practically relevant for most renewable energy systems: flat solar collectors, heat pumps, etc. Next in fairly close order are low-temperature waste heat recovery technologies and evacuated tube solar collectors, followed by air source and water and wastewater source heat pumps by a small margin. The latter are followed by ground source heat pumps, absorption heat pumps and deep geothermal systems. The last positions were occupied by technologically expensive solar energy transformation technologies: parabolic, concentrated solar collectors and PV-thermal panels. This is what really shapes the initial view of the current techno-economic situation. Of course, in the case of individual projects, the current situation in the specific location, geographical conditions, available heat sources, etc. must be taken into account.

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2.6. Suitability of technologies vs local heat maps

The 15 technologies identified and ranked in Section 3 were set along with local heat maps, indicating

potential sources of heat in the 4 studied cities. Detailed tables are given in Appendices D-G. Here, a summarized table is given for each of the 4 DH systems.

Table 2.6. Summary of technologies referred to the local heat map in Opole

No.	Technology name	Count	MW	MWh
1	Flat solar collectors,		0	0
2	Evacuated tube solar collectors		0	0
3	Parabolic trough solar collectors		0	0
4	Concentrated solar thermal technologies		0	0
5	PV-thermal panels		0	0
6	Water and wastewater source heat pumps	22	27,7	66 306
7	Ground source heat pumps		0	0
8	Air source heat pumps	1	0,4	944
9	Absorption heat pumps		0	0
10	Deep geothermal systems		0	0
11	Direct waste heat recovery from liquids	4	10,3	21 776
12	LT waste heat recovery from gasses (H2O condensing systems)	10	7,3337	15 357
13	Heat storage tanks - short-term storage		0	0
14	Large scale heat storage - seasonal storage		0	0
15	High temperature thermal energy storage		0	0
	Other (out-of-scope) technologies within the Investment Plans			
16	High-temperature waste heat recovery from industry	3	17,3	36 681
17	High-temperature waste heat recovery from waste incineration		0	
18	High-efficiency natural gas CHP		0	
19	Biomass based CHP		0	
20	Low temperature zones with shunts		0	

As it can be seen, ECO Opole has identified 22 locations with **water or wastewater** that can be used as a heat **source for heat pumps**. Moreover, 4 locations are suitable for **direct waste heat recovery for liquids**. 10 locations are suitable for **low-temperature waste heat recovery** if exhaust **gasses** are cooled below 120°C and a H_2O condensing system is applied. Finally, 1 location suitable for an air source heat pump has been identified.

3 identified sites for high-temperature waste heat recovery from industry are outside of the direct scope of the SET_HEAT project, however, they are additionally presented due to their significant potential. All of these sites are also counted for Technology #12, i.e., it is assumed that the exhaust gases are first cooled to 120°C (conventional WHR) and then their potential is further exploited in low temperature waste heat recovery.

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The potential has been identified as follows:

a) Source temperature below 120°C:

It is assumed that the potential indicated by ECO directly corresponds to Technology #12.

b) Source temperature above 120°C:

It is assumed that the potential indicated by ECO corresponds to waste heat recovery to the conventional level of 120°C. Additional potential below 120°C has been estimated as:

$$\dot{Q}_{LT} \approx \dot{Q}_{HT} \frac{120°\text{C} - 50°\text{C}}{T_{\text{exhaust}} - 120°\text{C}},$$

Where T_{exhaust} is the source (exhaust gas) temperature indicated by ECO.

In total, the total recoverable power in sites found by ECO Opole is about **63 MW** of which 45.7 MW can be achieved using the considered low-temperature technologies plus . The annual quantity of heat production is about **141 000 MWh** of which 104 000 MWh in LT technologies. The equivalent utilization time for the declared power is **2238 h**.

Table 2.7. Summary of technologies referred to the local heat map in Zagreb

No.	Technology name	Count	kW	MWh
1	Flat solar collectors,		0	0
2	Evacuated tube solar collectors		0	0
3	Parabolic trough solar collectors		0	0
4	Concentrated solar thermal technologies		0	0
5	PV-thermal panels		0	0
6	Water and wastewater source heat pumps	1	5000	42500
7	Ground source heat pumps		0	0
8	Air source heat pumps	1	100	850
9	Absorption heat pumps		0	0
10	Deep geothermal systems		0	0
11	Direct waste heat recovery from liquids	8	7800	66300
12	LT waste heat recovery from gasses (H2O condensing systems)		0	0
13	Heat storage tanks - short-term storage		0	0
14	Large scale heat storage - seasonal storage		0	0
15	High temperature thermal energy storage		0	0

As it can be seen, the highest potential in Zagreb is attributed to **direct waste heat recovery from liquids** (the identified temperature in most cases is about 85°C), followed by **water and wastewater source heat pumps**, and **air source heat pumps**.

The presented heat map of Zagreb should be treated as a nucleus for a full heat map, since the number of available objects is certainly higher. Currently, the identified potential is about **12.9 MW**, and the annual potential for heat production is claimed to be at **109 000 MWh**, which

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is relatively high compared to the declared thermal power. To achieve this production, the thermal power would require **8450 hours** of utilization per year.

Table 2.8. Summary of technologies referred to the local heat map in Bucharest

No.	Technology name	Count	MW	MWh
1	Flat solar collectors	197	202,8	243 322
2	Evacuated tube solar collectors		0	0
3	Parabolic trough solar collectors		0	0
4	Concentrated solar thermal technologies		0	0
5	PV-thermal panels	3	6,3	7 500
6	Water and wastewater source heat pumps	5	56,5	451 936
7	Ground source heat pumps		0	0
8	Air source heat pumps	3	7,3	62 000
9	Absorption heat pumps		0	0
10	Deep geothermal systems	3	1,9	15 340
11	Direct waste heat recovery from liquids		0	0
12	LT waste heat recovery from gasses (H2O condensing systems)		0	0
13	Heat storage tanks - short-term storage		0	0
14	Large scale heat storage - seasonal storage		0	0
15	High temperature thermal energy storage		0	0

In Bucharest, the highest potential is attributed to water and wastewater source heat pumps. Interestingly, the 2nd place is occupied by flat solar collectors, which have been found to be possible to install in 197 locations, mostly in transformer or substation buildings. High potential is also expected from air source heat pumps (subway and data centres), deep geothermal systems, and PV-thermal panels.

The total thermal power reaches 275 MW, and the expected heat production amounts to 780 000 MWh, which yields a technology utilization time of 2836 hours. Both the power and the potential are the highest amount all 4 partners, due to the size of the Bucharest city.

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Table 2.9. Summary of technologies referred to the local heat map in Vilnius

No.	Technology name	Count	MW	MWh
1	Flat solar collectors,		0	0
2	Evacuated tube solar collectors		0	0
3	Parabolic trough solar collectors		0	0
4	Concentrated solar thermal technologies		0	0
5	PV-thermal panels		0	0
6	Water and wastewater source heat pumps	6	17.5	155 977
7	Ground source heat pumps		0	0
8	Air source heat pumps	147	58.6	480 264
9	Absorption heat pumps		0	0
10	Deep geothermal systems		0	0
11	Direct waste heat recovery from liquids	18	3,9	34 427
12	LT waste heat recovery from gasses (H2O condensing systems)		0	0
13	Heat storage tanks - short-term storage		0	0
14	Large scale heat storage - seasonal storage		0	0
15	High temperature thermal energy storage		0	0

In Vilnius, 147 sites have been identified for air source heat pumps, with the highest power potential obtained. Other technologies comprise water and wastewater heat pumps (2^{nd} largest in terms of potential), as well as direct waste heat recovery from liquids.

Table 2.10 and Fig. 2.10 present a matrix of technologies vs heat maps for all studied 4 DH systems.

Table 2.10. Quantitative summary: technologies vs. heat maps for all 4 studied DH systems

No.	Technology name	Count	MW	MWh
1	Flat solar collectors,	197	202,8	243 322
2	Evacuated tube solar collectors	0	0	0
3	Parabolic trough solar collectors	0	0	0
4	Concentrated solar thermal technologies	0	0	0
5	PV-thermal panels	3	6,3	7 500
6	Water and wastewater source heat pumps	34	106.7	716 719
7	Ground source heat pumps	0	0	0
8	Air source heat pumps	152	66.4	544 058
9	Absorption heat pumps	0	0	0
10	Deep geothermal systems	3	1.9	15 340
11	Direct waste heat recovery from liquids	30	22.0	122 503
12	LT waste heat recovery from gasses (H2O condensing systems)	10	7.3	15 357
13	Heat storage tanks - short-term storage	0	0	0
14	Large scale heat storage - seasonal storage	0	0	0
15	High temperature thermal energy storage	0	0	0

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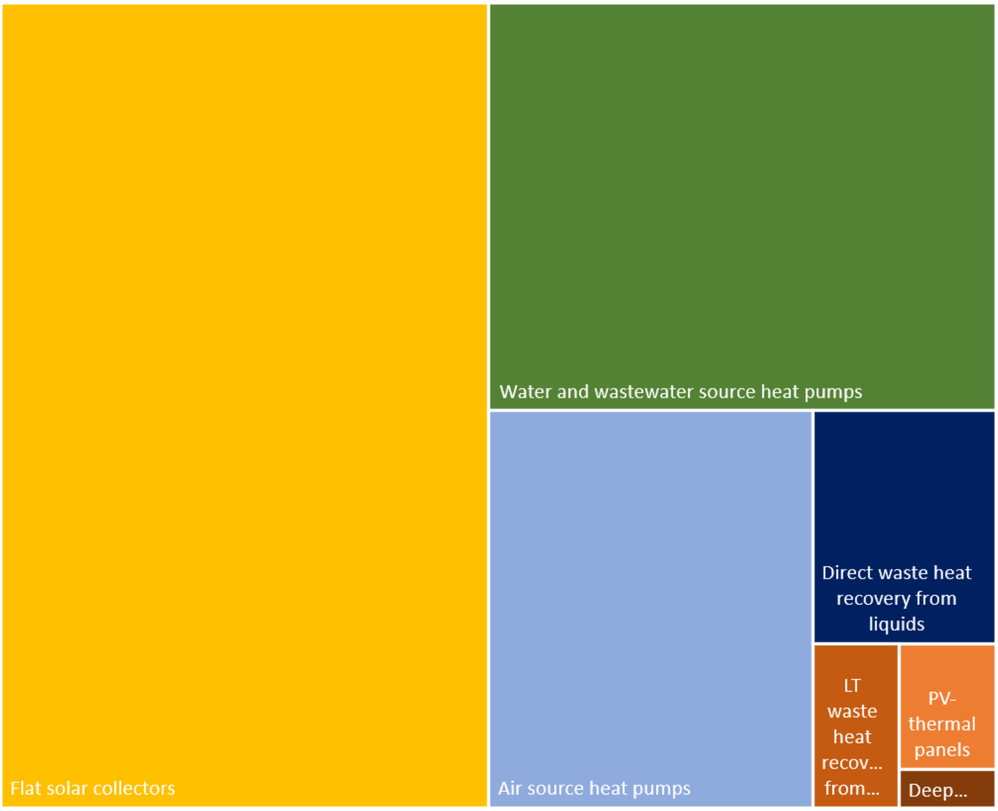

Fig. 2.10. Visualization of the thermal power potential for the identified technologies summarized for the 4 studied DH systems. (The smallest item reads 'Deep geothermal systems')

Numerical data regarding Fig. 5.1. are presented in Table 5.5. As it can be concluded, the most significant potential is related to the identified surfaces for solar collectors (in Bucharest), followed by water/wastewater sources and ventilation air as a heat source for heat pumps. Next, direct waste heat recovery from hot liquids, low temperature waste heat recovery from gasses, and PV-thermal panels can play a role. These carriers are available in all or most studied systems. Deep geothermal systems have only been declared as identified in Bucharest and Zagreb.

2.7. Suitability of technologies vs investment projects

The 4 DH companies participating in the project have indicated technologies included in their respective investment plans. In some cases, the identification of technology was not directly corresponding to the classification of 15 technologies as listed in Section 2.3. Moreover, some technologies in the investment plans are out of scope of the SET_HEAT project, however, they are listed below to make the vision more complete.

The declared investment projects related to the studied technologies are listed below in Table 2.11.

Table 2.11. Technologies vs. investment plans incidence matrix. 0: no plans, 1: interested, 2: included in the plan, 3: included & estimated, 4: at least 1 object specified (size, location, year), 5: at least 1 object in the design phase, 6: at least 1 object under construction or built

ID	Technology	Short name	ECO Opole	HEP Zagreb	TEB Bucharest	VST Vilnius	Total score	Ranking
1	Flat solar collectors,	FSC	6	2	3	0	11	2
2	Evacuated tube solar collectors	ETSC	0	0	0	0	0	12
3	Parabolic trough solar collectors	PTSC	0	0	0	0	0	12
4	Concentrated solar thermal technologies	CSTT	0	0	0	0	0	12
5	PV-thermal panels	PVT	4	0	0	0	4	9
6	Water and wastewater source heat pumps	WSHP	4	2	3	3	12	1
7	Ground source heat pumps	GSHP	0	0	2	0	2	11
8	Air source heat pumps	ASHP	4	2	0	5	11	2
9	Absorption heat pumps	AHP	0	0	0	6	6	5
10	Deep geothermal systems	DGS	2	2	2	0	6	5
11	Low-temperature waste heat recovery from liquids	LWWHS-L	1	2	3	4	10	4
12	Low-temperature waste heat recovery from gasses (H2O condensing systems)	LWWHS-G	0	0	0	4	4	9
13	Heat storage tanks - short-term storage	TTES	0	0	0	5	5	8
14	Large scale heat storage - seasonal storage	SHS	2	2	0	2	6	5
15	High temperature thermal energy storage	HTTES	0	0	0	0	0	12
	Other (out-of-scope) technologies within the Investment Plans							
17	High-temperature waste heat recovery from industry	WHR	3	2	0	3		
18	High-temperature waste heat recovery from waste incineration	WHR-WI	3	2	0	0		
19	High-efficiency natural gas CHP	NG-CHP	3	2	2	0		
20	Biomass based CHP	B-CHP	1	2	0	3		
21	Low temperature zones with shunts	LTZ	0	0	0	6		

It can be seen, that the most interest is given to:

1. Water and wastewater source heat pumps (all companies have it at least declared in their plans);
2. Air source heat pumps and flat solar collectors (ex aequo);
3. Low temperature waste heat recovery from liquids;
4. Absorption heat pumps, deep geothermal systems and large scale heat storage (ex aequo);
5. Heat storage tanks for short-term storage;
6. Low temperature waste heat recovery from gasses with H_2O condensation and PV-thermal panels (ex aequo);
7. Ground source heat pumps.

The remaining 4 technologies (high-temperature thermal energy storage and 3 other solar technologies) have not been included in the investment plans so far.

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On the contrary, other technologies not included in the scope of the SET_HEAT project have been listed as technologies of interest in the investment plans (high-temperature waste heat recovery from industry and waste incineration plants, natural- and biogas-based CHP units, and low temperature zones with shunts). These technologies are also of importance for upgrading the heating systems from the 2nd generation to higher categories.

2.8. Integrated assessment of technical options

The TOPSIS assessment tool presented in Sections 4, local heat maps and company investment plans have provided different rankings for technology evaluation. First, to compare the rankings, each of them has been normalized with respect to the maximum score (max score = 1). The original and the normalized rankings are presented in Tables 2.12-2.14.

Table 2.12. The TOPSIS ranking with the original punctuation and the normalized values

ID	Technology name	points	normalized
14	Large scale heat storage - seasonal storage	0.6624	**1.0000**
13	Heat storage tanks - short-term storage	0.6451	0.9739
15	High temperature thermal energy storage	0.6312	0.9529
11	Direct waste heat recovery from liquids	0.6073	0.9168
1	Flat solar collectors	0.5899	0.8906
12	Low-temperature waste heat recovery from gasses (H2O condensing systems)	0.5828	0.8797
2	Evacuated tube solar collectors	0.5821	0.8787
8	Air source heat pumps	0.5548	0.8376
6	Water and wastewater source heat pumps	0.5544	0.8369
7	Ground source heat pumps	0.5505	0.8311
9	Absorption heat pumps	0.5406	0.8161
10	Deep geothermal systems	0.5333	0.8050
3	Parabolic trough solar collectors	0.5150	0.7774
5	PV-thermal panels	0.4600	0.6944
4	Concentrated solar thermal technologies	0.3898	0.5884

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Table 2.13. Production potential indicated from the local heat maps – total score

ID	Technology name	Direct MWh/a	Corrected MWh/a	Normalized
6	Water and wastewater source heat pumps	716 719	716 719	1.000
8	Air source heat pumps	544 058	544 058	0.759
2	Evacuated tube solar collectors	0	259 543	0.362
4	Concentrated solar thermal technologies	0	253 055	0.353
1	Flat solar collectors	243 322	243 322	0.339
3	Parabolic trough solar collectors	0	240 078	0.335
11	Direct waste heat recovery from liquids	122 503	122 503	0.171
13	Heat storage tanks - short-term storage	0	58 194	0.081
12	LT waste heat recovery from gasses (H2O condensing systems)	15 357	15 357	0.021
10	Deep geothermal systems	15 340	15 340	0.021
5	PV-thermal panels	7 500	7 500	0.010
14	Large scale heat storage - seasonal storage	0	5 173	0.007
7	Ground source heat pumps	0	0	0.000
9	Absorption heat pumps	0	0	0.000
15	High temperature thermal energy storage	0	0	0.000

Table 2.13. includes both direct and corrected production potential. Direct potential results from the heat maps provided by manufacturers and the 'first choice' of technology. For example, the direct potential for flat solar collectors is 243 322 MWh/a, as all surfaces suitable for solar technologies have been virtually 'equipped' with flat solar collectors (except for a few locations where PV-thermal panels have been declared). Accordingly, the direct potential for all other technologies (evacuated tube, concentrated solar etc.) is 0.

However, this approach discriminates the technologies which have not been the first choice. To make the ranking more justified, it was assumed that other solar technologies also have a potential comparable to flat solar collectors, the only difference is that the potential has to be corrected by average efficiency (elaborated within Deliverable D1.7).

- Flat solar collectors $\eta = 0.75$
- Evacuated tube solar collectors $\eta = 0.80$
- Parabolic trough solar collectors $\eta = 0.74$
- Concentrated solar thermal technologies $\eta = 0.78$

The potential for technologies other than flat solar collectors (FSC) have been estimated as:

$$Q_i = Q_{FSC} \cdot \frac{\eta_i}{\eta_{FSC}}$$

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The corrections have also been applied to heat storage units. The heat maps fail to directly provide information on the heat storage potential, however, at this stage of the SET_HEAT project it is known that this potential exists. Heat storage potential is not directly related to any specific source of heat, but it results from the planned construction. Accordingly, this potential has been estimated as follows:

$$Q_{HS} = V_{HS} c_w \Delta T \cdot n$$

Where V_{HS} is the heat storage volume, c_w is the specific capacity of water (4.19 kJ/kgK), ΔT is the assumed feeding/return temperature difference (20 K), and n is the number of charging/discharging cycles equivalent to full capacity.

It has been assumed that the storage volume equals 50 000 m^3 for a short-term tank, and 200 000 m^3 for the seasonal storage, and that the number of full-capacity cycles is 50 and 4, respectively. While these assumptions are quite arbitrary and exemplary, they can provide a raw estimation of the thermal potential of heat storage technologies. It should be noted that assuming only 1 charging/discharging cycle yields a potential which is negligible compared to the listed heat sources. The exemplary values of V_{HS} and n have been discussed and agreed between the technical manager and the project manager.

Table 2.14. Ranking of technologies by interest expressed in investment plans

ID	Technology name	points	normalized
6	Water and wastewater source heat pumps	0.5000	1.0000
1	Flat solar collectors	0.4583	0.9167
8	Air source heat pumps	0.4583	0.9167
11	Direct waste heat recovery from liquids	0.4167	0.8333
9	Absorption heat pumps	0.2500	0.5000
10	Deep geothermal systems	0.2500	0.5000
14	Large scale heat storage - seasonal storage	0.2500	0.5000
13	Heat storage tanks - short-term storage	0.2083	0.4167
5	PV-thermal panels	0.1667	0.3333
12	LT waste heat recovery from gasses (H2O condensing systems)	0.1667	0.3333
7	Ground source heat pumps	0.0833	0.1667
2	Evacuated tube solar collectors	0.0000	0.0000
3	Parabolic trough solar collectors	0.0000	0.0000
4	Concentrated solar thermal technologies	0.0000	0.0000
15	High temperature thermal energy storage	0.0000	0.0000

Here, referring to Table 2.11, the total interest was first estimated using a scale 0-6 points. The maximum theoretical score is 24, which means that all companies would have set 6 points for the technology. The actual score was divided by the maximum score (for example, water and wastewater heat pumps have 12 interest points, which is 0.5 of the maximum). Next, the resulting points were normalized with respect to the maximum value.

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Having all rankings normalized, it was then straightforward to calculate averaged results, assuming that the importance of the three rankings (TOPSIS, potential and interest) is equal. The averaged ranking is presented in Fig. 2.11.

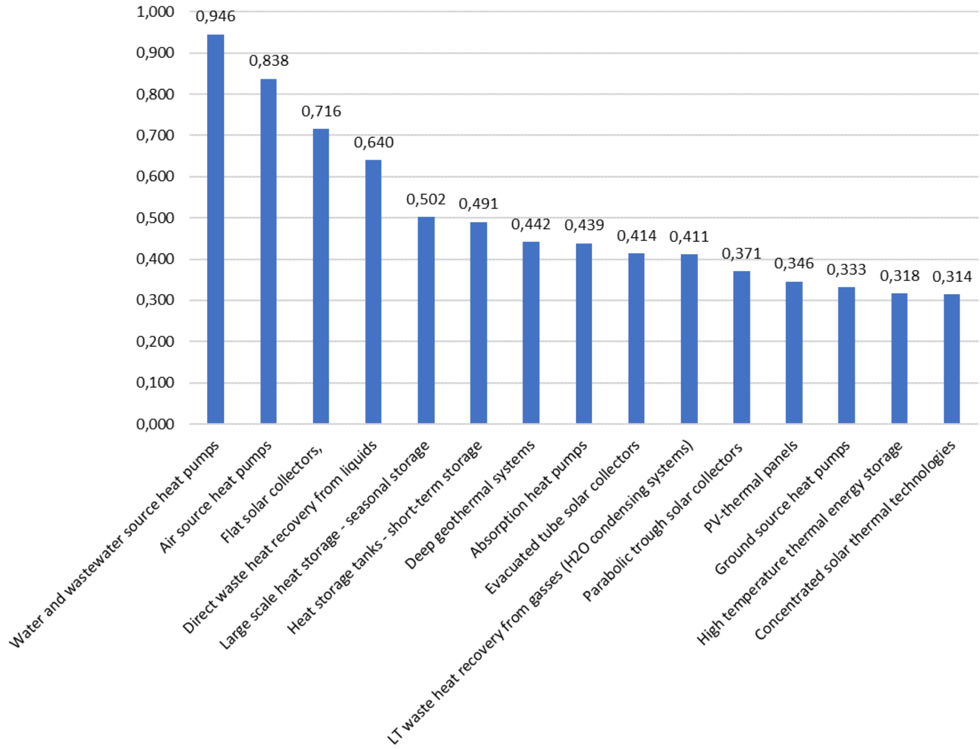

Fig. 2.11. Final ranking of technologies by all criteria as an input list for project recommendations

Having this ranking set, it is possible to proceed to conclusions and recommendations.

2.9. Conclusions from deliverable 3.1

To select technologies suitable as model investment projects, three different sets of information have been completed and quantified:

1. Scientific criteria describing the intrinsic quality of technologies, regardless of the installation size. The criteria have been specified by project partners (a long list), then they have been evaluated and a short list of criteria has been set. The short list comprises the following criteria:
    a. Maximum supply water temperature
    b. Share of electric energy in heat production
    c. Share of renewable energy sources
    d. Lifespan
    e. Specific capital expenditures
    f. Specific operational expenditures (fixed and variable)

g. Land use area
h. Levelized cost of heat
i. Suitability for peak load coverage and
j. Flexibility.

Moreover, weight coefficients have also been set.

2. On-site potential resulting from the local heat maps prepared within D1.4.
3. The current interest of district heating companies expressed by their investment plans.

The discussed 3 sets of information have been quantified and normalized to enable comparison and quantification in a form of a final ranking (Fig. 2.11). From the ranking, one can conclude that the following 6 technologies are recommended as model investment projects:

1. **Water and wastewater source heat pumps** (Score = 0.946)
2. **Air source heat pumps** (Score = 0.838)
3. **Flat solar collectors** (Score = 0.716)
4. **Direct waste heat recovery from liquids** (Score = 0.640)
5. **Large scale heat-storage (seasonal)** (Score = 0.502)
6. **Heat storage tanks (short-term)** (Score = 0.491)

While the quantification procedure is still based on many arbitrary assumptions, the proposed various rankings compare different perspectives and points of view and the proposed final selection list is in agreement with intuitive assessment by managers of the 4 district heating companies involved in the SET_HEAT projects. The proposed ranking has been accepted by all Project partners.

3. Report on definition of model investment projects

Model investment projects, that could be replicated internally within the consortium as well as taken up and implemented by other market actors (external DH companies) are core components of the SET_HEAT project.

The main idea of the SET_HEAT project is to support energy transition and decarbonisation of district heating (DH) systems in four Eastern European countries (Croatia, Lithuania, Poland and Romania) through the development of specific projects, that could be replicated internally within the consortium as well as taken up and implemented by external DH companies. The action aims to facilitate the development and implementation of specific technology solutions by delivering supportive documentation and data for decision-makers. The overall project's planning pathway and the approach to impact creation are depicted in Fig. 3.1.

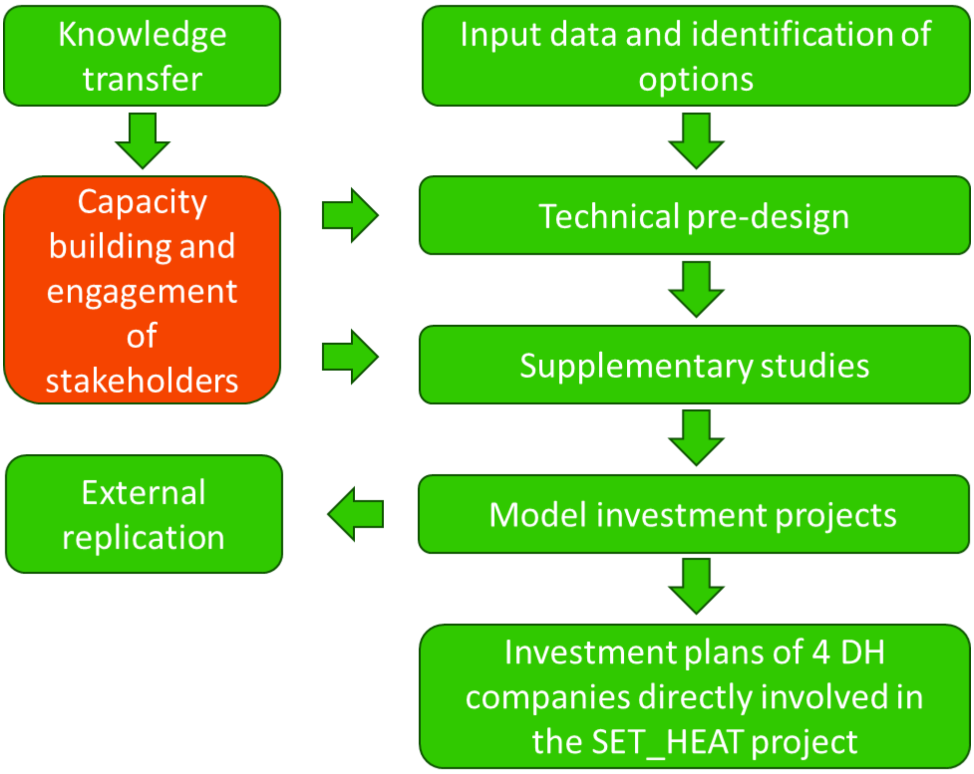

Fig. 3.1. SET_HEAT project's approach to impact creation

The model projects focus on the integration of low-grade renewable energy and waste heat sources into district heating networks and a significant reduction in the share of fossil fuel and biomass combustion in heat production.

It was initially planned that six model investment projects would be defined and thoroughly analysed within the next project's tasks. At the stage of the project proposal, the following technology solutions were considered: solar heating, heat recovery from sewage treatment plants, heat pumping from water resources such as lakes and rivers, different options for heat storage, connections of heat prosumers, and industrial waste heat recovery. Sector integration and specific roles of district heating in future energy systems were supposed to be considered as well.

In the deliverable D3.2, the specific model investment projects are defined. Initial technical specifications of the six model investment projects are provided. The departure point is the deliverable D3.1 titled: Report on technical options for investment projects.

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Based on the deliverable D3.1, technical options for replicable projects in those systems are defined. The model (typical) investment projects focused on the integration of low-grade and waste heat sources in DH networks are considered. Technology options such as biomass boilers, electric boilers and other high-temperature technologies are excluded. The overall methodology adopted in the SET_HEAT project for the definition of the replicable model investment project is depicted in Fig. 3.2.

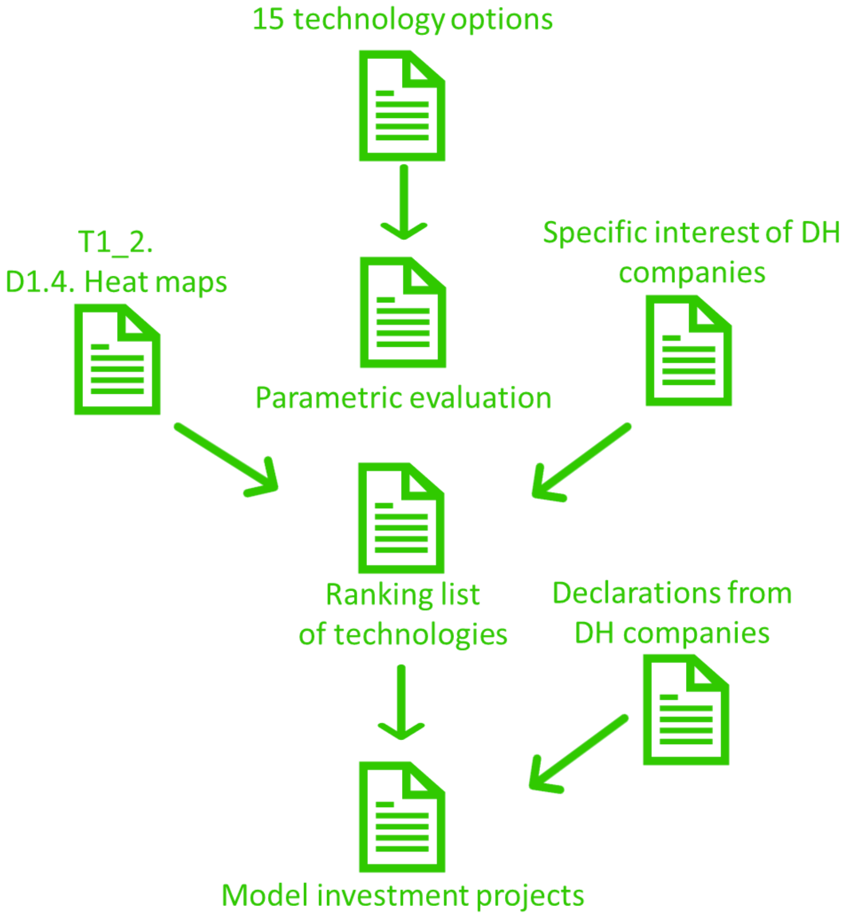

Fig. 3.2. Methodology for selection of specific model investment projects

The definition of a project is understood as its preliminary technical specification. The information required to precisely define the model projects has been requested from the national development teams. The following survey has been developed for this purpose:

1/ Specific functionality. What is the problem to be addressed in the project and what makes the replicability potential? What are the project objectives? What is the opportunity the project is going to use?

2/ Specific technology selection: What type of equipment will be considered in the project? Since the pre-feasibility study considers different options, different types of specific equipment can be taken into consideration for selection. What is the technological scope to be considered (i.e. main technology, supplementary installations etc.)?

3/ Integration options: What is the intended location of the system (i.e. central or distributed)? How the system is going to be integrated with the DH network (i.e. return-forward, return-return, other)? How the system is going to be integrated with the heat source (i.e. directly, heat exchanger, etc.)?

4/ Selection of parameters: What are key design parameters (i.e. temperatures, pressure, volume, etc.)? What is the scope of specific parameters to be considered (i.e. source temperature range, network temperature range, pressure range, etc.)?

5/ Options for operating modes: What is the primary output (e.g. heat, cold, electricity, service)? What are potential additional outputs? Are there any possibilities to shift operation priorities?

6/ Control options: What control options will be taken into consideration (e.g. temperature control, flow control, full load operation, on-off operation, load-following operation, network pressurisation, etc.)

7/ Sector integration: What sectors will be integrated by this project? How other sectors will influence the project (e.g. by price signals, by demand response measures, by demand management measures, etc)?

8/ Degree of innovation: How does the project go beyond the state-of-the-art? Are there any innovative elements?

9/ Any other relevant information.

3.1. Model investment projects

After considering the interest of district heating companies in developing specific investment projects, as well as implementing other solutions through internal replication, six model projects were defined. These are presented in Table 3.1.

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Table 3.1. Specific projects to be studied and converted into model projects

Project No.	Specific project	Technology category	Main development team
1	Sewage treatment plant waste heat recovery	Water and wastewater source heat pumps	SUT, PO, ECO, KELVIN
2	Heat recovery from supermarket	Water and wastewater source heat pumps; Air source heat pumps	VST, VILNIUS-TECH
3*	River water heat pump	Water and wastewater source heat pumps	HEP, UNIZAG-FSB
4	Air source heat pump	Air source heat pumps	VST, VILNIUS-TECH
5*	Distributed small-scale solar heating plants	Flat panel solar collectors	TEB, CMESB
6	Pit Thermal Energy Storage (PTES) seasonal storage facility	Large-scale heat storage – seasonal storage	SUT, PO, ECO, KELVIN

* The projects will be developed in collaboration between Croatian and Romanian teams. In addition to the river water heat pump, there will be also developed a side project of using lake water as a heat source. This project will be triggered in Romania. In addition to the distributed small-scale solar heating plants, there will be also triggered a project on a centralised solar heating plant in Croatia.

3.1.1. Specific project 1 - Heat recovery from treated sewage

Table 3.2. Project 1 definition card

Project name: Heat recovery from treated sewage
Project acronym: SET_HEAT_SEWAGE
Development team: ECO, PO, SUT, KELVIN
1. Specific functionality

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Heating DH network water and optimisation of heat production cost. Potential functionality is to provide ancillary services for the electricity market (frequency balancing of electricity grid).
2. Problem to be addressed
The main problem is to make use of the waste heat potential that occurs at municipal sewage treatment plants. The specific problem is to propose a process flowsheet integrating different waste heat sources available at sewage treatment plants, select appropriate heat pump technology and auxiliary systems, size it and integrate the facility with the uneven flow of treated wastewater, and varying electricity spot market prices.
3. Opportunity to be harnessed
Considerable flows of treated wastewater in cities and an elevated water temperature. Variable electricity prices in the market. Availability of other waste heat sources such as air compression stations which, and sometimes biogas-fired internal combustion engines.
4. Replicability potential
Sewage treatment plants are located in every larger city with a district heating system, which results in high replication potential in terms of heat source availability.
5. Specific project objectives
- To examine alternative technology options and propose optimised solutions to harvest waste heat available at sewage treatment plants; - To identify key determinants for project implementation; - To examine productivity and energy performance, and identify key constraints. - To develop an optimisation procedure for heat source system design and operation.
6. Type of equipment will be considered in the project
Heat pumps; heat exchangers, wastewater and network pumps, wastewater buffers. Also heat pump refrigerant is a subject for optimisation.
7. Technological scope to be considered
Large-scale turbomachinery-based heat pumps, screw and piston compressor heat pumps in cascaded systems, heat exchangers for heat recovery from sources at the temperature level of 50-70°C.

Different refrigerants will be considered (e.g. R1234ze, R1233zd, NH_3, etc.).
8. Intended location of the heat source system
Decentralised, at wastewater treatment plant. Hydraulic studies are required to identify heat transfer constraints.
9. Hydraulic integration options
Direct or through heat exchangers depending on heat pump technology; Parallel return-forward; In series return-return; flexible depending on operating conditions. Local heat storage is an option. Supply of heat to internal systems of sewage treatment plants is also an option.
10. Key design parameters
Heat pump rated heating capacity, heat pump type, treated wastewater flow and temperature, district heating network flow and temperatures, electricity grid voltage.
11. Ranges of specific parameters
A facility of MW scale heating output will be considered. The typical range is 0,5 to 50 MW depending on the location and sewage treatment plant technology. The temperature of the treated wastewater, depending on the location and season, ranges from 8 to 25°C. Source temperature drop of 5 to 10°C will be considered. The range of output temperature of DH forward network water is 65 to 90°C. The return network water temperature at the heat pump condenser inlet is 35 – 70°C. This range of parameters enables integration of the heat source into the existing heating network and enables its operation in the case the network temperature is lowered in the future.
12. What is the primary output
Heat.
13. Options for operating modes
On/off; full load; waste heat tracking; heat demand tracking; electricity price tracking; Tracking demand for ancillary services; Depending on the size of the system there are also options for parallel operation with other heat sources in the DH system, and single heat source operation in the DH system (winter operation/summer operation). In case local storage is applied, there is also an option for island (isolated) operation.
14. Control options

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DCS (Distributed Control System). Integrated with district heating network controller for optimisation of heat production cost. Key control signals that must be taken into consideration are: - DH network parameters such as water flow, pressure, and temperature. - Flow and temperature of treated wastewater. - Electricity price. - Water level in the treated wastewater buffer tank; - Storage level (optional). DH network pressurisation option should be considered in the case the plant is the only source of heat in the system (summer operation) The part-load operation should be enabled.
15. Sector integration
Three sectors are integrated by this project, namely heating, electricity and wastewater treatment.
16. Influence of other sectors on the project
Each of the integrated sectors may have a considerable impact on the operation of this type of installation depending on the mode of operation. Signals from all three sectors will influence the momentary heat production cost.
17. Degree of innovation
An innovative element may be the integration of various waste heat sources within one plant and their joint recovery using a heat pump cascade
18. Other relevant information.
Collaboration of relevant stakeholders is required. The key ones are waste heat producers, technology suppliers, local electricity companies and municipalities. Locations are typically under the risk of flood. Therefore, a special design is required. The treated wastewater buffer vessel should be appropriately sized to ensure uninterrupted operation of the heat pump under variable wastewater flow conditions.

3.1.2. Specific project 2 - Heat recovery from a supermarket

This project is generic and represents heat recovery from liquids at a temperature level below the heating network return temperature. Depending on the case, waste heat recovery from gasses can be also considered for the integration. The heat is recovered at a third-party supplier side. This third-party supplier can be any facility, which is equipped with a cooling system and/or ventilation system. In particular, the following types of objects can be considered:

- industrial plant;
- office building;
- supermarket;
- hospital;
- data centre;
- leisure centre.

The source of waste heat is a cooling process. It can be:

- industrial cooling process;
- refrigeration process;
- air conditioning system.

In some cases, also ventilation air can be considered for the integration with the DH system as well as surplus heat from the onsite solar hot water heating system. In such a case a multisource system can be established.

An overall assumption is that waste heat is available in a liquid carrier, that can be supplied to the evaporator side of a bosting heat pump and then delivered to the district heating network. The heat can also be partially recirculated with the system of the third-party supplier (onsite recovery).

Table 3.3. Project 2 definition card

Project name: Heat recovery from a supermarket
Project acronym: SET_HEAT_RETAIL
Development team: VST, VILNUS-TECH
1. Specific functionality
Utilisation of waste heat available at supermarkets for district heating. Potential functionality is to provide ancillary services for the electricity market (frequency balancing of electricity grid). Flexible production of heat and consumption of electricity is an option.

2. Problem to be addressed
The main problem is to make use of low-temperature waste heat potential that occurs at supermarkets and other objects of similar type. The specific problem is to propose a process flowsheet integrating different waste heat sources available at a selected supermarket, select appropriate heat pump technology and auxiliary systems, size it and integrate the facility with the district heating system, and electricity market.
3. Opportunity to be harnessed
Considerable number of distributed low-temperature waste heat sources in cities.
4. Replicability potential
Since there are many supermarkets of various sizes in cities (see Vilnius waste heat map), and usually a number of them are located close to apartment buildings, the replicability potential of this project is considerable. A successful pilot project could open doors for many replicable projects in Vilnius and other cities.
5. Specific project objectives
– To test how much waste heat can be recovered from a pilot supermarket energy system. – To develop a standardised interconnection scheme. – To develop a relevant control strategy. – To examine temperatures and heat balance over throughout the year. – To develop a relevant business model to facilitate standardised interconnections for other objects of this type. – To generate relevant information for dialogues with stakeholders.
6. Type of equipment will be considered in the project
Heat pumps, heat exchangers. Also heat pump refrigerant is a subject for optimisation.
7. Technological scope to be considered
Screw and piston compressor heat pumps, heat exchangers for heat recovery from sources at the temperature level of 20-40°C. Various temperature drops will be considered. A cascaded system for high sink temperatures is an option. Different refrigerants will be considered (e.g. CO_2, NH_3, R245fa, etc.)

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8. Intended location of the system
Decentralised. Since local heat maps revealed the high potential of supermarkets in Vilnius, the model project will be triggered there. A pilot site will be selected for this project.
9. Hydraulic integration options
Direct or through heat exchangers; Parallel return-forward; In series return-return; flexible depending on operating conditions. Supply of heat to the internal systems of a supermarket (heating, sanitary hot water) is also an option.
10. Key design parameters
Heating capacity, source temperature, sink temperature.
11. Ranges of specific parameters
The potential heating capacity of a single system is typically in the range of tens to hundreds of kW (in general below 1 MW). Source temperature range: 20-40, up to 90°C in case of CO_2 chiller, network pressure: forward ~10 bar, return ~5 bar, network temperature: forward 65-115°C, return 40-60°C. For replicability, network temperatures below 100°C should be considered.
12. What is the primary output
Heat.
13. Options for operating modes
On/off; Heat source tracking; heat demand tracking; Electricity price tracking; Demand for ancillary services tracking.
14. Control options
Local control integrated with heat source control. Heat output control. Water outlet temperature control. Operating pressure set by the network. Partial load enabled; on/off operation enabled; seasonal operation enabled. Implementation of heat demand response mechanisms is an option.
15. Sector integration
Three sectors are integrated: retail, district heating and electricity.
16. Influence of other sectors on the project
The electricity sector influences the project by price signals and demand for ancillary services. Demand-side response functionality is an

option. The retail sector influences the project by the specificity of retail operations (e.g. shop opening hours; seasonality of products, etc.).

17. Degree of innovation

There are very few existing examples; a business model of shared benefits could be innovative (DH company and supermarket owners' collaboration), and also standardised modular solution for similar supermarkets could be considered innovative.

An innovative idea is to establish multisource systems at supermarkets, which combine heat recovery from refrigeration/cooling processes, air conditioning coolers, ventilation air, and flat plate solar collectors that can be installed on-site. Local heat storage is an option.

In addition, VST together with VILNIUS-TECH has an idea to evaluate quite an innovative joint approach based on the use of the Vilnius DH return line. In this concept, the supermarket waste heat recovery system will be connected to the DH return line together with multi-flat apartment buildings with underfloor heating connection to the DH return line (hot water could be provided with local very efficient booster heat pumps). Such an approach could lead to:

• Higher COP of supermarket waste heat pump (because the needed temperature raise is only up to DH return temperature ~40-50°C);

• Cheaper DH heat for multi-flat apartment buildings with underfloor heating (because of connection to DH return line);

• Supermarkets can reduce their heating costs, making the location more desirable for tenants. In addition, this leads to lower carbon emissions, aligning with sustainability goals and green certifications.

• Increased efficiency of many condensing flue gas economizers in Vilnius DH network (because connection of buildings to return DH line will lower return line temperature).

• Increased efficiency of back pressure turbines in Vilnius DH network (because connection of buildings to return DH line will lower return line temperature).

18. Other relevant information.

Know-how from already delivered similar projects in Denmark and Sweden could be used.

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A pilot supermarket is required for this project. The work should start with a detailed energy audit of the facility to initially examine suitability. Close cooperation with stakeholders is required. The key ones are the following: supermarket owners, supermarket staff, technology suppliers; electricity companies.

3.1.3. Specific project 3 - River water heat pump

River water and water from natural reservoirs (e.g., lakes) form important sources of renewable heat in many cities. Currently, there is no such system in operation in the SET_HEAT project countries. In this model project the installations will be designed for HEP (Croatia) and TEB (Romania).

Table 3.4. Project 3 definition card

Project name: River water heat pump
Project acronym: SET_HEAT_WATER
Development team: HEP, UNIZAG-FSB in cooperation with TEB and CMESB on a lake water project
1. Specific functionality
Utilisation of renewable ambient heat available in rivers and lakes for district heating and optimisation of heat production costs using electricity market instruments.
2. Problem to be addressed
The main problem is to make use of the low-temperature renewable heat potential of natural water flows and reservoirs that are present in many cities. The specific problem is to satisfy (or adjust) legal regulations, propose a process flowsheet integrating water sources with the district heating (including necessary water terminals, piping and fittings), select appropriate heat pump technology and auxiliary systems, size it and integrate the facility with the electricity market, and develop an appropriate control strategy.
3. Opportunity to be harnessed
Availability of low-temperature renewable heat in natural water flows and reservoirs.

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4. Replicability potential
High since rivers and lakes are present in many cities in the SET_HEAT project countries.
5. Specific project objectives
– To test hourly productivity and energy performance. – To examine temperatures and heat balance over the year. – To develop a standardised interconnection scheme. – To develop a relevant control strategy. – To generate relevant information for dialogues with stakeholders. – To elaborate data for the necessary permits.
6. Type of equipment will be considered in the project
Large-scale heat pumps, and heat exchangers. Also heat pump refrigerant is a subject for optimisation.
7. Technological scope to be considered
Turbomachinery, screw and piston compressor heat pumps, heat exchangers for heat recovery from sources at the temperature level of 5-20°C. Cascaded systems for high sink temperatures are an option. Different refrigerants will be considered (e.g. R1234ze, R1233zd, NH_3, etc.).
8. Intended location of the system
Decentralised or centralised depending on the location of the water source. The pilot project will be developed for Zagreb (Croatia) and the primary water source is the Sava River. Additional installation will be developed for TEB (Romania) whet the sources of water are the Herastrau and Tineretului Lakes.
9. Hydraulic integration options
Direct or indirect through heat exchangers depending on the heat pump technology; Parallel return-forward; In series return-return; flexible depending on operating conditions. Heat storage is an option to enable capturing opportunities resulting from the variable electricity prices and the demand for ancillary services.
10. Key design parameters
Heating capacity, source temperature, sink temperature.
11. Ranges of specific parameters

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Source temperature range: 5-20°C; source temperature drop of 5 to 10°C; network pressure: forward ~10 bar, return ~5 bar, network temperature: forward 65-115°C, return 40-60°C.
12. What is the primary output
Heat. Ancillary services are an option.
13. Options for operating modes
On/off; Full load; Heat source tracking; heat demand tracking; electricity price tracking; Demand for ancillary services tracking.
14. Control options
DCS integrated with district heating system controller for optimisation of heat price. Heat output control. Water outlet temperature control. Operating pressure set by the network. Full load enabled; Partial load enabled; on/off operation enabled; seasonal operation enabled. Implementation of heat demand response mechanisms is an option.
15. Sector integration
Two sectors are integrated: district heating and electricity.
16. Influence of other sectors on the project
The electricity sector influences the project by price signals and demand for ancillary services. Demand-side response functionality is an option.
17. Degree of innovation
The innovation potential is moderate since several examples of such systems exist in the EU countries. Potential innovation is a new heat pump technology or a new refrigerant. At a smaller scale (kW to several MW range) innovation potential lays also in the possibility for multisource heat pump systems.
18. Other relevant information.
Know-how from already delivered similar projects in Germany, Denmark and Sweden could be used. Close cooperation with stakeholders is required. The key ones are the following: environmental protection entities responsible for permitting, technology suppliers; electricity companies, municipalities.

3.1.4. Specific project 4 – Air Source Heat Pump

Air Source Heat Pumps (ASHPs) are location-independent solutions. ASHPs can be installed almost everywhere if only a sufficient plot of land is available. Although there are already many examples of ASHP implementations in EU countries, there are only a few in the countries covered by the SET_HEAT project. Moreover, there is no sufficient data publicly available that could facilitate the planning of such investments.

Table 3.5. Project 4 definition card

Project name: Air source heat pump
Project acronym: SET_HEAT_AIR
Development team: VST and VILNIUS-TECH
1. Specific functionality
The utilisation of renewable heat, which is available in ambient air, for district heating and optimisation of heat production costs using electricity market instruments. The main source of heat in remote subnetworks, especially in places where low-temperature DH network is in operation. Project functionality is also to provide renewable heat in places where other, more attractive renewable and waste heat sources cannot be found. Providing ancillary services in the electricity market is an option.
2. Problem to be addressed
The main problem is to make use of low-temperature renewable heat potential that occurs everywhere and is location-independent. The specific problem is to select optimal heat pump technology and auxiliary systems (with heat storage as an option), propose a process flowsheet diagram of the process, system sizing and its integration with the district heating system, and electricity market, examination of productivity and energy performance and identification of constrains. In the case of ASHP installation in a subnetwork, the problem is also the interconnection and cooperation with the main network via a transmission pipeline. In the case of isolated remote (island) networks, the problem is also the selection of supplementary heat sources and/or storage technology.

An option is to consider the integration of different heat sources into a multisource heating system. Examples are air + river/lake, air + flue gasses, air + seasonal energy storage, air + waste heat.
3. Opportunity to be harnessed
Utilisation of abundant low-temperature heat source.
4. Replicability potential
Since ambient air is a source available everywhere, the replicability potential of this project is very high.
5. Specific project objectives
– To test hourly productivity and energy performance. – To examine temperatures and heat balance over the year. – To develop a standardised interconnection scheme. – To develop a relevant control strategy.
6. Type of equipment will be considered in the project
Heat pumps, heat exchangers of different types, and storage tanks.
7. Technological scope to be considered
Screw and piston compressor heat pumps, heat exchangers for heat recovery from sources at the temperature level of -15°C to 35°C. Large-scale turbomachinery-based heat pump is an option. A cascaded system for high-sink temperatures is an option.
8. Intended location of the system
Decentralised. The pilot location will be at the smaller separate DH network of Vilnius.
9. Hydraulic integration options
Direct interconnection; Standard connection of return-forward type.
10. Key design parameters
Heating capacity, temperature lift.
11. Ranges of specific parameters
Heating capacity in the range of several MW. Source temperature range: -20 to +35°C; source temperature drop of 5 to 7°C; network pressure: forward ~10 bar; return ~5 bar; network temperature: forward 65-115°C, return 40-60°C.
12. What is the primary output
Heat.
13. Options for operating modes

On/off; full load; base load operation; heat demand tracking; electricity price tracking; demand for ancillary services tracking; heat source tracking in case of multisource installations. Flexible production of heat and consumption of electricity could be considered, depending on electricity prices.
14. Control options
In remote systems local control. In integrated systems DCS. Heat output control. COP control (below ca. -10°C air temperature shut down should be considered due to low COP), water outlet temperature control. Operating pressure set by the network. Partial load enabled; on/off operation enabled; seasonal operation enabled. Implementation of heat demand response mechanisms is an option.
15. Sector integration
Two sectors are integrated: district heating and electricity. In the option with waste heat utilisation also the sector of waste heat origin is integrated
16. Influence of other sectors on the project
The electricity sector influences the project by price signals and demand for ancillary services. Demand-side response functionality is an option if heat storage is applied.
17. Degree of innovation
The degree of innovation is low regarding existing examples. However, an innovation potential lies in the implementation of innovative heat pump technology as well as in multisource system arrangement.
18. Other relevant information.
Requires cooperation with stakeholders. The key ones are the electricity company, municipality (regarding system location), heat users (regarding low-temperature solutions and demand side response options). VST's know-how from the 3 MW HP + 2900 m^3 TTES project currently under development should be used.

3.1.5. Specific project 5 – solar plant as a distributed heat source

Solar district heating is a well-known technology proven in dozens of systems worldwide. The biggest markets for solar district heating are Denmark (124 systems), Germany (43), Sweden (22), Austria (19), and China (18). On the other hand, there is no sufficient experience with solar district heating in the SET_HEAT project countries.

In existing DH systems solar heating plants can be implemented at centralised or distributed locations depending on land availability. Usually in big cities distributed solar heating plants are more relevant since the availability of land in densely built-up areas is reduced. Therefore, this option is taken into consideration for the model investment project.

Table 3.7. Project 5 definition card

Project name: Solar plant as a distributed heat source
Project acronym: SET_HEAT_SOLAR
Development team: TEB and CMESB (Romania) in cooperation with HEP and UNIZAG-FSB (Croatia) on a centralised solar plant
1. Specific functionality
The utilisation of solar energy for district heating.
2. Problem to be addressed
The main problem is to make use of solar energy for district heating in large cities where different plots of land and building roofs are scattered around the city. The specific problem is to select appropriate solar collector technology and auxiliary systems (with heat storage as an option), propose a process flowsheet diagram of the process, system sizing and its integration with the district heating system, examination of productivity and energy performance and identification of constraints. The problem is also to appropriately address the intermittent supply of heat from solar plants. An option is to consider the integration of different heat sources into a multisource heating system. Examples are solar + ambient air, solar + river/lake, and solar + waste heat.
3. Opportunity to be harnessed
Utilisation of abundant renewable low-temperature heat source; availability of scattered areas for the solar plant installation.
4. Replicability potential
Moderate replicability potential because of the availability of land, which is not attractive for other uses in cities. Successful pilot

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projects of small-scale distributed solar plants could open doors for many replicable projects in large cities.
5. Specific project objectives
– To select optimal collector technology. – To test hourly productivity and energy performance. – To examine temperatures and heat balance over the year. – To develop a standardised system configuration and interconnection scheme. – To develop a relevant control strategy.
6. Type of equipment will be considered in the project
Flat panel solar collectors, heat exchangers of different types, and storage tanks.
7. Technological scope to be considered
Large-surface hot water flat panel solar collectors, variable speed circulation pumps (with frequency inverters), tank thermal energy storage.
8. Intended location of the system
Decentralised. The pilot location will be on the roof of the selected thermal point (heat exchanger substation at the interconnection between transmission and distribution networks) in Bucharest. In addition, to cover the full scope of possibilities resulting from the implementation of solar systems, a centralised plant will be developed for a selected system in Croatia.
9. Hydraulic integration options
Indirect interconnection through heat exchanger; standard connection of return-forward type. Since the plant will be located relatively close to consumers, an option is an interconnection with secondary building internal installations.
10. Key design parameters
Collector area, heating capacity, hot water temperature, heat exchanger temperatures and pressures.
11. Ranges of specific parameters
Heating capacity in the range of tens of kW up to several MW, network pressure: forward ~10 bar; return ~5 bar; network temperature: forward 65-95°C, return 40-60°C.
12. What is the primary output
Heat.

13. Options for operating modes
Direct supply (base load operation); Supply and storage charge/discharge (heat demand tracking; heat source tracking); storage charge only, storage discharge only.
14. Control options
DCS to coordinate multiple components of the district heating system with distributed solar heating plants. Due to the intermittent nature of solar energy availability, a Model Predictive Control (MPC) that uses a model of the solar heating system to predict future behaviour and optimize control actions will be required. Operating pressure set by the network; seasonal operation enabled. Implementation of heat demand response mechanisms is an option.
15. Sector integration
There is no sector integration enabled by this project.
16. Influence of other sectors on the project
Not applicable
17. Degree of innovation
Innovation potential lies in the implementation of small-scale distributed solar plants located close to consumers. A certain innovation potential lies also in multisource system arrangement and hybridisation.
18. Other relevant information.
Requires cooperation with heat users (regarding low-temperature solutions and demand-side response options).

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3.1.6. Specific project 6 – remote seasonal Pit Thermal Energy Storage facility in district heating network

Large-scale storage is a necessary component of district heating systems if surplus heat available in summer is considered to be shifted for autumn or winter. Initial simulations revealed that this technology can be also used in daily balancing of heat production both in the summer and the winter.

Heat storage technology based on PTES technology is the most widespread heat storage technology today. It involves storing hot water in earth tanks with an insulated floating cover. The sides and bottom of the storage will be covered with a high-density polyethylene (HDPE) thermoplastic polymer liner which should be suitable to store water up to a maximum temperature of approximately 95°C with the durability of the polymer linings to ensure lifespan for at least 30 years. The upper lining of the storage facility should have sufficient thermal insulation, be weatherproof, should be resistant to UV radiation, and should be equipped with a suitable rainwater drainage system. The supplementary water-water heat pump system is also considered as a piece of supplementary equipment that increases the thermal capacity of the PTES.

Table 3.8. Project 6 definition card

Project name: Remote seasonal PTES facility
Project acronym: SET_HEAT_PTES
Development team: ECO, PO, KELVIN, SUT
1. Specific functionality
Increasing flexibility in the absorption of renewable energy and waste heat, and district heating system balancing. Also enabling heat production cost optimisation.
2. Problem to be addressed
Temporal disconnection between heat demand and heat generation to enable improved uptake of heat from waste heat or renewable heat producers
3. Opportunity to be harnessed
Availability of surplus heat. In addition, the PTES technology can take advantage of opportunities resulting from existing conditions such as land availability, location in relation to heat sources and distance

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from possible connection points in the DH grid, geological and hydrogeological characteristics of the site and soil structure.
4. Replicability potential
The replicability potential of thermal energy storage solution (PTES in particular) is significant due to the need to tackle the commonly occurring problem of the periodic nature of renewable resources and the mismatch between waste heat supply and system heat demand.
5. Specific project objectives
– To store surplus heat and shift it to periods of high demand. – To develop PTES sizing procedure. – To test hourly energy performance. – To develop a relevant control strategy for the district heating system with storage. – To examine temperatures and heat balance over the year. – To develop a standardised system configuration and interconnection scheme.
6. Type of equipment will be considered in the project
Pit Thermal Energy Storage Technology, heat exchangers. Heat pump is an option.
7. Technological scope to be considered
PTES of 150 000 – 250 000 m^3 of storage volume, plate heat exchangers, screw or piston compressor heat pumps.
8. Intended location of the system
Decentralised. The pilot storage facility will be developed for the Opole DH system.
9. Hydraulic integration options
Indirect interconnection through heat exchanger. The connection type (return-forward, return-return, other) will be determined once the conceptual and design work has been completed, however, the hydraulic circuit of the storage facility should be closed circuit. This is due to the need for water quality, which should not affect the durability of the HDPE membrane. It is recommended to fill the storage with treated water.
10. Key design parameters
Storage volume, storage temperature, heat exchanger area.

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11. Ranges of specific parameters
Storage volume, network pressure: forward ~10 bar; return ~5 bar; network temperature: forward 65-95°C, return 40-60°C.
12. What is the primary output
Heat.
13. Options for operating modes
It will not be designed as a typical seasonal thermal storage. The operation mode of the planned PTES will be multifunctional, depending on the number, type and operation priority of the connected heat sources loading the storage pit.
14. Control options
DCS supervisory control to coordinate multiple components of the district heating system with large storage volumes. Operating pressure set by the network. The basic control parameters of the PTES are the temperature distribution in the storage which consequently influences the current level of storage load.
15. Sector integration
Seasonal storage indirectly enables the integration of district heating, electricity and industry sectors. It enables flexible operation and optimisation of other components such as cogeneration units, heat pumps and electric boilers, harvesting various energy inputs from different sectors and capturing opportunities resulting from variable prices and intermittent availability of waste and renewable heat.
16. Influence of other sectors on the project
Depending on specific systems, different sectors may impact the project considerably. Such an impact will result in different optimal storage volumes.
17. Degree of innovation
In this particular case, the innovative elements of the project are the innovative and unique construction solutions that have been used for the geologically difficult location of a storage facility in a marl pit.
18. Other relevant information.
Requires cooperation with stakeholders. The key ones are the municipality (regarding system location and permits), heat users (regarding low-temperature solutions and demand side response options), waste heat owners and electricity companies.

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PTES should be optimised considering the target structure of a given DH system and the components that will be added to it in the future. Hour-by-hour simulation of the annual operation of the planned PTES has to be performed on account of proper sizing and considering the various scenarios of possible sources supplying the pit.

4. Prefeasibility studies of model investment projects

The previous WP3 activities resulted in a ranking list of DH technologies suitable for the decarbonisation of the sector. Based on the ranking list, 6 so-called model investment projects were defined:

a) SET_HEAT_SEWAGE, which focuses on heat recovery from treated sewage,

b) SET_HEAT_RETAIL, which focuses on heat recovery from supermarkets,

c) SET_HEAT_WATER, which focuses on a surface water heat pump,

d) SET_HEAT_AIR, which focuses on an air source heat pump,

e) SET_HEAT_SOLAR, which focuses on a solar plant as a distributed heat source,

f) SET_HEAT_PTES, which focuses on a remote seasonal PTES facility.

The identified types of projects were addressed with extensive pre-feasibility studies and other ready-made documentation that aimed at the development of documentation that would facilitate and streamline the development process, implementation and replication. In the course of the work SET_HEAT_WATER was split into SET_HEAT_RIVER and SET_HEAT_LAKE projects. In addition, the SET_HEAT_CHP project was taken into consideration, which focuses on waste heat recovery from low-temperature cooling circuits of existing gas engine cogeneration units.

In the SET_HEAT project task 3.2, the model investment projects were developed to the level of pre-feasibility study. The pre-feasibility study is a more detailed analysis of technological options for a given project. For example, heat recovery from sewage treatment plants may be based on different types of heat pumps and different system arrangements. A project is feasible when it meets technical, environmental, legal, organizational, financial, economic, and other requirements. In a pre-feasibility, it is initially checked for all identified technical options of the project.

The level of detail should enable an initial assessment of technology performance in a given district heating system. This should include

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technical performance, environmental performance, financial performance, and socioeconomic performance. The technical performance is the basis for the other assessments.

The aim of the pre-feasibility study is to select an optimal variant of the project for further feasibility study. In particular, the pre-feasibility study aims at the following:

- Precise identification of the needs of end users (quantitatively and qualitatively);
- First-level quantification of the contributions to the strategic goals;
- Clarification of project technical options;
- Determination of the number and scope of detailed studies required in various variants at the stage of feasibility study.
- Identification of significant technological constraints;
- Verification of compliance with regulations and standards;
- Whether the project does not threaten the environment (emissions, waste, wastewater, noise, radiation);
- Determination of flowsheet diagrams and technological parameters;
- Determination of cost of materials and scope of work;
- Definition of possible production programme and annual mass and energy balances;
- Estimation of capital expenditures (CAPEX);
- Estimation of operating expenditures (OPEX);
- Initial determination of the method of financing
- Preliminary analysis of the profitability of investment in different variants
- Determination of material and financial implementation schedule;
- Macroeconomic analysis taking into account externalities.

The layout of the technical pre-feasibility study to be performed within task T3.2 for each model investment project is the following:

Section 1: Project concept and overall technical characteristics
Overall characteristics of the project. Innovative elements. System integration characteristics.

Section 2: Input data
Reference models of loads, ambient conditions, etc.

Section 3: Technology options and characteristics

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Description of key components. Balance of Plan (BoP) components. Selection of specific equipment to be considered (different options). Basic engineering data and applicable standards (technical specification sheets). Description of the supplier market and availability of key system components. Benchmark parameters such as availability, reliability, auxiliary energy consumption, etc. Environmental impact data (emissions, wastes, sewage, noise and radiation).

Section 4: Process identification diagram
System boundary definition. Alternative system configuration schemes.

Section 5: System integration
Alternative interconnections with key systems (i.e. heat source, district heating,

Section 6: Technical design parameters
Main equipment sizing, auxiliary equipment sizing, selection of thermodynamic parameters (temperature, pressure, volume, etc.)
Parameters for design, parameters for monitoring (KPIs)

Section 7: Operational characteristics
Assumptions for operational characteristics. Range of parameters in operation window, Minimum and maximum parameters, etc.

Section 8. System control
Alternative control methods, control signals, defining operation modes and control recommendations.

Section 9. System modelling
Mathematical models of the system enabling hourly simulations. System simulations under variable boundary conditions. Identification of key technical constraints.

Section 10: Production profile, mass and energy balance
Summary of system simulations. Aggregation of results for further environmental, financial and economic studies.

Section 11. Service and maintenance requirements
Typical maintenance procedures. Maintenance schedules and instructions if possible.

Section 12. Scalability and replicability conditions.

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Location and site requirements. Possible range of technical parameters (e.g. equipment size). District heating network requirements (e.g. temperature characteristics). Requirements for external systems (e.g. electricity supply, water supply, etc.).

The **SET_HEAT_SEWAGE** Project addresses the integration of a wastewater-source heat recovery system into the district heating network (DHN) of Opole, Poland. The objective is to recover renewable low-temperature heat from treated wastewater at the Opole Central Sewage Treatment Plant (CSTP) and supply it to ECO S.A.'s district heating system using high-temperature heat pumps (HTHPs). The expected installed capacity is 10–12 MW_{th}, covering a significant portion of Opole's base heat load. The project demonstrates how municipal wastewater infrastructure can be coupled with district heating to create a circular, low-emission, and energy-efficient urban energy system.

At the reference state, ECO S.A.'s district heating network serves around 120,000 residents in Opole and the surrounding areas. It is currently supplied mainly by natural gas-fired combined heat and power (CHP) units and coal-fired peak-load boilers.

The installation site is situated at the CSTP, which discharges treated effluent into the Odra River. Treated wastewater leaving the CSTP maintains a stable annual temperature between 13 °C and 27 °C, providing a reliable heat source for recovery. Water-to-water heat pumps will upgrade this energy to 70–95 °C for district heating. Four system configurations were analysed, combining modular and single industrial heat pump systems for efficiency, redundancy, and scalability.

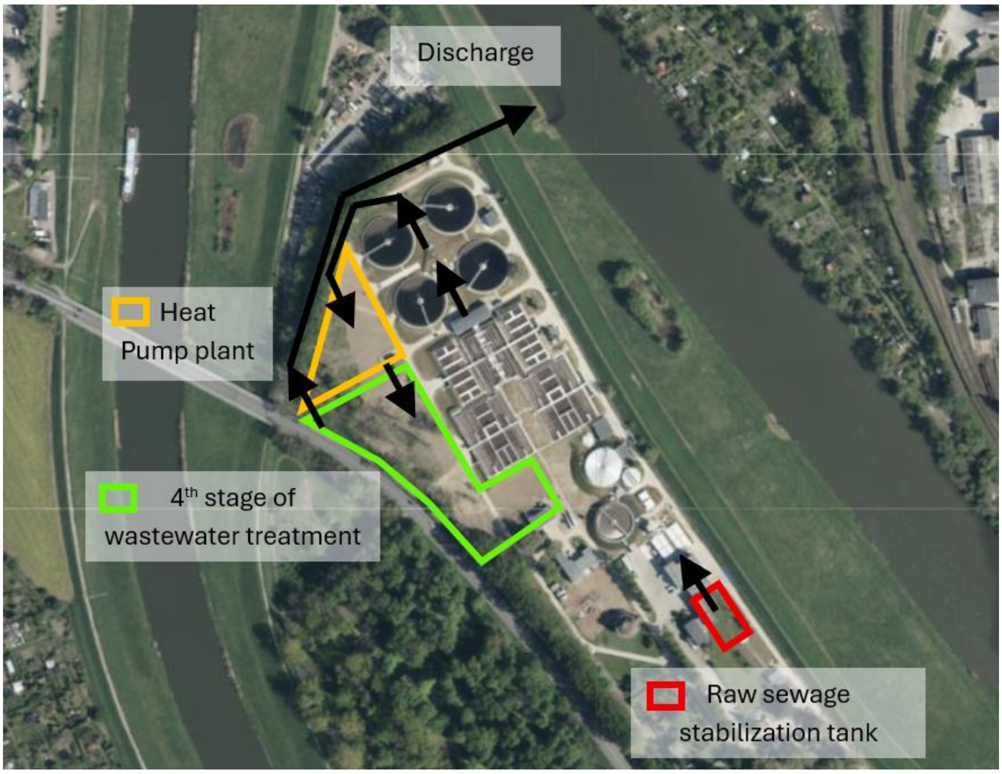

Fig. 4.1. Location of the heat pump system for heat recovery from treated sewage in Opole

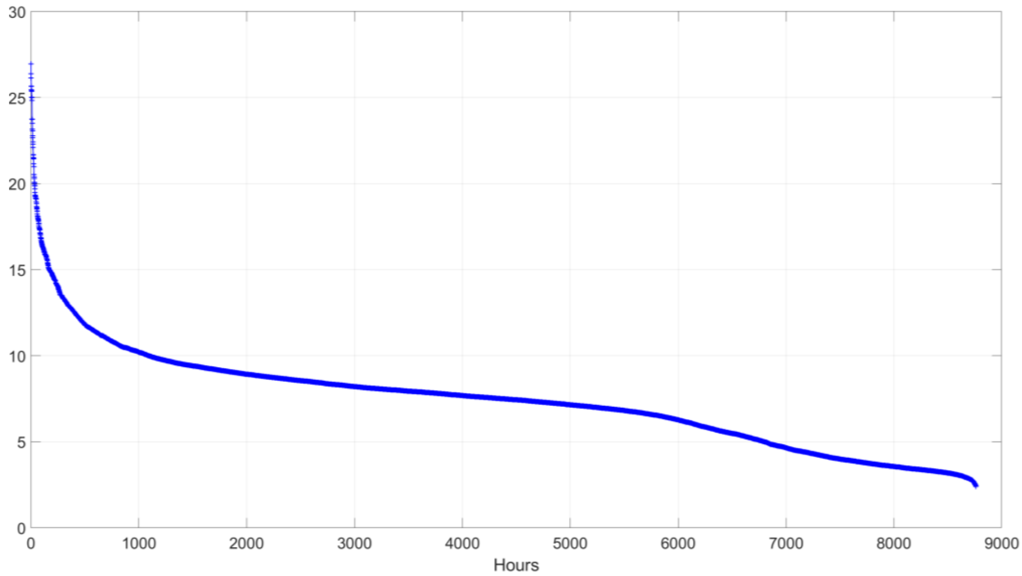

Fig. 4.2. Heat recovery potential from treated sewage in Opole

The installation will comprise:

- Wastewater intake and screening systems,
- Wastewater buffer tank of around 125 m3 capacity for flow and temperature stabilisation,
- High-temperature industrial heat pump system,

- Technical building (approx. 400 m²) with heat exchangers and DHN water pumping station,
- Intermediate heat exchangers separating the wastewater and heat pump circuits (optional, depending on heat pump solution),
- Medium-voltage (20 kV) grid interconnection and protection systems,
- Electrical transformer station,
- Hydraulic interconnection with pre-insulated pipelines connecting to the DH network
- SCADA and DCS control systems.

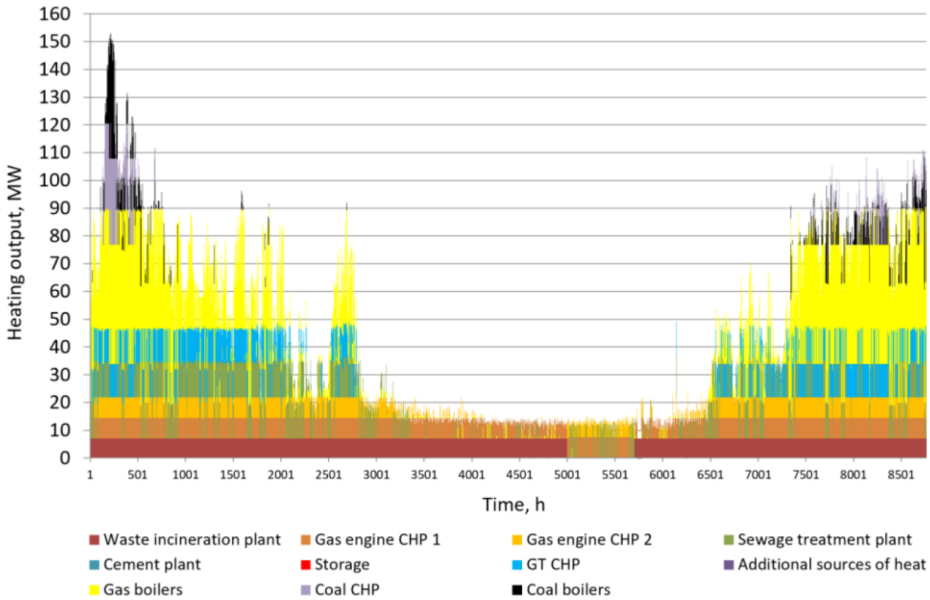

Fig. 4.3. Operation of the heat pump in the district heating system

The public version of the SET_HEAT_SEWAGE pre-feasibility study is available at: https://setheat.polsl.pl/resources/26

The **SET_HEAT_RETAIL** project aims to demonstrate how waste heat from supermarket refrigeration systems can be recovered and integrated into district-heating (DH) networks, replacing fossil fuel-based heat production. The IKI Brasta supermarket in Kaunas, Lithuania, serves as a pilot case to show the feasibility of connecting Danfoss Heat Recovery Unit (HRU) systems to the municipal DH grid operated by Kauno Energija. The project demonstrates a replicable model for local energy cooperation between the retail and district heating sectors.

The public version of the SET_HEAT_RETAIL prefeasibility study is available at: https://setheat.polsl.pl/resources/33

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The pilot installation is located at IKI Brasta, Brastos g. 28, Kaunas, Lithuania. The site was selected due to its proximity to the Kaunas DH network, availability of a modern CO_2 refrigeration system, and cooperation readiness of IKI Lietuva UAB. The project consists of the installation of the HRU (actually, it is already in place), heating substation, and controls.

Fig. 4.4. CO_2 refrigeration machine in supermarket

Fig. 4.5. Danfoss Heat Recovery Unit

The system captures waste heat from the CO_2 refrigeration cycle via a Danfoss Heat Recovery Unit (HRU) with a nominal heat capacity of 337 kW. Part of this heat is used internally at the supermarket for space heating and domestic hot water. The surplus heat, approximately 1,240 MWh per year, is exported through a prefabricated heat-station module connected to the Kaunas district heating return line. The exported water temperature is maintained at 60–65°C, suitable for injection into the DH grid. The HRU operates at an average seasonal COP of 3.0, consuming roughly 415 MWh of electricity annually.

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The **SET_HEAT_RIVER** Project is an important decarbonisation initiative for the City of Zagreb. It integrates a 21 MW water-to-water heat pump system that utilises the Sava River as a renewable heat source, reducing dependency on natural gas and enhancing energy efficiency within the city's district heating network.

While the heat pump's operation is generally environmentally friendly compared with fossil fuel-based heat production, several ecological impacts must be considered. The heat pump system extracts heat from river water and returns it 3–4°C cooler. With the TE-TO's existing discharge already raising river temperature by around 6°C, the combined thermal dynamics must be analysed.

Fig. 4.6. Heat pump location at TE-TO plant

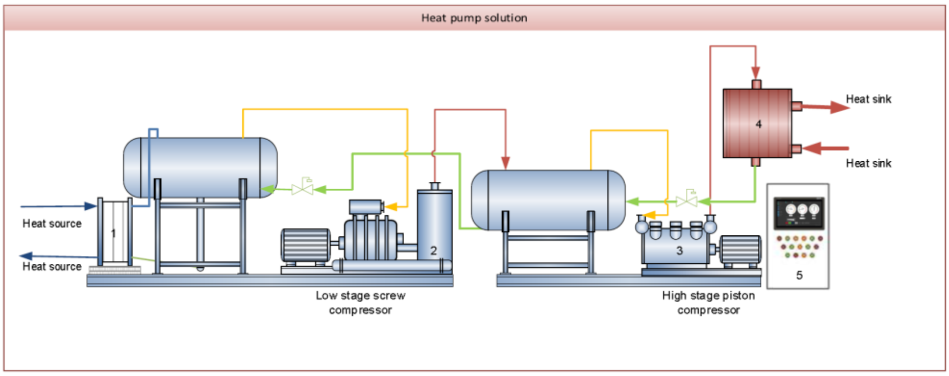

Fig. 4.7. Proposed NH_3 heat pump solution

The project consists of:

– Using Sava River as a renewable heat source (4–25°C seasonal temperature range),

– Installation of six 3.5 MW GEA GSHP ammonia heat pump units,

– Grid electricity supply with future integration of local solar PV,

– Integration with TE-TO Zagreb district heating infrastructure,

– Digital monitoring and control systems for predictive optimisation.

The public version of the SET_HEAT_RIVER prefeasibility study is available at: https://setheat.polsl.pl/resources/28

The **SET_HEAT_LAKE** project aims to demonstrate a viable pathway toward decarbonisation of Bucharest's centralised district heating system by replacing fossil-fuel-based heat generation with renewable heat derived from Lake Morii through a large-scale lake-water-source heat pump system. The project also addresses the challenge of urgent and strategic modernisation of Bucharest's district heating system through an innovative, replicable heat pump technology capable of delivering up to 50 MW_{th} of renewable heat. The project has significant societal relevance as it affects hundreds of thousands of Bucharest residents and supports Romania's broader sustainability transition.

Lake Morii, with a surface area of 2.46 km² and operational depths of 10–12 m, offers a substantial and relatively stable water volume suitable for large-scale heat extraction. Although constructed primarily as a flood-control reservoir, its size and depth provide favourable thermal inertia, allowing the lake to maintain workable temperatures for heat-pump operation throughout the year.

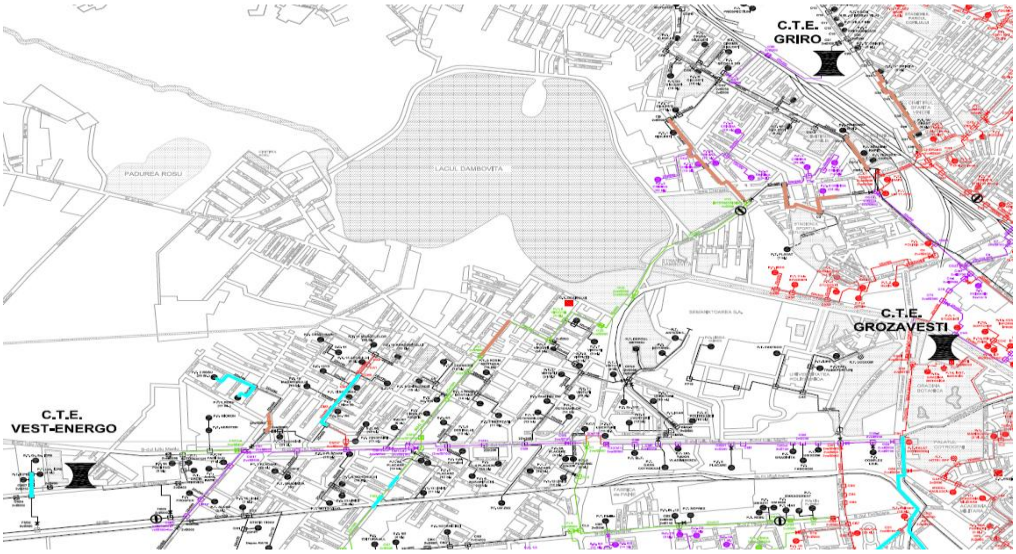

Fig. 4.8. Lake Morii location against DH infrastructure in Bucharest

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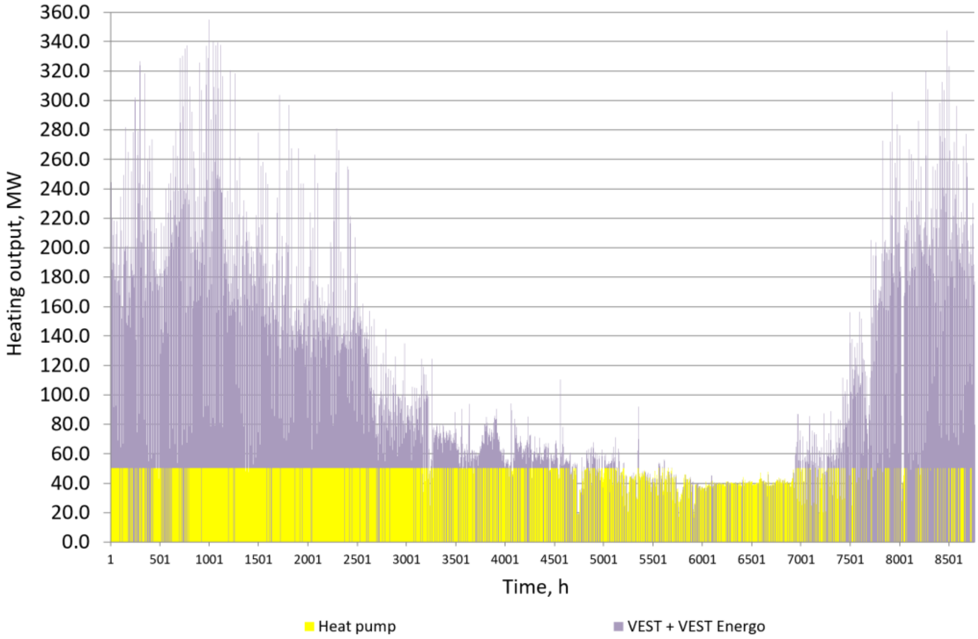

Fig. 4.9. Simulated operation of $50MW_{th}$ lake water heat pump in Bucharest

Seasonal water temperatures at usable intake depths typically range from 6 °C in winter to 22 °C in summer. This moderate variation supports efficient heat-pump performance, particularly because deeper layers are less affected by daily or weather-related fluctuations. Winter temperatures remain high enough to ensure reliable operation, while summer conditions enable high COP values and operational flexibility.

The technical scope of the SET_HEAT_LAKE project encompasses the full chain of systems required to extract renewable thermal energy from Lake Morii, upgrade it using industrial high-temperature heat pumps, and deliver it into the Bucharest district heating network (SACET). At its core, the project proposes the installation of a 50 MW_{th} water-to-water heat pump facility, composed of two 25 MW_{th} CO_2 (R744)-based heat pump trains, capable of supplying hot water at approximately 95–100°C.

Heat pump installation forms the central element of the technical scope. Each CO2 heat pump train includes high-speed compressors, gas coolers, evaporators, expansion devices, and fully integrated automation and safety systems. These units operate on a transcritical cycle capable of achieving high output temperatures while maintaining seasonal efficiencies around a COP of 3.0. The twin-train configuration ensures redundancy, allowing the facility to operate continuously even during maintenance and providing flexible load modulation in response to network demand or electricity market signals.

Electricity supply and electrical integration represent another major component of the technical scope. The facility requires an estimated peak electrical load of roughly 17–18 MWe, supplied through new or upgraded 10–20 kV medium-voltage feeders from the municipal grid.

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Dedicated transformers, switchgear, protection systems, and harmonic mitigation ensure stable and compliant operation. An energy management system (EMS) coordinates heat pump operation with hourly electricity prices and district-heating requirements.

The public version of the SET_HEAT_LAKE prefeasibility study is available at: https://setheat.polsl.pl/resources/30

The technical scope of the **SET_HEAT_AIR** project encompasses the modernization and partial decarbonization of the Naujoji Vilnia district heating system in Vilnius, Lithuania, through the integration of advanced low-temperature renewable heat technologies and thermal energy storage. In particular, the project features an integration of air source heat pumps (ASHPs) and a 3,000 m^3 thermal storage tank (TTES) into the district heating (DH) network.

The project objectives are:

– Reduce natural gas consumption and related CO_2 emissions.

– Increase energy efficiency by integrating industrial-scale ASHPs.

– Improve system flexibility and resilience through thermal energy storage.

– Enable participation in electricity balancing markets (mFRR/aFRR).

– Support EU climate neutrality targets for 2050.

The core of the project is the installation of two air-to-water ASHP units with a combined nominal thermal output of approximately 4.9 MW under standard conditions, capable of supplying water at temperatures up to 80–85 °C. The selected technology, based on CO_2 refrigerant and an eight-compressor modular design, ensures high efficiency (COP of around 2.5 at 0 °C ambient temperature) and aligns with the EU's F-gas phase-down requirements by using low-GWP refrigerants. The heat pumps are designed to operate reliably down to outdoor temperatures of –10 °C, beyond which existing biomass and gas boilers take over as peak-load or backup sources. Their role is primarily to serve the base thermal load during milder weather and fully cover summer heat demand, thereby electrifying a significant share of the annual heat production.

The TTES, sized at approximately 3,000 m^3, is a central enabling component of the system. As a large, above-ground, atmospheric hot-water tank with stratified operation, it provides the ability to buffer heat production and decouple generation from immediate consumption. By storing excess heat during hours of low electricity prices or high renewable electricity availability, the tank optimises the operating schedule of the heat pumps and reduces the cycling and partial-load inefficiencies

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of the existing biomass boilers. Additionally, the TTES mitigates the thermal dip that may occur during ASHP defrost cycles and supports peak-shaving during high-demand periods, thus enhancing supply reliability. Its integration into the return and supply lines via top-bottom diffusers allows for efficient use of the full temperature differential available in the district heating network.

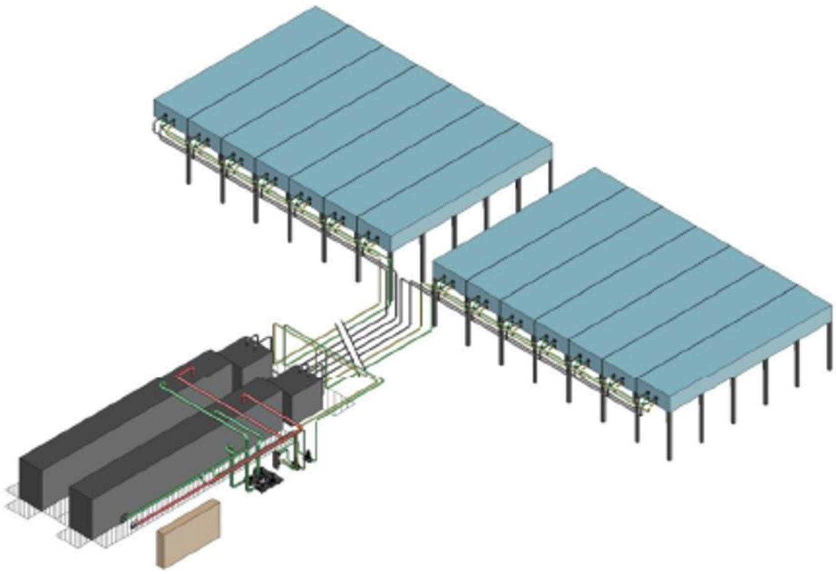

Fig. 4.10. Proposed arrangement of air-source heat pumps

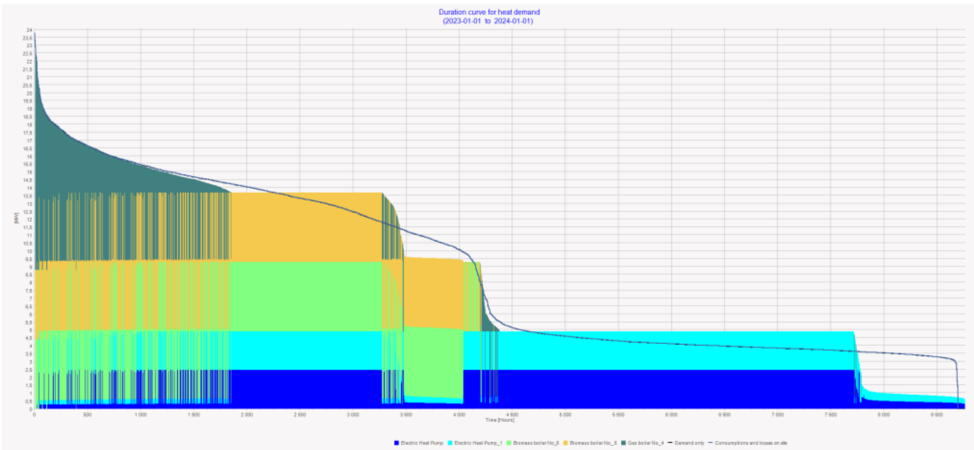

Fig. 4.11. Simulated operation of air-source heat pumps

The public version of the SET_HEAT_AIR prefeasibility study is available at: https://setheat.polsl.pl/resources/29

The **SET_HEAT_SOLAR** project is a multi-country initiative implemented under the broader SET_HEAT framework, aiming to assess the technical and economic feasibility of integrating large-scale solar thermal systems into existing district heating (DH) networks. The prefeasibility work covers two complementary sub-projects:

1. Rooftop-based solar district heating integration in existing district heating systems in Bucharest, Romania, implemented in cooperation

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with Compania Municipală Termoenergetica București (CMTEB). The technical documentation provides detailed insights into land constraints, technology selection, operational integration, and the socio-economic relevance of decentralised solar heat production in densely built urban areas.

Fig. 4.12. Proposed arrangement of rooftop solar heating plants in Bucharest

2. A centralised solar thermal plant combined with thermal storage and auxiliary systems in Zaprešić, Croatia, implemented together with HEP-Toplinarstvo. The project explores multiple technological configurations, namely high-temperature and low-temperature solar collectors, thermal storage options, and heat pumps.

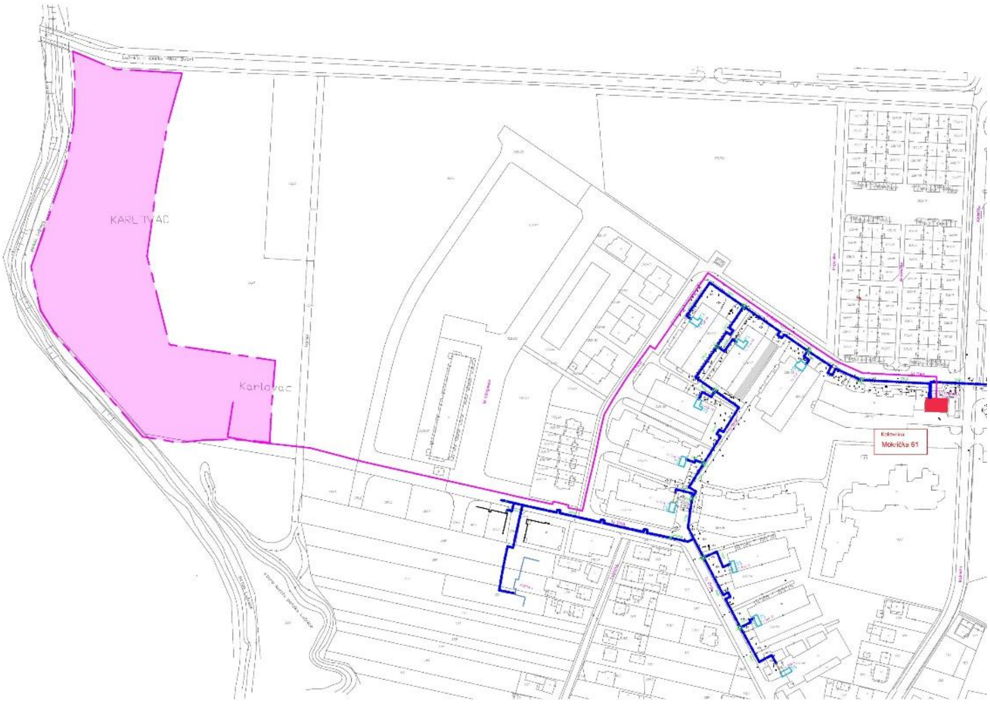

Fig. 4.13. Proposed central solar heating plant in Zaprešić

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The Bucharest component explores the integration of solar thermal systems at two district heating substations: PT 2 Fundeni and PT Ramuri Tei. These substations currently rely exclusively on centrally produced thermal energy. Installation of rooftop vacuum-tube solar collectors, thermal storage tanks, and system integration equipment is proposed to deliver at least 50 MWh/year of solar heat per site.

The Zaprešić sub-project evaluates the feasibility of constructing a large ground-mounted solar collector field (~4,000 m²), thermal storage (600 m³), and potential auxiliary systems (geothermal heat pumps, dry coolers) to supply heat to the local closed DH system. The analysis was structured around four scenarios (S1–S4), integrating high-temperature vacuum collectors, low-temperature flat-plate collectors, and different storage and auxiliary technologies.

The public version of the SET_HEAT_SOLAR prefeasibility study is available at: https://setheat.polsl.pl/resources/32

The **SET_HEAT_PTES** Project examines the technical, environmental, economic, and regulatory feasibility of integrating a large-scale Pit Thermal Energy Storage (PTES) system into the Opole district heating (DH) system.

The Opole PTES concept is not just a heat-storage project. It is explicitly designed as a sector-coupling asset that links the district heating (DH) system with the electricity system. The study assumes a future DH infrastructure that actively interacts with the power system through: flexible CHP operation, large heat pumps (HPs), an electric boiler, and the PTES itself. Together, these assets form a controllable portfolio of electricity generation and demand that can respond to market prices and system needs.

At the system level, this integration is driven by rapidly growing RES penetration in Poland and the emergence of frequent low and even negative wholesale electricity prices. These conditions make it attractive to shift electricity consumption (heat pumps, electric boiler) into low-price/RES-surplus hours, and increase electricity generation from high-efficiency CHP units in high-price hours, using PTES to absorb or release the corresponding heat.

The PTES with an integrated "lift-and-store" hub (co-located HP) is explicitly conceived as a node where the DH network, multiple heat sources and the utility power grid (UPG) meet.

The technical scope of the project covers:

- Heat sources such as CHP units, waste incineration plant, cement plant, industrial heat pump, future solar thermal and waste heat sources.
- Geological conditions such as favourable marl and sandstone formations, low groundwater flow, are suitable for large-scale seasonal storage.
- Market conditions, including variable electricity pricing, increasing RES penetration, CO_2 price uncertainty.
- Technical data, such as pit volumes between 100,000–500,000 m^3, storage efficiency 75–87% (improving over time), integration options with a heat pump to widen the usable temperature range.
- Required infrastructure upgrades, such as network interconnections, pumping, heat exchangers, permitting, and engineering.

Gas-fired CHP units in Opole are operated according to both heat demand and electricity price signals. When power prices are high, the marginal cost of heat from CHP can become negative, since electricity revenues exceed fuel and CO_2 costs, so CHP is prioritised after the waste-to-energy plant. When prices are low or negative, CHP operates only if its heat is still cheaper than alternative sources (coal/gas boilers).

With PTES, CHP operation is decoupled from instantaneous heat demand. In high-price hours, CHP can run closer to full load, with surplus heat charged into PTES instead of throttling units down. In low-price hours or low heat demand, CHP can be backed off while heat is withdrawn from PTES to meet the load. The findings reveal that seasonal storage significantly increases electricity generation from high-efficiency cogeneration, although this may increase local CO_2 emissions if gas CHP output is expanded.

The industrial HP at the sewage treatment plant provides low-temperature heat via the DH network. To use this heat for charging PTES at around 90–95 °C, an additional HP at the PTES site is proposed: the lift-and-store hub. This configuration draws surplus low-temperature heat from the network, lifts its temperature with electricity, and stores it seasonally in PTES.

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Fig. 4.14. Considered PTES site in Opole

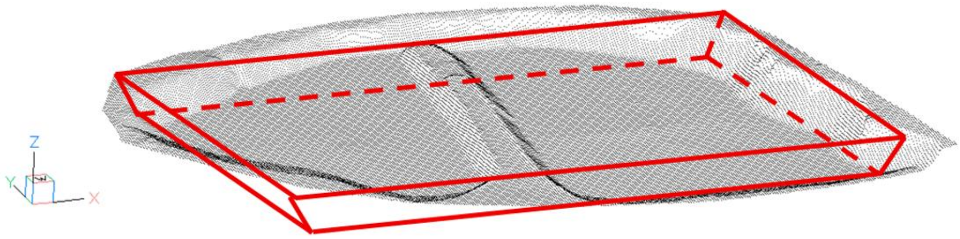

Fig. 4.15. Sizing PTES site in Opole

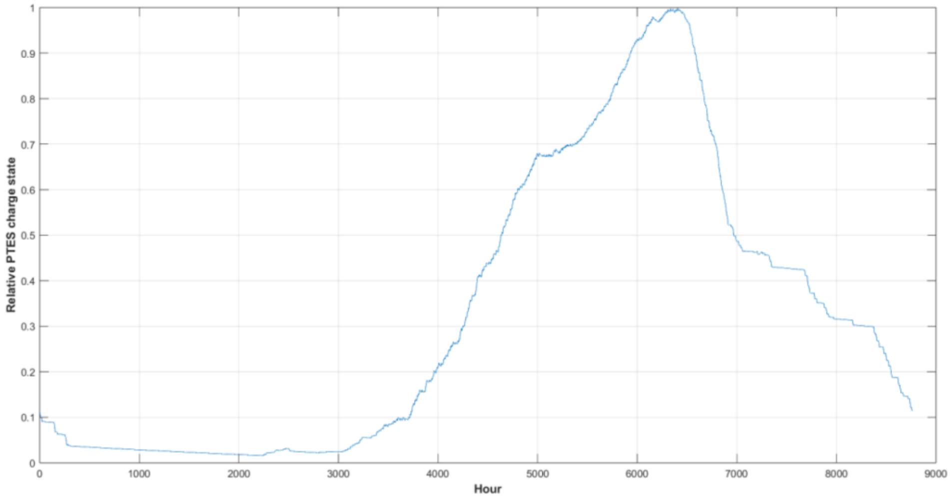

Fig. 4.16. Sample PTES state of charge simulation

The public version of the SET_HEAT_PTES prefeasibility study is available at: https://setheat.polsl.pl/resources/27

The proposed **SET_HEAT_CHP** project concerns the modernisation and partial decarbonisation of the district heating (DH) system in Opole through the deployment of an integrated hybrid heat-recovery and heat-pump system. The intervention targets low-temperature (LT) and medium-temperature (MT) waste-heat streams originating from

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gas-engine cogeneration units and couples them with high-efficiency industrial heat pumps to increase the usable share of renewable and waste-heat sources in district heat supply.

The project introduces two technological pathways for utilising these waste-heat streams, namely Variant 1 and Variant 2. Both involve the installation of new heat-exchange equipment, a two-stage condensing economiser (ECO II), and industrial water-source heat pumps (WSHPs). Variant 1 separates LT and MT heat recovery, using a medium-sized WSHP to upgrade LT heat and integrating the economiser directly with the DH return. Variant 2 integrates both LT and MT heat into a single larger WSHP for full upgrading. In both cases, an air-source heat pump (ASHP) system provides renewable-based heat during engine down-time, enabling operational flexibility and greater overall utilisation of low-cost electricity.

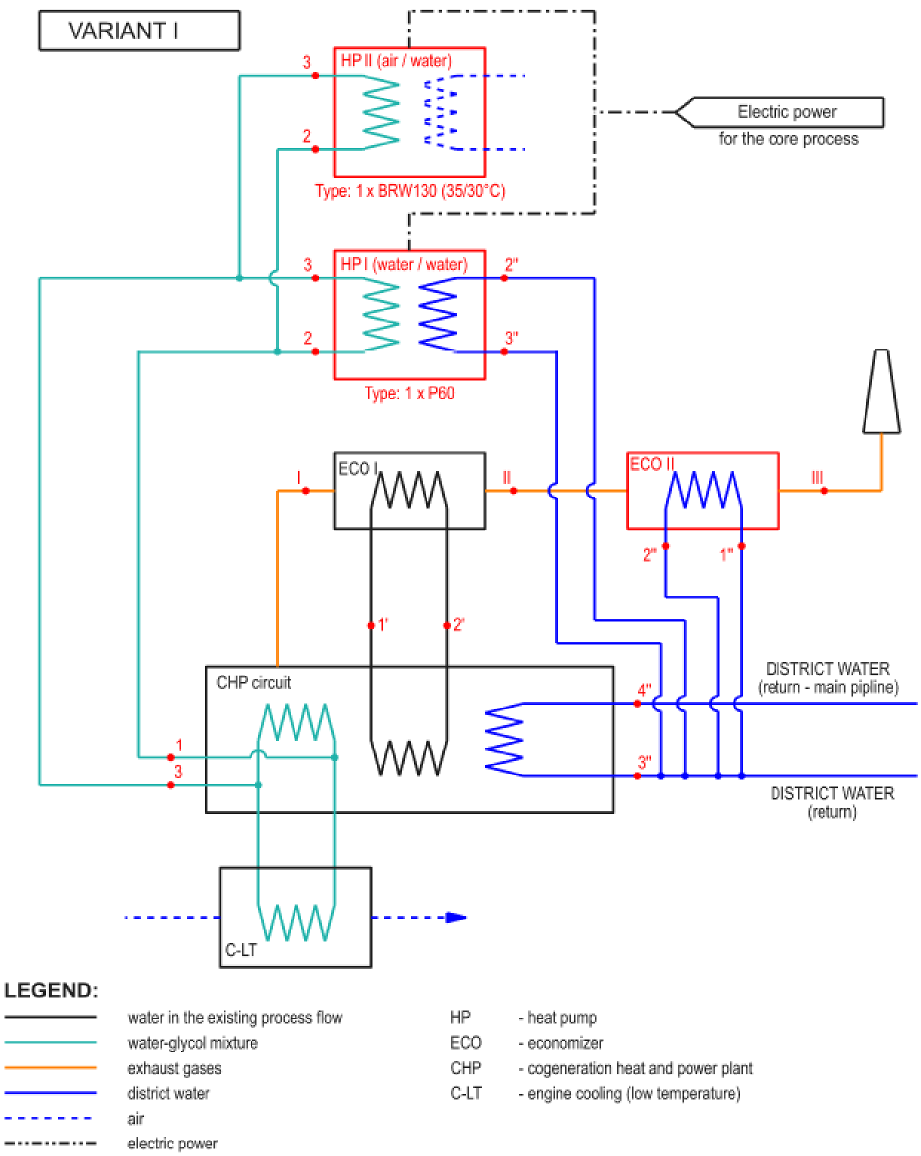

Fig. 4.17. Sample system configuration for recovery of additional heat from existing gas engine CHP units

The public version of the SET_HEAT_CHP prefeasibility study is available at: https://setheat.polsl.pl/resources/31

5. District heating network performance, recommendations and guidelines for network technical interventions

The transition toward low-temperature, decentralised, and decarbonised district heating systems represents one of the most complex modernisation challenges facing the European heating sector. Deliverable D3.4 of the LIFE SET-HEAT project addresses this challenge by presenting a comprehensive methodological framework for evaluating district heating network performance and identifying technically sound pathways for system optimisation. Although the document offers preliminary insights, it emphasises throughout that definitive operational recommendations must be supported by detailed engineering analyses and project-specific assessments.

At the heart of the report lies the recognition that contemporary district heating systems must evolve rapidly in response to both technical and economic pressures. The optimisation of supply and return temperatures is essential for enhancing network efficiency and enabling the transition toward fourth- and fifth-generation district heating, where supply temperatures do not exceed 90 °C or 70 °C respectively. Lower temperatures not only reduce heat losses but also support the integration of renewable and waste heat sources, whose operating characteristics differ substantially from those of conventional high-temperature fossil-fuel-based production. However, temperature optimisation requires careful analysis: even seemingly minor modifications to operating parameters can produce cascading effects across thermally and hydraulically interconnected networks. This is especially true in systems where multiple heat sources, often decentralised, must operate in concert, and where heat generation is increasingly shaped by volatile electricity market conditions.

To address these complexities, the report adopts a two-stage methodological approach. First, an in-depth operational audit is carried out to establish a reliable baseline. This includes the verification of GIS, SCADA, and billing data, and the construction of a digital twin capable of replicating actual system behaviour through thermal and hydraulic modelling. The Leanheat Network software serves as the analytical backbone, enabling simulations of current and future operating scenarios. The second stage involves forward-looking scenario analyses where optimisation potential is examined under conditions such as the integration of low-temperature heat sources, the reconfiguration of pumping

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strategies, the division of networks into supply zones, and the replacement of static control tables with dynamic multi-source control algorithms.

Two case studies, Opole in Poland and District 6 of Bucharest in Romania, were selected to demonstrate and refine this methodology. The system in Opole benefits from extensive and reliable data, enabling the creation of a highly accurate digital twin. The modelling revealed that the system, although well-developed, is constrained by several hydraulic bottlenecks, particularly at the network peripheries. Initial simulations showed that significant pressure limitations would arise if supply temperatures were reduced under current infrastructure conditions. However, by calibrating actual return temperatures from more than 1,400 substations, the model was able to reproduce realistic operating behaviour and uncover opportunities for optimisation. This allowed the authors to construct an improved heating curve that better reflects actual system demand patterns. Moreover, the integration of eight waste heat sources, representing 26.3 MW of additional capacity, proved to be a decisive factor in enabling further supply temperature reductions, even down to 100/54.5 °C, provided selective pipeline upsizing was implemented at identified bottlenecks. The Opole case thus illustrates how a combination of data-driven modelling and targeted investment can unlock significant efficiency potential while supporting decarbonisation goals.

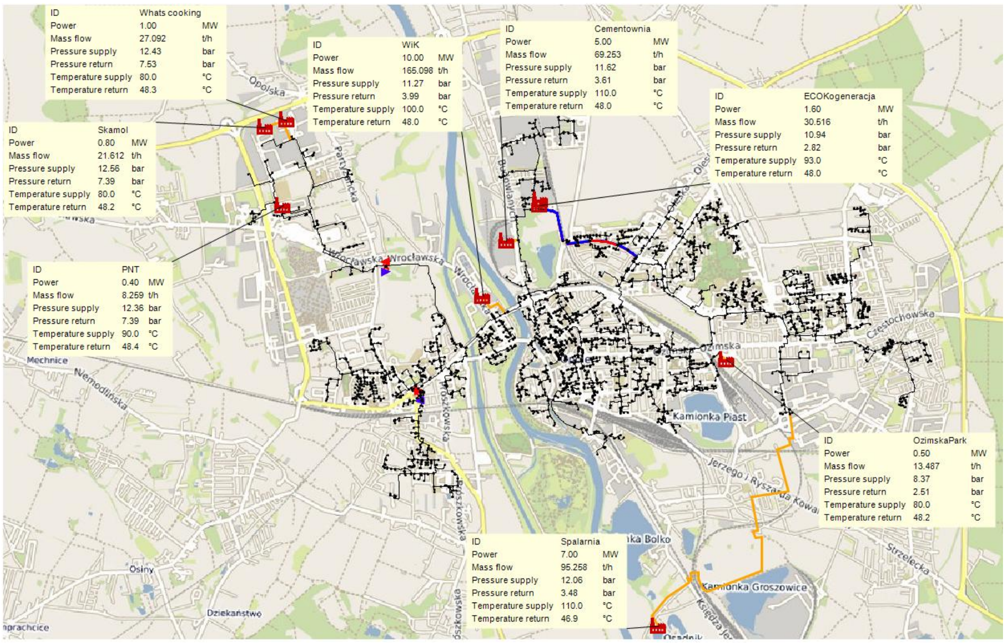

Fig. 5.1. DHN in Opole with waste heat sources of a high probability of connection

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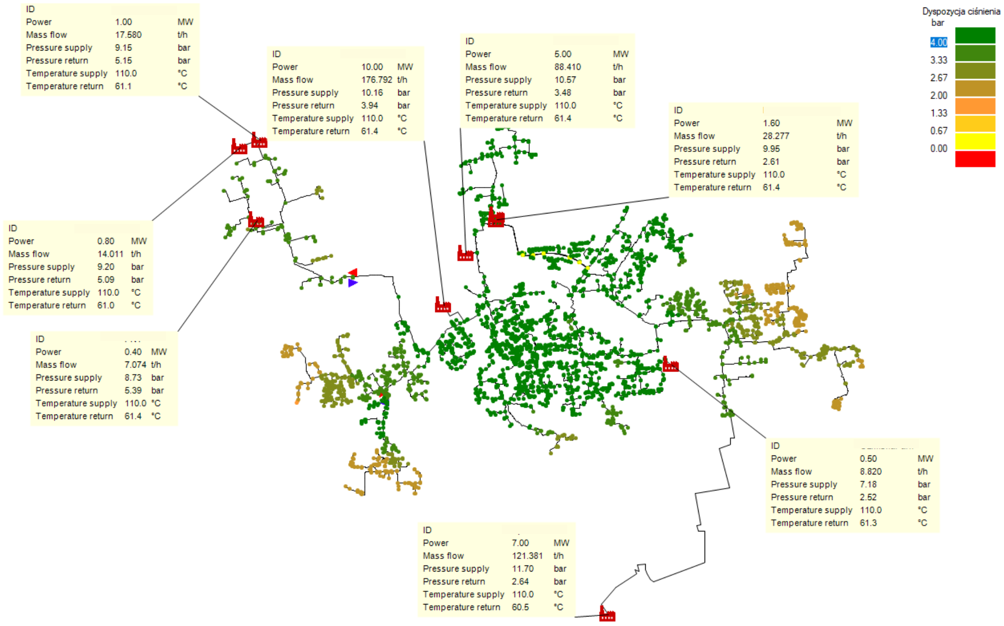

Fig. 5.2. Opole DHN pressure difference theme for parameters 110/61.5 °C at an ambient temperature of -20 °C

The Bucharest case study presents a markedly different context. Here, the challenge does not stem primarily from high performance but rather from systemic degradation and data inconsistency. The absence of a standardised GIS system, incomplete topology information, and the need to manually match attributes across DWG and Excel files reveal the magnitude of the city's modernisation needs. Despite these limitations, the construction of a partial digital model was still possible, laying the groundwork for more comprehensive future analyses. The Bucharest case stands as a clear example of how institutional and data-management shortcomings can become barriers to technical optimisation, underscoring the necessity of robust digital infrastructure before sophisticated modelling and temperature-reduction strategies can be meaningfully applied.

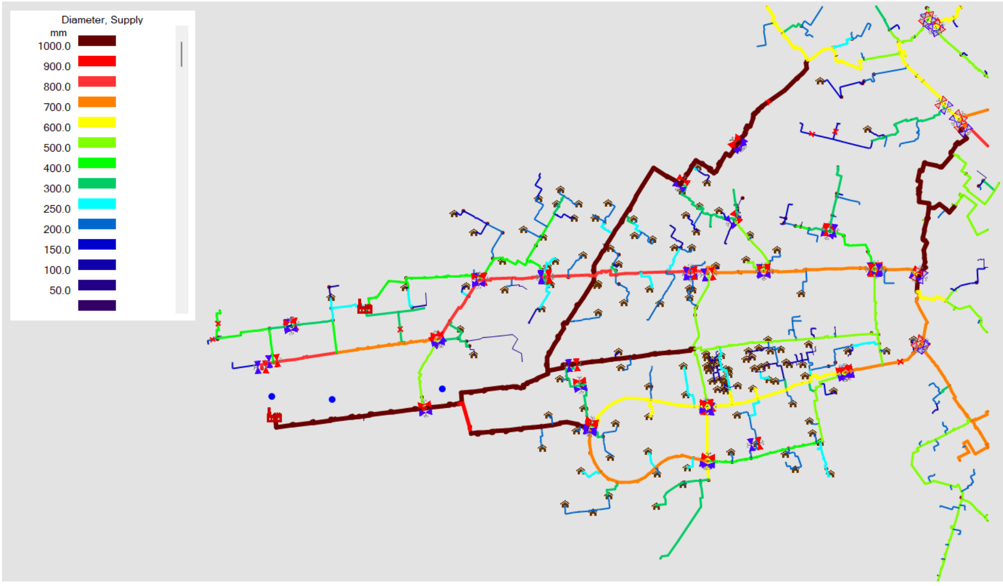

Fig. 5.3 Map of the Bucharest system with pipelines divided into nominal diameters in Sector 6

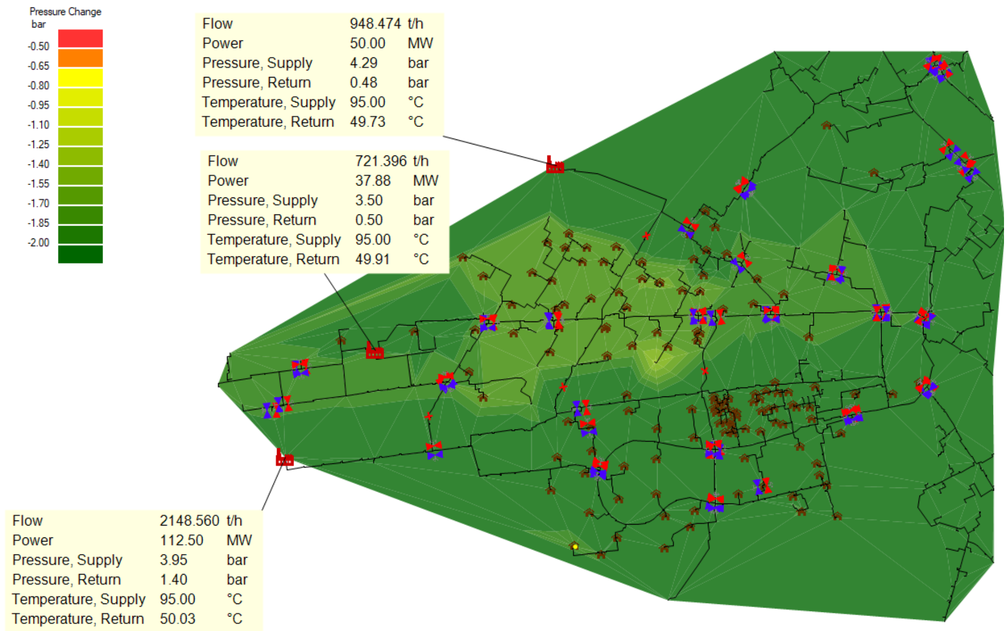

Fig. 5.4. Differential pressure distribution in zone 6 supplied with heat from 3 heat sources working in parallel, considering current technical conditions of the network

Across both case studies, several overarching insights emerge. First, digital twins are not optional, they are indispensable tools for planning, decision-making, and risk mitigation in modern district heating systems. Second, data quality significantly influences the reliability of any analysis; calibration exercises routinely identify sensor malfunctions, outdated GIS attributes, and incorrect design assumptions. Third, hydraulic bottlenecks pose real limits to system flexibility, meaning that strategic, often localised, investments in pipeline upsizing or pumping station optimisation can yield substantial operational improvements. Finally, the

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integration of renewable and waste heat sources offers considerable potential for reducing reliance on traditional high-temperature operation, but only when supplemented with carefully designed hydraulic and control strategies.

In conclusion, the report underscores that the transformation of district heating networks into low-temperature, multi-source, smart energy systems is achievable but demands a rigorous, data-centric approach. The experience gathered in Opole demonstrates how digital modelling, heating curve optimisation, and targeted infrastructure upgrades can collectively reduce temperature parameters and enable the effective integration of waste heat. Meanwhile, the Bucharest case highlights the foundational importance of data governance and modern digital tools in enabling future optimisation. Together, these insights provide a replicable blueprint for the broader consortium of 15 district heating systems within SET-HEAT and offer a compelling argument for the critical role of digital twins, data integration, and structured technical analysis in Europe’s heat-sector decarbonisation..

6. Technical risk assessment

This *Technical risk assessment report* provides a comprehensive examination of the challenges, uncertainties, and opportunities associated with the ongoing energy transition in the European district-heating (DH) sector. As heating networks across Europe begin shifting away from fossil fuels toward decentralised, renewable and waste-heat-based systems, they encounter new layers of technical complexity that require systematic risk governance.

The successful implementation of investment projects in the DH sector depends on the ability to systematically identify, analyse and manage a diverse set of technical risks throughout the project lifecycle. District heating projects, whether involving renewable heat sources, heat pumps, boilers, thermal storage, network upgrades, or cogeneration units, are characterised by complex interactions between infrastructure, energy systems, environmental conditions, regulatory frameworks and operational practices. These complexities introduce uncertainties that may affect safety, performance, costs, timelines, or long-term asset reliability.

Effective technical risk management ensures that potential threats to project success are recognised early and handled proactively rather than reactively. A structured and transparent risk process improves decision-making, reduces cost overruns, enhances safety and reliability, and contributes to the long-term sustainability of district heating systems.

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A general methodology for identifying, assessing and mitigating technical risks in production-asset investments within the DH sector is structured into two main parts:

– Risk identification and assessment methodology, which consists of the systematic approach used to detect, classify and evaluate risks based on probability and impact.

– Risk mitigation methodology, which defines how risks are controlled, reduced or monitored through technical, organisational and procedural measures.

The adopted methodology follows internationally recognised risk management frameworks such as ISO 31000, IEC 60812, and standard engineering practices applied across the energy and infrastructure sectors.

6.1. Risk identification and assessment methodology

Investment risk is the likelihood of failing to achieve stated economic objectives due to an inability to predict future events. It is caused by a lack of reliable information. In practice, risk and the accuracy of established underlying values cannot be fully predicted. Consequently, there may be:
– a smaller financial benefit than expected;
– no financial benefit;
– a financial loss.

The risks most frequently encountered in technical projects in the energy industry are:
– technological,
– availability of fuels and energy,
– failure to meet contract terms,
– management,
– political,
– legal,
– social,
– interest rates,
– inflation,
– liquidity,
– cyclical price developments,
– competition.

Technical risk identification and assessment is the structured process of determining what could go wrong, why it could occur, and how severely it may affect project performance. The objective is to provide a clear and prioritised view of risks that require active management.
Risk identification in district heating projects is grounded in several universal principles:

- Comprehensiveness, which ensures that all relevant components, processes and interfaces are considered, including production units, thermal networks, pumping stations, control systems, and power supply.
- Lifecycle orientation, which ensures that risks are analysed across all project phases, namely, design, procurement, construction, commissioning, operation, and end-of-life.
- Interdisciplinary perspective, which means that engineering, environmental, economic and operational experts should contribute to the identification process.
- Evidence-based approach, which ensures that lessons learned, historic failures, incident databases and benchmarking with similar installations are used.
- Transparency and documentation, which ensure that the identified risks are recorded in a structured, traceable manner.

Typical sources of technical risks include equipment failure, design flaws, supply-chain issues, grid disturbances, hydrological changes, thermal load variability, control-system faults, and insufficient maintenance capacity.

At the stage of pre-feasibility analysis, a combination of techniques ensures a complete identification process was used to identify potential risks. These are:

- DH expert meetings and brainstorming sessions,
- Consultations with technology providers,
- Process flow and system diagrams review,
- Site inspections and due-diligence visits,
- Review of similar projects and benchmarking,
- Simulation and modelling results (hydraulic, thermal, electrical).

Once risks were identified, each was evaluated according to two main dimensions:

1/ Probability (Likelihood), which is the estimated frequency or chance of occurrence.

2/ Impact (Consequence), which considers the expected magnitude of effect on technical performance, safety and reliability, environmental compliance, operational continuity, financial and schedule outcomes

A standard 1–5 scale was used as shown in Table 6.1.

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Table 6.1. Scale of probability and impact

Level	Probability	Impact
1	Very unlikely	Negligible effect
2	Unlikely	Low effect
3	Possible	Moderate effect
4	Likely	High effect
5	Very likely	Critical effect

The combination of probability and impact yields a Risk Score, which is the Probability multiplied by the Impact. Risk scores were classified into five levels:

- Negligible Risk (1–2), which is fully acceptable.
- Small Risk (3-4), which is acceptable with routine monitoring.
- Medium Risk (5-10), which is acceptable if effective mitigation measures are proposed and active monitoring is implemented.
- High Risk (12-16), which is acceptable if priority actions are defined, which take into consideration potential design changes or contingency measures.
- Very High Risk (20–25), which is acceptable under certain controlled, well-justified, and rigorously managed conditions.

A risk severity matrix is presented in Table 6.2.

Table 6.2. Risk Severity Matrix (Score = Likelihood × Impact)

Impact ↓ / Likelihood →	1	2	3	4	5
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

Legend: criterion score meaning
5 - Very High
4 - High
3 - Medium
2 - Small
1 - Insignificant

Legend: risk severity
Negligible Risk
Small Risk
Medium Risk
High Risk
Very High Risk

A risk heatmap is used to visualise and compare risks across categories. This enables asset owners, operators and project managers to focus attention on the most critical areas.

All risks are recorded in a structured Risk Register, which was developed for each specific project respectively. The Risk Register covers:

- Risk category
- Risk description
- Probability and impact ratings
- Risk score and heatmap position
- Root causes and triggers

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- Proposed mitigation measures
- Monitoring indicators
- Risk owner (responsible organisation)

Maintaining a continuously updated risk register ensures that risk management is dynamic and integrated into all project phases.

In addition, the analysis distinguishes between the initial and residual risks. The "initial risk" assumes worst-case conditions and no mitigation. The "residual risk" assumes:

- full mitigation measures implemented,
- control systems functioning,
- stakeholder agreements in place,
- maintenance and monitoring are active.

6.2. Risk mitigation methodology

While risk identification and assessment highlight where attention is required, the purpose of risk mitigation is to reduce risks to an acceptable level and ensure controlled, reliable project execution and operation. In district heating production-asset projects, risk mitigation combines technical, organisational, contractual and monitoring measures.

Risk mitigation strategies fall into four categories:

- Avoidance – modifying the design or eliminating a risky component or process.
- Reduction (Control) – implementing measures to lower probability or impact (redundancy, safeguards, design improvements).
- Transfer – shifting risk to third parties (insurance, performance guarantees, EPC contracts).
- Acceptance – tolerating low risks that are economically impractical to reduce.

In the DH sector, reduction and control measures are most commonly used.

Mitigation measures were grouped into:

1) Technical measures.
   - Redundancy in pumps, heat exchangers, controls,
   - Enhanced material specifications,
   - Automated monitoring sensors and alarms,
   - Backup power systems,
   - Hydrological and thermal modelling before design approval,
   - Fail-safe control logic and cybersecurity safeguards.
2) Operational measures.
   - Preventive and predictive maintenance programs,
   - Staff training, certification and competency development,

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- Operating procedures and emergency response plans.

3) Contractual and procurement measures.
   - Performance guarantees from suppliers (availability, efficiency, SCOP),
   - Quality assurance and factory acceptance tests,
   - Clear delivery schedules and penalties for delays.
4) Monitoring and review measures.
   - KPIs for reliability, performance, downtime and network losses,
   - Remote monitoring and data analytics,
   - Periodic audits and risk review sessions,
   - Updating risk registers through the full lifecycle.

Mitigation measures are aligned with the particular stages of a project:
- Design Stage, where there are considered lessons learned, robust engineering standards and redundancy.
- Procurement Stage, where there are considered supplier quality, warranties and contractual safeguards.
- Construction Stage, where there are considered safety and quality supervision.
- Commissioning Stage, where there are considered operational testing, tuning, and control validation.
- Operation Stage, where there are considered continuous monitoring, maintenance and performance optimisation.

Mitigation is not considered to be a one-time activity, because risks evolve due to:
- ageing infrastructure,
- climate change influencing hydrological conditions,
- energy market fluctuations,
- regulatory changes.

Therefore, risk management should be dynamic, with regular quarterly or semi-annual reviews to adjust probability, impact or mitigation plans.

For each specific project a risk tool was created in the form of an MS Excel workbook. The tools enable effective documentation and monitoring of the identified risks. The full list of risk tools is:

- SET_HEAT_SEWAGE_Risk_Tool.xlsx,
- SET_HEAT_RETAIL_Risk_Tool.xlsx,
- SET_HEAT_RIVER_Risk_Tool.xlsx,
- SET_HEAT_LAKE_Risk_Tool.xlsx,
- SET_HEAT_AIR_Risk_Tool.xlsx,
- SET_HEAT_SOLAR_Risk_Tool.xlsx,
- SET_HEAT_PTES_Risk_Tool.xlsx,

– SET_HEAT_CHP_Risk_Tool.xlsx.

In the next chapters, key risk identification analysis results are presented for each specific SET_HEAT sub-project.

6.3. SET_HEAT_SEWAGE technical risk analysis report

Results of an initial risk identification and analysis are presented in Table 6.3. Overall, seventeen technical risks have been identified, which are related to:

- T-P Technology performance,
- T-I Technology integration,
- T-C Technology control,
- T-S Technology safety,
- T-AR Technology availability and reliability.

Table 6.3. Technical risk identification for SET_HEAT_SEWAGE project

Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
Insuficient wastewater quality	Impurities in wastwater above limits (e.g. struvite, dead birds, plants, plastics, wipes, grit)	3	4	12	High	Consider dual-stage filtration, automatic raking screens, and separate sludge and solids removal loop
Heat pump system not working as expected	Achievable heating output too low, minimum load level too high, inappropriate dynamics to provide electricity grid services.	3	3	9	Medium	Implement rigorous equipment and system design; Consider oversizing of key components.
Lower-than-expected COP	HP COP below target value	3	3	9	Medium	Implement rigorous equipment and system design; Consider oversizing of key components.
Integration issues with existing systems	Buffer tank too small, insufficient flow of wasterwater, insuficient flows of DH network water	2	4	8	Medium	Implement rigorous design; use CFD modelling; consider oversising.
Faulty control	Software or hardware failures, improperly tuned controls	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
Compressor failures	Heat pump compressor failures	2	5	10	Medium	Implement robust monitoring and maintenance procedures aligned with best industrial practices
Insuficient integration with local electricity grid	No electricity from CSTP's CHP	3	1	3	Low	Engage with CSTP staff early; implement rigorous design.
Insuficient integration with utility grid	Insufficient availability of electricity from utility grid	2	5	10	Medium	Engage with local DSO early, implement rigorous design, consider interventions on external grid; appropriately design interconnection point
Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the development stage; provide flexibility for redesign and adjustments.
Heat exchanger fouling	Wastewater heat exchanger fouling and bio	3	4	12	High	Redesign with improved pre-filtration, frequent high-temperature CIP cleaning, automated self-cleaning filtration, HX materials with fouling-resistant surfaces, oversized heat exchangers and consider redundancy
Toxicity and leakage of NH_3	NH_3 is toxic and corrosive to human tissue; leaks pose acute health hazards in enclosed plant rooms.	3	5	15	High	Use sealed systems with low refrigerant charge; Install continuous ammonia detection and alarm systems; Provide forced ventilation and emergency exhaust; Maintain proper operator training
Flammability of NH_3	NH_3 is flammable in air at 15–28% by volume, though ignition energy is high	3	5	15	High	Ensure ventilation and leak-containment zoning; Avoid ignition sources; apply ATEX compliance for electrical equipment.
Unacceptable noise level	Noise exceeding regulatory limits	3	3	9	Medium	Install soundproofing
R1234ze chemical stability concerns at high temperatures	At elevated discharge temperatures, R1234ze can degrade, producing corrosive by-products in presence of moisture or metals.	2	3	6	Medium	Ensure dry and clean system before charging; Use POE oil compatible with R1234ze; Maintain discharge temperature within limits.
Mild flammability of R1234ze	R1234ze is classed as A2L: low-to-mild flammability. Under specific conditions, it can ignite casusing fire hazard during maintenance or in leak situations in confined spaces.	2	3	6	Medium	Comply with EN 378/ISO 5149 safety requirements; Ensure proper ventilation and leak detection; Use equipment certified for A2L refrigerants; Limit charge size; maintain safe machinery room design.
Inadequate maintenance	Corrosion of heat exchangers and piping leading to performance loss and lifetime shortening	3	3	9	Medium	Develop preventive maintenance program and include online monitoring and predictive maintenance tools; Use specialized corrosion-resistant alloys (254 SMO, titanium); Replace plate HX with spiral/tube HX in high-risk zones; Implement monitoring

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Overall, the technical risk level for the SET_HEAT_SEWAGE project is assessed as moderate to high. These can be mitigated through robust feasibility studies and technical design, and early engagement with relevant stakeholders.

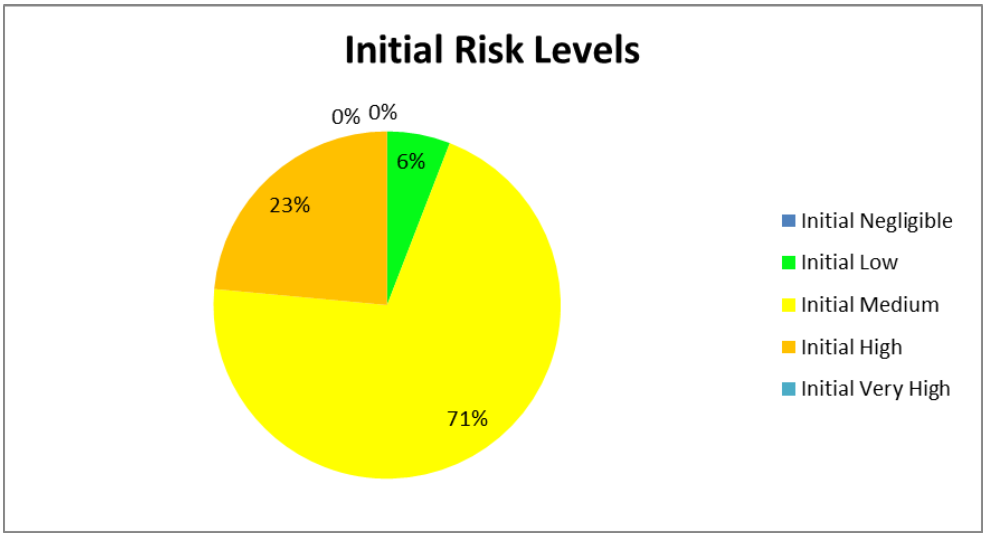

Fig. 6.1. Initial technical risk levels for the SET_HEAT_SEWAGE project

Table. 6.4. SET_HEAT_SEWAGE project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	1	0	0
2	0	0	0	0	0
3	0	2	7	0	0
4	0	1	2	0	0
5	0	2	2	0	0

Table. 6.5. SET_HEAT_SEWAGE top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-S 1	Toxicity and leakage of NH3	15	HSE Manager	Open
T-S 2	Flammability of NH3	15	HSE Manager	Open
T-P 1	Insuficient wastewater quality	12	Engineering Lead	Open
T-P 4	Heat exchanger fouling	12	Operations	Open
T-AR 3	Compressor failures	10	Operations	Open

The initial technical risk identification for the SET_HEAT_SEWAGE project reveals complex but manageable risks. Although most risks fall within low to medium probability ranges, several high-impact factors require careful mitigation to ensure project viability and long-term stability.

Technical performance risks, including potential low availability during early operation, shortage of skilled personnel, or reduced heat demand, may compromise system performance and revenue streams. The risk matrix highlights the particular importance of operator competence and reliable integration with existing district heating processes. In addition, reduced sewage flow, although of medium likelihood, is a high-impact risk since it directly affects the heat source's availability.

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Overall, the analysis concludes that the project's technical risk exposure is acceptable, and with appropriate controls in place, the project can proceed toward full feasibility analysis with confidence in its technical and economic potential.

6.4. SET_HEAT_RETAIL technical risk analysis report

In the case of the SET_HEAT_RETAIL Project, the risk is identified as for the implementation case of IKI Barista Supermarket, which, due to the existence of a CO_2 refrigeration system, does not require an additional heat pump. Therefore, the range of technical risks is reduced compared to other projects. The risk identification and analysis Table 6.6 presents a structured overview of the principal uncertainties associated with the supermarket waste-heat recovery project.

Table 6.6. Technical risk identification for SET_HEAT_RETAIL project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-I 1	Technical	Integration issues with existing systems	Integration failure with supermarket systems and the district heating network.	2	4	8	Medium	Implement rigorous design; use CFD modelling; consider oversising.
2	T-AR 1	Technical	Faulty control	Software or hardware failures, improperly tuned controls; Control system communication failure	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
3	T-AR 2	Technical	Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
4	T-I 2	Technical	Faulty integration with supermarket electricity grid	Startup currents causing local grid disturbance or trips.	2	2	4	Low	Rigourous integration design.
5	T-I 3	Technical	Insuficient integration with utility grid	Insufficient availability of electricity from utility grid	2	3	6	Medium	Early coordination with DSO; rigorous interconnection design,
6	T-C 1	Technical	Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the develpment stage; provide flexibility for redesign and adjustments.
7	T-AR 4		Equipment failure/downtime (other than compressor)	Major component failure (i.e., pumps, valves, etc.)causing heat shortfall.	3	3	9	Medium	Predictive maintenance; spares strategy; vendor quality acceptance.

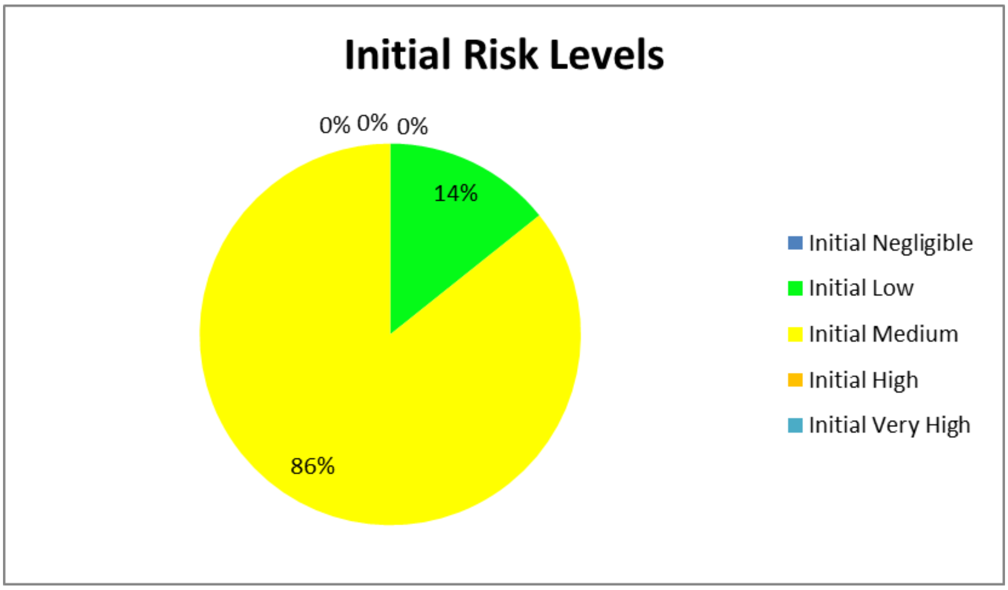

Fig. 6.2. Initial technical risk levels for the SET_HEAT_RETAIL project

Table. 6.7. SET_HEAT_RETAIL project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	1	0	0	0
3	0	1	4	0	0
4	0	1	0	0	0
5	0	0	0	0	0

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Table. 6.8. SET_HEAT_RETAIL top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-AR 1	Faulty control	9	Operations	Open
T-AR 2	Low availability in the initial period of operation	9	Permitting Lead	Open
T-C 1	Inefective control	9	Project Controls	Open
T-AR 4	Equipment failure/downtime (other than compressor)	9	Operations	Open
T-I 1	Integration issues with existing systems	8	Engineering Lead	Open

Across the listed risks, recurring themes emerge that reflect the technical and operational complexity of integrating supermarket refrigeration systems with district heating infrastructure. Several risks relate to technical performance, such as the ability of the system to deliver stable heat output, maintain low return temperatures, or avoid operational disturbances in refrigeration equipment. These appear consistently as medium-severity risks, indicating that while the technical challenges are well understood, they remain significant enough to require robust engineering controls and continuous monitoring in operation.

Another set of risks concerns system integration and control, including software, communication, and synchronisation challenges between refrigeration units, heat pumps, and district heating networks. These are evaluated similarly, with medium scores, emphasising the potential for control-system malfunctions or suboptimal regulation to reduce efficiency or even compromise heat delivery.

The table also flags risks linked to external conditions, for example, seasonal variations in cooling load, electricity price fluctuations, or dependency on external stakeholders. These are inherently less controllable but still manageable through adaptive control strategies, contractual arrangements, and operational flexibility.

Mitigation actions are implied to involve a combination of engineering refinement, preventive maintenance, optimised control strategies, and clear operational procedures. The clustering of risks within the medium category signals that effective risk management will require a systematic, proactive approach rather than isolated fixes.

Overall, the project's risk profile is moderate but stable, characterised by manageable technical and integration-related uncertainties. With appropriate design, commissioning, and ongoing monitoring, none of the identified risks appear prohibitive, and the project can proceed with confidence provided that mitigation measures are duly implemented.

6.5. SET_HEAT_RIVER technical risk analysis report

The identified SET_HEAT_RIVER Project technical risks are summarised in Table 6.9. It also presents an assessed likelihood, impact, and the proposed mitigation measures.

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Table 6.9. Technical risk identification for SET_HEAT_RIVER project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-P 1	Technical	Insuficient river water quality	Impurities in river water above limits (e.g., dead birds, plants, plastics, grit)	3	4	12	High	Consider dual-stage filtration, automatic raking screens, and separate sludge and solids removal loop
2	T-P 2	Technical	Heat pump system not working as expected	temperature variability. Achievable heating output too low, minimum load level too high, inappropriate dynamics to provide electricity grid services.	3	3	9	Medium	Rigorous system design; Detailed hydraulic simulations; Phased modular commissioning; Factory acceptance tests; Consider oversizing of key components.
3	T-P 3	Technical	Lower-than-expected COP	HP COP below target value	3	3	9	Medium	Implement rigorous equipment and system design; Consider oversizing of key components.
4	T-I 1	Technical	Integration issues with existing systems	Integration failure with TE-TO Zagreb network; Integration issues between heat pump and existing primary circuit leading to hydraulic/thermal imbalance.	2	4	8	Medium	Implement rigorous design; use CFD modelling; consider oversising.
5	T-AR 1	Technical	Faulty control	Software or hardware failures, improperly tuned controls	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
6	T-AR 2	Technical	Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
7	T-AR 3	Technical	Compressor failures	Heat pump compressor failures	2	5	10	Medium	Implement robust monitoring and maintenance procedures aligned with best industrial practices
8	T-I 2	Technical	Insuficient integration with local electricity grid	Startup currents causing local grid disturbance or trips.	3	1	3	Low	Rigourous integration design; VFDs/soft-start; coordination with TE-TO plant staff; staged starts.
9	T-I 3	Technical	Insuficient integration with utility grid	Insufficient availability of electricity from utility grid	2	5	10	Medium	Early coordination with DSO; rigorous interconnection design,
10	T-C 1	Technical	Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the develpment stage; provide flexibility for redesign and adjustments.
11	T-P 4	Technical	Heat exchanger fouling and corrosion	River-borne fouling reduces transfer efficier	3	4	12	High	Redesign with improved pre-filtration, frequent high-temperature CIP cleaning, automated self-cleaning filtration, HX materials with fouling-resistant surfaces, oversized heat exchangers and consider redundancy
12	T-S 1	Technical	Toxicity and leakage of NH_3	NH_3 is toxic and corrosive to human tissue; leaks pose acute health hazards in enclosed plant rooms.	3	5	15	High	Use sealed systems with low refrigerant charge; Install continuous ammonia detection and alarm systems; Provide forced ventilation and emergency exhaust; Maintain proper operator training
13	T-S 2	Technical	Flammability of NH_3	NH_3 is flammable in air at 15–28% by volume, though ignition energy is high	3	5	15	High	Ensure ventilation and leak-containment zoning; Avoid ignition sources; apply ATEX compliance for electrical equipment.
14	T-C 1	Technical	Unacceptable noise level	Noise exceeding regulatory limits	3	3	9	Medium	Install soundproofing
15	T-AR 4		Equipment failure/downtime (other than compressor)	Major component failure (i.e., pumps, valves, etc.)causing heat shortfall.	3	3	9	Medium	Predictive maintenance; spares strategy; vendor quality acceptance.
16	T-P 5	Technical	Inadequate maintenance	Corrosion of heat exchangers and piping leading to performance loss and lifetime shortening	3	3	9	Medium	Develop preventive maintenance program and include online monitoring and predictive maintenance tools; Use specialized corrosion-resistant alloys (254 SMO, titanium); Replace plate HX with spiral/tube HX in high-risk zones; Implement monitoring

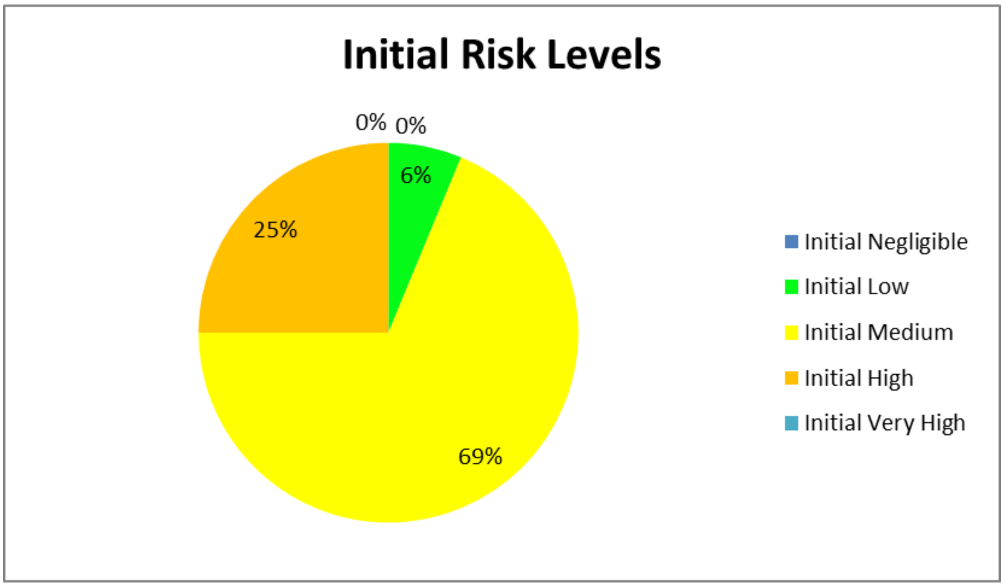

Fig. 6.3. Initial technical risk levels for the SET_HEAT_RIVER project

Table. 6.10. SET_HEAT_RIVER project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	1	0	0
2	0	0	0	0	0
3	0	0	8	0	0
4	0	1	2	0	0
5	0	2	2	0	0

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Table. 6.11. SET_HEAT_RIVER top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-S 1	Toxicity and leakage of NH3	15	HSE Manager	Open
T-S 2	Flammability of NH3	15	HSE Manager	Open
T-P 1	Insuficient river water quality	12	Engineering Lead	Open
T-P 4	Heat exchanger fouling and corrosion	12	Operations	Open
T-AR 3	Compressor failures	10	Operations	Open

The SET_HEAT_RIVER Project demonstrates a well-balanced and mitigated risk structure. No single risk poses a critical threat to technical feasibility or financial viability. With robust engineering, renewable electricity integration, and strong stakeholder coordination, the project represents a low-to-moderate risk investment with significant environmental and strategic benefits for Zagreb and the wider region.

Technical risks reflect the project's reliance on complex high-temperature ammonia heat pump technology and its integration into an existing large district heating network. Key risks include potential underperformance of heat pump components, efficiency losses during peak or low Sava River temperatures, and failures in auxiliary systems such as compressors, heat exchangers, and river-water intake infrastructure. These are generally assessed as medium likelihood with medium to high impact, resulting in numerous medium-severity risks. Mitigation emphasises rigorous system design, continuous monitoring, redundancy in critical components, preventive maintenance schedules, and the adoption of digital control systems for predictive operation. The technical documentation reinforces the importance of advanced modelling, correct sizing, and adaptive control to stabilise heat pump performance across seasonal variations.

Integration and system-wide risks include failures in interfacing with TE-TO Zagreb, insufficient peak-load coverage, and disturbances in the district heating network (e.g., temperature anomalies, pressure fluctuations). These risks reflect the complexity of merging modern heat pump systems with ageing infrastructure documented in the study. Most are assessed as medium severity. Mitigation includes detailed hydraulic modelling, phased commissioning, installation of bypass options, and ensuring gas-based backup units remain available for peak demand periods.

While several risks are classified as high severity, the analysis shows that none are unmanageable. The mitigation framework relies on a combination of robust engineering design, digitalisation, maintenance planning, financial hedging, and regulatory engagement. Overall, the risk profile confirms that the project is feasible, provided that proactive mitigation actions are implemented at each stage, from design and permitting to commissioning and long-term operation.

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6.6. SET_HEAT_LAKE technical risk analysis report

The technical risk identification and analysis conducted for the SET_HEAT_LAKE project provides a clear and structured view of the challenges that may influence successful project delivery. The assessment covers eighteen distinct risks across the technical domain. The results indicate that the project faces a predominantly moderate-to-high risk profile, with nearly half of the identified risks classified as high severity and the remainder falling into the medium range. No risks were assessed as low, underscoring the complexity and novelty of the project.

Table 6.12. Technical risk identification for SET_HEAT_LAKE project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-P 1	Technical	Insuficient lake water quality	Impurities in lake water above limits (e.g., dead birds, plants, plastics, wipes, grit, etc.)	3	4	12	High	Consider dual-stage filtration, automatic raking screens, and separate sludge and solids removal loop
2			Intake fouling / clogging	Biofouling or sediment clogging in intake pipes	3	4	12	High	Coarse/fine screens; backwash; chemical/UV treatment
3	T-P 2	Technical	Heat pump system not working as expected	temperature variability. Achievable heating output too low, minimum load level too high, inappropriate dynamics to provide electricity grid services.	3	3	9	Medium	Rigorous system design; Detailed hydraulic simulations; Phased modular commissioning; Factory acceptance tests; Consider oversizing of key components.
4	T-P 3	Technical	Lower-than-expected COP	HP COP below target value	3	3	9	Medium	Implement rigorous equipment and system design; Consider oversizing of key components.
5	T-I 1	Technical	Integration issues with existing systems	Integration failure with SACET; Integration issues with lake leading to hydraulic/thermal imbalance.	3	4	12	High	Implement rigorous design; use CFD modelling; consider oversising.
6	T-AR 1	Technical	Faulty control	Software or hardware failures, improperly tuned controls	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
7	T-AR 2	Technical	Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
8	T-AR 3	Technical	Compressor failures	Heat pump compressor failures do to relatively new design	3	5	15	High	Implement robust monitoring and maintenance procedures aligned with best industrial practices
9	T-I 2	Technical	Issues with location	Unavailable or unfavourable land for HP system location	3	4	12	High	Engage with municipalkity and other stakeholders early.
10	T-I 3	Technical	Inappropriate interaction with electricity grid	Startup currents causing local grid disturbance or trips.	3	2	6	Medium	Rigourous integration design; VFDs/soft-start; coordination with TE-TO plant staff; staged starts.
11	T-I 4	Technical	Insuficient integration with utility grid	Insufficient availability of electricity from utility grid, insufficient quality of medium-voltage grid	3	5	15	High	Early coordination with DSO; rigorous interconnection design,
12	T-C 1	Technical	Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the develpment stage; provide flexibility for redesign and adjustments.
13	T-P 4	Technical	Heat exchanger fouling and corrosion	Dambovira River-borne fouling reduces trar	3	4	12	High	Design with improved pre-filtration, frequent high-temperature CIP cleaning, automated self-cleaning filtration, HX materials with fouling-resistant surfaces, oversized heat exchangers and consider redundancy
14	T-S 1	Technical	CO_2 overpressure	CO_2 overpressure or vent release.	3	5	15	High	Relief systems; safe vent; CO_2 sensors; procedures.
15	T-S 2	Technical	Flammability of R600a	Flammability incident in mechanical room	3	5	15	High	Ensure ventilation and leak-containment zoning; Avoid ignition sources; apply ATEX compliance for electrical equipment.
16	T-C 1	Technical	Unacceptable noise level	Noise exceeding regulatory limits	3	3	9	Medium	Install soundproofing
17	T-AR 4	Technical	Equipment failure/downtime (other than compressor)	Major component failure (i.e., pumps, valves, etc.)causing heat shortfall.	3	3	9	Medium	Predictive maintenance; spares strategy; vendor quality acceptance.
18	T-P 5	Technical	Inadequate maintenance	Corrosion of heat exchangers and piping leading to performance loss and lifetime shortening	3	3	9	Medium	Develop preventive maintenance program and include online monitoring and predictive maintenance tools; Use specialized corrosion-resistant alloys (254 SMO, titanium); Replace plate HX with spiral/tube HX in high-risk zones; Implement monitoring

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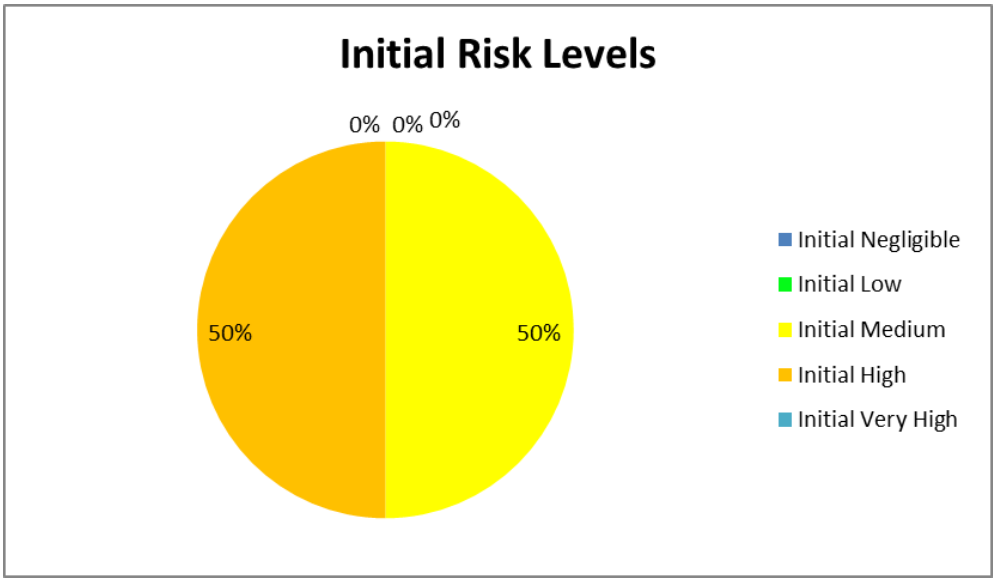

Fig. 6.4. Initial technical risk levels for the SET_HEAT_LAKE project

Table. 6.13. SET_HEAT_LAKE project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	0	1	0	0
3	0	0	8	0	0
4	0	0	5	0	0
5	0	0	4	0	0

Table. 6.14. SET_HEAT_LAKE top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-S 1	CO_2 overpressure	15	HSE Manager	Open
T-S 2	Flammability of R600a	15	HSE Manager	Open
T-AR 3	Compressor failures	15	Operations	Open
T-I 4	Insuficient integration with utility grid	15	Engineering Lead	Open
T-P 1	Insuficient lake water quality	12	Engineering Lead	Open

The analysis concludes that while overall project risk is moderate to high, key technical challenges exist in technology integration and validation. Mitigation measures focusing on early stakeholder engagement, robust engineering design, and adaptive risk governance are critical to ensure successful implementation and replication.

On the technical side, the project must contend with the possibility that equipment performance, especially the heat pump COP, may fall short of projections if district-heating temperatures remain high or if lake temperature profiles differ from expectations. Construction scheduling, integration with the existing district-heating infrastructure, and the reliability of new technologies such as large CO_2 heat pumps all require careful planning. Technical risks also arise from the need for highly specialised maintenance knowledge and the possibility of unexpected outages, especially during peak heating periods when system reliability is crucial.

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Despite this broad range of risks, effective mitigation actions are available. Many risks can be managed through early coordination with regulatory bodies, rigorous engineering validation, and transparent communication with stakeholders. Some risks can be addressed through predictive maintenance and long-term service contracts with equipment manufacturers. Overall, the analysis reveals a project characterised by significant but manageable risks. When addressed proactively, these risks do not impede the project but rather highlight the importance of structured planning and cross-institutional cooperation.

6.7. SET_HEAT_AIR technical risk analysis report

Industrial air-source heat pumps (ASHPs) are generally reliable and increasingly deployed, but several technical, operational, environmental, and integration-related issues have been reported in real projects.

Table 6.15. Technical risk identification for SET_HEAT_AIR project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-P 2	Technical	Heat pump system not working as expected	ASHP underperformance in cold conditions. Achievable heating output too low, minimum load level too high, inappropriate dynamics to provide electricity grid services.	3	3	9	Medium	Rigorous system design; Performance guarantees; Validated modelling.
2	T-P 3	Technical	Lower-than-expected COP	HP COP below target value; COP drops significantly at low outdoor temperatures.	3	3	9	Medium	Implement rigorous equipment and system design. ASHPs cannot serve peak loads; backup boilers must compensate.
3	T-I 1	Technical	Integration issues with existing systems	Integration failure with existing heating plant infrastructure; Integration issues between heat pump and existing primary circuit leading to hydraulic/thermal imbalance.	2	4	8	Medium	Implement rigorous design; use CFD modelling; consider oversising.
4	T-AR 1	Technical	Faulty control	Software or hardware failures, improperly tuned controls	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
5	T-AR 2	Technical	Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
6	T-AR 3	Technical	Compressor failures	Heat pump compressor failures	2	5	10	Medium	Implement robust monitoring and maintenance procedures aligned with best industrial practices
7	T-AR 4	Technical	Issues with defrosting system	Frost accumulation reduces output and increases energy use; Defrost cycles also introduce thermal instability unless mitigated by storage tanks.	3	3	9	Medium	Rigorous system design. Optimise airflow and maintain clean evaporators; Optimised defrost algorithms; Refrigerant selection and operating point optimisation.
8	T-I 3	Technical	Insuficient integration with utility grid	Insufficient availability of electricity from utility grid; Startup currents causing local grid disturbance or trips.	2	5	10	Medium	Early coordination with DSO; rigorous interconnection design; A new cable line or substation upgrade is required.
9	T-I 4	Technical	Signifficant space requirements	ASHPs and thermal tanks require significant footprint.	2	4	8	Medium	Extensive space audit; dismantle existing equipment no longer in use.
9	T-C 1	Technical	Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the develpment stage; provide flexibility for redesign and adjustments.
10	T-P 4	Technical	Air heat exchanger fouling and corrosion	Air heat exchanger fouling and corrosion is	3	4	12	High	Hydrophobic / epoxy-coated fins, stainless steel or coated tube materials; anti-corrosion surface treatments; optimised air intake positioning; prefilters or mesh screens; scheduled coil washing; condition-based maintenance triggered by pressure drop; regular airflow and fan-speed monitoring; avoiding installation near dust sources; oversized coil surface area to tolerate mild fouling; easy access for maintenance; vertical coil orientation in high-dust environments.
11	T-S 1	Technical	Toxicity and leakage of NH_3	NH_3 is toxic and corrosive to human tissue; leaks pose acute health hazards in enclosed plant rooms.	3	5	15	High	Use sealed systems with low refrigerant charge; Install continuous ammonia detection and alarm systems; Provide forced ventilation and emergency exhaust; Maintain proper operator training
12	T-S 2	Technical	Flammability of NH_3	NH_3 is flammable in air at 15–28% by volume, though ignition energy is high	3	5	15	High	Ensure ventilation and leak-containment zoning; Avoid ignition sources; apply ATEX compliance for electrical equipment.
13	T-C 1	Technical	Unacceptable noise level	Noise exceeding regulatory limits; Industrial ASHP fans and evaporators are noisy	3	3	9	Medium	Site planning and smart positioning; Soundproofing; Low-noise fans; Airflow optimization; Acoustic monitoring and predictive control.
14	T-AR 4	Technical	Equipment failure/downtime (other than compressor)	Major component failure (i.e., pumps, valves, etc.)causing heat shortfall.	3	3	9	Medium	Predictive maintenance; spares strategy; vendor quality acceptance.
15	T-P 5	Technical	Maintenance complexity	Inappropriate maintenance of air heat exchangers and piping leading to performance loss and lifetime shortening	3	3	9	Medium	Develop preventive maintenance program and include online monitoring and predictive maintenance tools; Consider service agreements with sepcialised providers.

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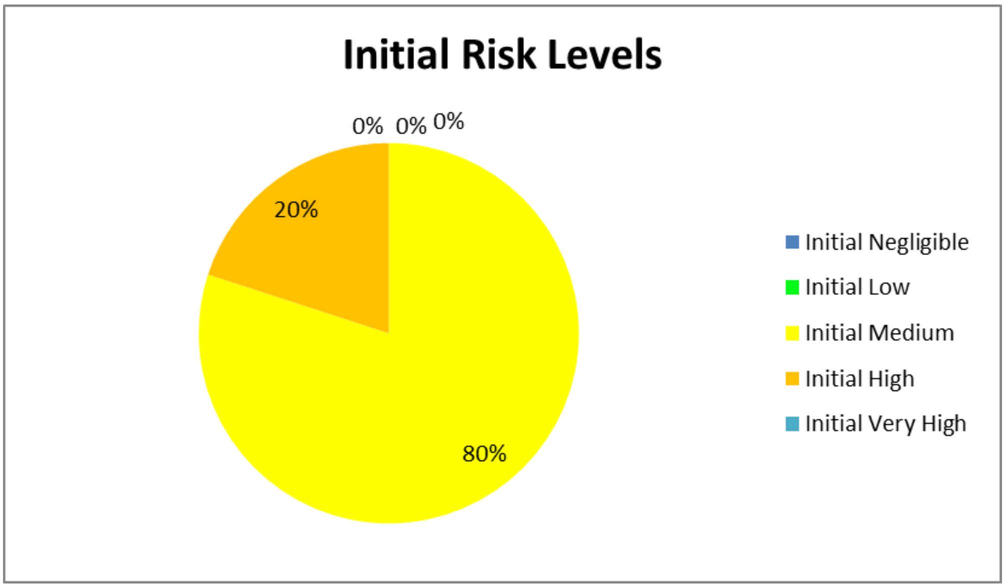

Fig. 6.5. Initial technical risk levels for the SET_HEAT_AIR project

Table 6.16. SET_HEAT_AIR project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	9	0	0
4	0	2	1	0	0
5	0	2	2	0	0

Table 6.17. SET_HEAT_AIR top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-S 1	Toxicity and leakage of NH3	15	HSE Manager	Open
T-S 2	Flammability of NH3	15	HSE Manager	Open
T-P 4	Air heat exchanger fouling and corrosion	12	Operations	Open
T-AR 3	Compressor failures	10	Operations	Open
T-I 3	Insuficient integration with utility grid	10	Engineering Lead	Open

The risk analysis for the industrial air-source heat pump (ASHP) system identifies a wide spectrum of technical risks that could affect the reliability, performance, and operational continuity of the proposed installation. Most risks arise from the inherent complexity of integrating high-capacity heat pumps into an existing district heating environment, where interactions between hydraulics, controls, electrical infrastructure and environmental conditions are tightly coupled. Although many risks fall into the medium severity category, several are classified as high-severity, highlighting priority areas requiring careful engineering, proactive maintenance, and strong safety protocols.

A prominent cluster of risks relates to performance uncertainty, particularly under cold climatic conditions. The analysis notes that ASHPs may underperform during low ambient temperatures, leading to insufficient heat output and degraded COP. Because heat pumps cannot meet peak demand in very cold weather, backup boilers must compensate, underscoring the need for validated system modelling, rigorous design, and performance guarantees. Closely linked to performance are risks associated with frosting and defrost cycles, which reduce output, increase energy consumption, and can create thermal instability unless mitigated by thermal storage and efficient defrost control algorithms.

Another major group of risks concerns system integration and commissioning. Integration failures, whether due to mismatched thermal regimes, hydraulic incompatibility, or commissioning issues, could lead to unstable operation during early phases. The risk table highlights the need for computational modelling, robust commissioning protocols, and manufacturer-supported optimisation to ensure seamless coordination between the heat pumps and the existing district heating plant. Software optimisation challenges are also noted; ineffective control logic can limit system flexibility and undermine economic performance, emphasising the importance of extensive testing and adaptive control strategies.

Electrical-related risks appear as well, particularly the potential insufficient availability of grid capacity, which may impair system operation. Given that ASHPs draw significant power, disturbances or constraints in the local grid become a critical vulnerability. Early coordination with the distribution system operator and potential reinforcement of the electrical connection are identified as key mitigations.

Several risks are associated with equipment reliability, especially concerning compressors, auxiliary components, and air-side heat exchangers. Compressor failures, fouling and corrosion of air heat exchangers, and equipment ageing or downtime represent tangible operational threats. These issues are accentuated in real-world outdoor installations exposed to pollution, moisture, and varying climatic conditions. The analysis, therefore, emphasises preventive maintenance, condition-based monitoring, industrial-grade components, and appropriate surface coatings to prolong asset life.

Spatial and environmental constraints are also recognised. Large ASHP units require significant space and can produce noise levels that exceed regulatory limits if not adequately mitigated. Site planning, acoustic shielding, low-noise fans, and noise monitoring are recommended to avoid community disturbance and ensure compliance.

Finally, the analysis includes refrigerant-related safety risks, specifically tied to ammonia (NH_3) in high-temperature or high-capacity heat pumps. NH_3's toxicity and flammability introduce acute safety concerns, requiring ATEX-compliant zones, robust leak detection, staff training, and emergency procedures. These risks are among the highest-severity entries, reflecting the need for stringent safety engineering.

Overall, the risk Table 6.15 presents a comprehensive overview of the technical challenges associated with deploying industrial ASHPs in district heating. While several risks require targeted mitigation, the proposed actions, including advanced design validation, strengthened

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operational protocols, proactive maintenance, safety measures, and integration with thermal storage, provide a robust pathway to ensure system reliability and successful implementation.

6.8. SET_HEAT_SOLAR technical risk analysis report

The risk analysis for the solar thermal district heating project identifies a broad spectrum of technical vulnerabilities inherent to the design, integration, and long-term operation of solar collectors, thermal storage, and associated mechanical and control systems. Overall, the assessment highlights that while the project is feasible, its success depends on rigorous engineering standards, quality assurance throughout installation, and proactive operational management.

Table 6.18. Technical risk identification for SET_HEAT_SOLAR project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-P 1	Technical	Underperformance of solar collector field compared to design	Incorrect tilt/orientation, shading, fouling, lower solar resource than assumed, control setpoints not optimized,	3	4	12	High	Rigorous design, adjust operating strategy, use bankable solar yield studies, conservative assumptions, high-quality collectors, performance guarantees and regular cleaning.
2	T-P 2	Technical	Underperformance of termal storage tank	Thermal storage tank performance issues (stratification loss, leaks, insulation defects); design errors, poor construction quality, inadequate insulation or instrumentation	2	4	8	Medium	Use experienced tank designer, quality control during fabrication, proper insulation and commissioning tests.
3	T-I 1	Technical	Integration issues with existing systems	Integration failure with existing heating plant infrastructure; Integration issues between solar plant and existing primary circuit leading to hydraulic/thermal imbalance.	3	4	12	High	Detailed hydraulic modelling, phased integration, factory and site acceptance tests, design review with DH engineers, isolate solar loop, corrective redesign of integration scheme.
4	T-AR 1	Technical	Inapropriate control	Software or hardware failures, improperly tuned controls, suboptimal control strategy between solar field, storage, and boilers.	3	3	9	Medium	Advanced control design (PLC/SCADA), digital monitoring and optimization, tuning parameters (superheat, flow, pressure), staged commissioning with manufacturer and involvement.
5	T-AR 2	Technical	Failure of heat exchangers, pumps, valves, sensors or control system components	Equipment defects, inadequate specifications, poor maintenance	3	3	9	Medium	Specify proven components with CE/EN compliance, redundancy on key pumps, stock critical spares, preventive maintenance plan, Allow for rapid replacement based on spares stock, temporary manual operation, escalation to supplier under warranty.
6	T-AR 3	Technical	Overheating or stagnation in solar field in summer or during outages	Insufficient heat sink capacity, inadequate stagnation strategy, control failures	2	5	10	Medium	Design with stagnation strategy (dry cooler, controlled shutdown, safe fluid selection), temperature monitoring and alarms, emergency procedures.
7	T-AR 4	Technical	Insufficient resilience to critical weather events	Interaction with groundwater or flooding risk at solar field/storage site	2	4	8	Medium	Hydrological studies, elevation of critical equipment, robust drainage and flood protection
8	T-P 3	Technical	Insufficient data quality	Data quality issues for monitoring and verification	2	3	6	Medium	Redundant metering for key variables, robust data management procedures, regular calibration
9	T-I 2	Technical	Insufficient roof load-bearing capacity	Bucharest case, applies if the PT roof cannot carry the load	2	4	8	Medium	Structural assessment, consider independent support structure next or attached to the building.
10	T-S 1	Technical	Fluid leakage or glycol degradation	Glycol degradation is a known issue in STDH when stagnation periods occur.	3	5	15	High	Annual quality inspections, monitoring pH and concentration.
11	T-S 2	Technical	Wind uplift or vibration damage	Strong winds can tear off panels or supporting structures.	3	5	15	High	Proper anchoring, compliance with wind load standards, additional steel structures.
12	T-S 3	Technical	Panel/frame deformation due to snow loads	Heavy snow can bend or break collector frames, mounting brackets, vacuum tubes.	3	4	12	High	Expert structural check, compliance with snow load codes, and possible reinforcement.
13	T-AR 4	Technical	Cracked or broken vacuum tubes / glass collectors	Poteneial damages due to hail impact, thermal shock (rapid cloud/sun transitions), installation handling damage, bird impacts.	3	3	9	Medium	Certified hail-resistant glass, optimal tilt, protective screens, smart cooling mode, insurance, anti-stagnation control, high-temp-rated materials, adequate expansion vessels, short series strings, dry-stagnation collectors, installer training, proper lifting, temporary covers, pre-install inspection, safe scaffolding, manufacturer procedures, bird spikes, mesh, perch blockers, non-reflective materials, cleaning, visual/acoustic deterrents, habitat management.
14	T-P 4	Technical	Damage to piping (copper/steel)	Potential damages due to cracking at soldered joints, corrosion at uninsulated sections, mechanical stress from thermal expansion, vibration-induced fatigue, external impacts during maintenance work.	3	4	12	High	Brazed or welded joints for high-temperature solar circuits; avoid soft solder, minimize number of joints and provide support close to fittings to avoid bending loads, perform hydrostatic pressure testing after installation to verify tightness, insulate all hot piping, including fittings and valves, with UV-resistant, closed-cell insulation, apply protective coatings at exposed or uninsulated sections, prevent galvanic corrosion by isolating dissimilar metals, ensure insulation and routing avoid water pooling or moisture ingress, design piping with expansion loops, offsets, or bellows where needed, install clearly defined fixed points (anchors) and guided supports to control movement, use sliding supports to allow free expansion without stressing joints, use low-vibration pumps and variable-speed drives to reduce transients, flexible connectors at pump connections, lateral bracing near large valves, pumps, and direction changes, avoid long, unsupported pipe spans that can resonate, pipe guards or barriers in walkways, plant rooms, and roof areas.
15	T-P 5	Technical	Collector frame bending or misalignment	Potenetial performacne deterioration casued by wind, soil settlement, inadequate foundation, uneven frost heave.	2	3	6	Medium	Appropriate mechanical protection measures
16	T-P 5	Technical	High DH return temperatures	Solar thermal efficiency drops sharply with rising return temperatures.	3	3	9	Medium	Optimise DH network and lower system supply temperatures where possible.

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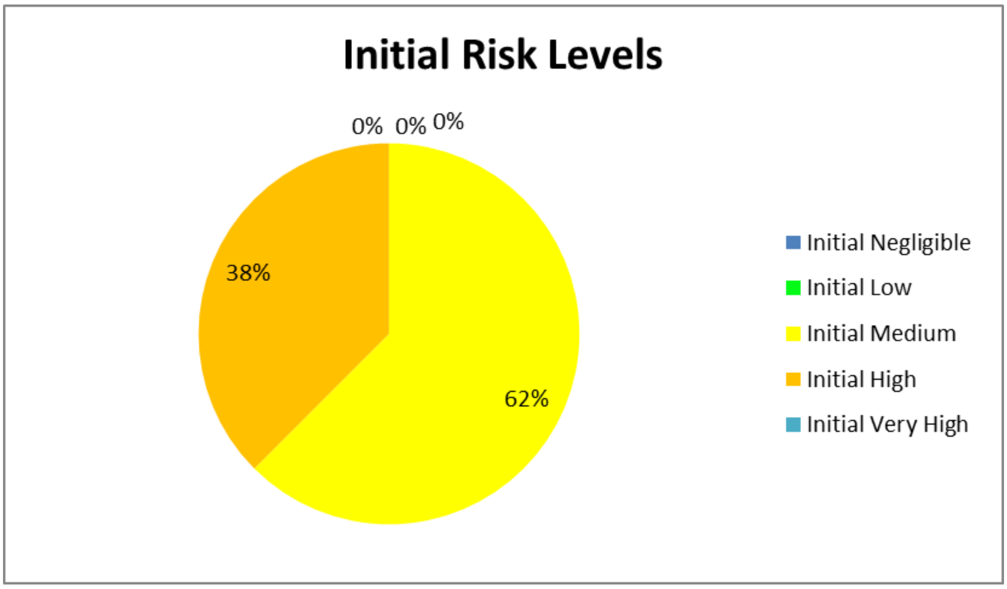

Fig. 6.6. Initial technical risk levels for the SET_HEAT_SOLAR project

Table. 6.19. SET_HEAT_SOLAR project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	2	4	0	0
4	0	3	4	0	0
5	0	1	2	0	0

Table. 6.20. SET_HEAT_SOLAR top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-S 1	Fluid leakage or glycol degradation	15	HSE Manager	Open
T-S 2	Wind uplift or vibration damage	15	HSE Manager	Open
T-S 3	Panel/frame deformation due to snow loads	12	Operations	Open
T-P 1	Underperformance of solar collector field compared to design	12	Operations	Open
T-I 1	Integration issues with existing systems	12	Engineering Lead	Open

A key group of risks concerns the performance of major thermal components, including the solar collector field and the thermal storage tank. Underperformance may arise from suboptimal installation conditions, such as incorrect tilt, shading, or fouling, or from inadequate tank design, poor insulation, thermal stratification loss, and construction deficiencies. These risks carry moderate to high severity, reflecting their significant influence on yearly energy yield. Mitigation focuses on using validated design tools, securing experienced designers and fabricators, applying high-quality insulation, and enforcing strong commissioning procedures.

Another major theme is the integration of the solar plant with existing district heating systems. Improper hydraulic design, imbalances, or poorly tuned controls can impair heat exchange efficiency or disrupt system stability. Advanced control strategies, precise tuning of pumps and valves, and careful hydraulic modelling are recommended to ensure seamless integration.

A number of risks relate to mechanical equipment reliability, including pumps, valves, sensors, and heat exchangers. Faults may result from inadequate specifications, manufacturing defects, or insufficient maintenance. Similarly, overheating or stagnation in summer operation is highlighted as a common threat in solar thermal systems, especially under high insolation and low demand. Mitigation actions stress the use of compliant components, redundant pumps, dry-coolers, improved control logic, and continuous monitoring.

Environmental and structural risks are also noted. Snow loads and strong winds can damage collector frames, while hail, thermal shock, installation mishandling, and bird activity pose additional threats to vacuum tubes and glass surfaces. These risks share high severity, given their potential to cause irreparable equipment failures. Mitigation measures combine structural verification, protective materials, strengthened supports, compliance with wind and snow standards, and protective features such as bird deterrents and impact-resistant glass.

The analysis also identifies piping-related risks, including cracking at soldered joints, corrosion at uninsulated sections, damage due to thermal expansion, vibration fatigue, and accidental impacts during maintenance. The proposed mitigations involve high-temperature-rated welded or brazed joints, comprehensive insulation, defined expansion control strategies, improved support and bracing systems, and protective barriers in critical areas.

Finally, high district heating return temperatures are recognised as a systemic issue that reduces solar thermal efficiency. The risk is mitigated by optimising operation, improving building-level controls, and lowering system supply temperatures where possible.

Overall, the risk assessment underscores that the project’s vulnerabilities are manageable using established engineering best practices. Emphasis on proper component selection, design accuracy, structural resilience, and sophisticated control systems will be central to ensuring long-term, high-performance operation of the solar thermal installation.

6.9. SET_HEAT_PTES technical risk analysis report

The risk identification and analysis Table 6.21. provides a structured overview of the principal threats that could affect the successful development, implementation, and long-term operation of the PTES (Pit Thermal Energy Storage) project. The risk analysis illustrates the multi-dimensional complexity of integrating large-scale seasonal heat storage into an existing district heating system.

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Table 6.21. Technical risk identification for SET_HEAT_PTES project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-I 1	Technical	Inadequate soil investigation	Soil parameters incorrectly characterised, leading to pit instability and unexpected ground behaviour.	4	5	20	Very High	Full Stage 3 geotechnical campaign; conservative design margins; independent review of geotechnical reports.
2	T-I 2	Technical	Inadequate groundwater assessment	Groundwater levels/flows mischaracterised, causing water ingress, higher heat losses or structural risk.	4	5	20	Very High	Detailed hydrogeological studies; monitoring wells; design drainage and liner system; allow for contingencies.
3	T-I 3	Technical	Unresolved landfill closure restrictions	Legal restrictions on post-closure land use delay or limit PTES construction on ash landfill site.	3	4	12	High	Early legal review; obtain sanitary and geotechnical opinions; request shortening of 50-year restriction in closure decision.
4	T-P 1	Technical	Thermal design errors	Insufficient lid insulation or incorrect pit geometry leading to excessive heat losses and lower efficiency.	3	5	15	High	Use proven PTES references; detailed thermal modelling (TRNSYS/CFD); design reviews with experienced PTES contractors.
5	T-P 2	Technical	Poor diffuser and hydraulic design	Diffusers cause mixing and stratification collapse, reducing usable storage capacity.	3	4	12	High	CFD analysis of diffusers; multi-level diffusers; commissioning tests to verify stratification.
6	T-P 3	Technical	Inadequate water quality management	Corrosion/fouling in PTES circuits and HX due to untreated or poorly treated water.	3	4	12	High	Define strict water quality specs; install treatment system; periodic sampling and chemical adjustments.
7	T-P 4	Technical	Undersized monitoring and SCADA	Insufficient sensors and monitoring prevent early detection of failures or performance deviations.	3	4	12	High	Design for comprehensive sensing (T, flow, pressure, leakage); redundancy; SCADA with data logging and alarms.
8	T-AR 1	Technical	Liner puncture or welding defects	Damage to liner during construction or poor weld quality leading to leaks.	3	5	15	High	Strict QA/QC procedures; certified welders; continuous leak detection; staged pressure and fill tests.
9	T-S 1	Technical	Slope or embankment instability	Slope failure during excavation or operation causing structural damage to PTES.	2	5	10	Medium	Geotechnical verification; appropriate slope angles and reinforcement; construction supervision by geotechnical engineer.
10	T-S 2	Technical	Adverse weather during liner/lid works	Rain, low temperatures or wind affect liner/lid installation quality and schedule.	3	3	9	Medium	Schedule sensitive works in favourable seasons; weather criteria in contracts; temporary protection structures.
11	T-AR 2	Technical	Liner or lid degradation over time	Ageing, UV or mechanical stress cause liner/lid damage, leaks, or reduced insulation.	3	5	15	High	Regular inspections; predictive maintenance; planned refurbishment after 15–20 years; warranty conditions.
12	T-AR 3	Technical	Drainage/lid water accumulation failure	Blocked drains cause water pooling on lid, overloading structure and degrading insulation.	3	4	12	High	Robust drainage design; access for cleaning; routine inspection; alarm thresholds for lid moisture/deflection.
13	T-P 5	Technical	SCADA/controls failure	Control system malfunction leads to inefficient operation, stratification loss, or safety incidents.	2	4	8	Medium	Redundant PLCs/servers; UPS; periodic testing of alarms; cybersecurity measures; fallback manual procedures.
14	T-AR 4	Technical	Overheating / boiling risk	Temperature increase above boiling point for water or above liner durability limit	3	4	12	High	Operating temperature limits, alarms, emergency discharge option
15	T-AR 5	Technical	Embankment cracking (freeze–thaw)	Pit structure damage	2	5	10	Medium	Climate-adapted design, frost-resistant materials, inspections
16	T-P 6	Technical	Poor integration with DH system	Inappropriate integration to ensure effective operation	3	3	9	Medium	System modeling, stakeholder workshops, flexible operating strategy

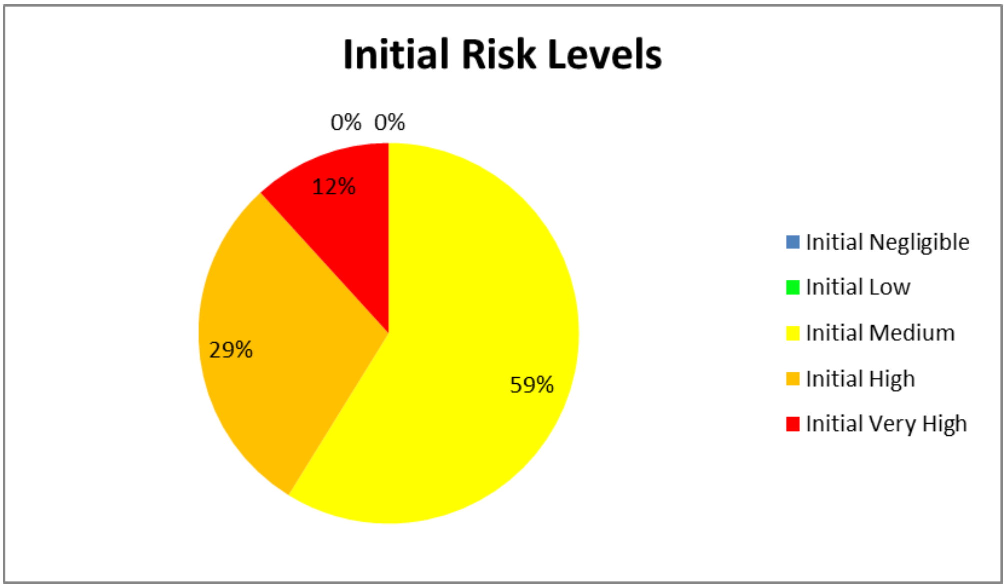

Fig. 6.7. Initial technical risk levels for the SET_HEAT_PTES project

Table. 6.22. SET_HEAT_PTES project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	2	0	0
4	0	1	6	0	0
5	0	2	3	2	0

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Table. 6.23. SET_HEAT_PTES top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-I 1	Inadequate soil investigation	20	Operations	Open
T-I 2	Inadequate groundwater assessment	20	Operations	Open
T-P 1	Thermal design errors	15	Operations	Open
T-AR 1	Liner puncture or welding defects	15	Engineering Lead	Open
T-AR 2	Liner or lid degradation over time	15	Operations	Open

Highest-severity risks are predominantly associated with construction feasibility and system performance uncertainty. These include the possibility of insufficient geological or structural stability, which could compromise the integrity of the storage pit, and technical underperformance of key components such as the lid, liner, or hydraulic systems. Such risks reflect the innovative nature of PTES technology and its dependency on favourable geotechnical conditions and precise engineering execution.

A second cluster of risks, scoring 12–15 (High), highlights constraints linked to system integration challenges. These include potential difficulties in synchronising PTES operation with existing heat production assets.

Medium-severity risks, scoring 8–10, are largely operational and managerial. These include risks of insufficient organisational capacity, supply chain disruptions, and maintenance challenges over the system's lifecycle. While individually less critical, they cumulatively influence the project's resilience and long-term cost structure.

Across all categories, mitigation strategies emphasise early-stage technical due diligence, robust geotechnical surveys, modular and redundant system design, and strong coordination with authorities and stakeholders.

Overall, the table presents a comprehensive and balanced risk landscape and acknowledges major uncertainties inherent in pioneering a large-scale PTES installation. This structured risk picture underscores the need for careful planning across engineering dimensions as the project progresses toward full feasibility and implementation.

6.10. SET_HEAT_CHP technical risk analysis report

The risk register Table 6.24 presents a structured assessment of the key threats associated with the implementation and operation of the hybrid low-temperature heat recovery system for gas-engine-based cogeneration in Opole.

Table 6.24. Technical risk identification for SET_HEAT_CHP project

Risk No.	Risk ID	Category	Risk Name	Description	Likelihood	Impact	Risk Score	Risk Severity	Mitigation Actions
1	T-P 2	Technical	Heat pump system not working as expected	WSHP/ASHP underperformance in cold conditions. Achievable heating output too low, minimum load level too high, inappropriate dynamics to provide electricity grid services.	3	3	9	Medium	Rigorous system design; Performance guarantees; Validated modelling.
2	T-P 3	Technical	Lower-than-expected COP	HP COP below target value; COP drops significantly at low outdoor temperatures.	3	3	9	Medium	Implement rigorous equipment and system design. ASHPs cannot serve peak loads; backup boilers must compensate.
3	T-I 1	Technical	Integration issues with existing systems	Integration failure with existing heating plant infrastructure; Integration issues between heat pump and existing primary circuit leading to hydraulic/thermal imbalance.	2	4	8	Medium	Implement rigorous design; use CFD modelling; consider oversising.
4	T-AR 1	Technical	Faulty control	Software or hardware failures, improperly tuned controls	3	3	9	Medium	Tuning parameters (superheat, flow, pressure), commissioning with manufacturer involvement
5	T-AR 2	Technical	Low availability in the initial period of operation	Low initial system availability due to commissioning or integration faults	3	3	9	Medium	Implement robust commissioning plan with manufacturer supervision and performance testing
6	T-AR 3	Technical	Compressor failures	Heat pump compressor failures	2	5	10	Medium	Implement robust monitoring and maintenance procedures aligned with best industrial practices
7	T-AR 4	Technical	Issues with defrosting system	Frost accumulation reduces output and increases energy use; Defrost cycles also introduce thermal instability unless mitigated by storage tanks.	3	3	9	Medium	Rigorous system design. Optimise airflow and maintain clean evaporators; Optimised defrost algorithms; Refrigerant selection and operating point optimisation.
8	T-I 3	Technical	Insuficient integration with utility grid	Insufficient availability of electricity from utility grid; Startup currents causing local grid disturbance or trips.	2	5	10	Medium	Early coordination with DSO; rigorous interconnection design; A new cable line or substation upgrade is required.
9	T-I 4	Technical	Signifficant space requirements	ASHPs and thermal tanks require significant footprint.	2	4	8	Medium	Extensive space audit; dismantle existing equipment no longer in use.
10	T-C 1	Technical	Inefective control	Control software does not perform well regarding optimisation	3	3	9	Medium	Implement extensive testing and simulation at the develpment stage; provide flexibility for redesign and adjustments.
11	T-P 4	Technical	Air heat exchanger fouling and corrosion	Air heat exchanger fouling and corrosion is	3	4	12	High	Hydrophobic / epoxy-coated fins, stainless steel or coated tube materials; anti-corrosion surface treatments; optimised air intake positioning; prefilters or mesh screens; scheduled coil washing; condition-based maintenance triggered by pressure drop; regular airflow and fan-speed monitoring; avoiding installation near dust sources; oversized coil surface area to tolerate mild fouling; easy access for maintenance; vertical coil orientation in high-dust environments.
12	T-C 1	Technical	Unacceptable noise level	Noise exceeding regulatory limits; Industrial ASHP fans and evaporators are noisy	3	3	9	Medium	Site planning and smart positioning; Soundproofing; Low-noise fans; Airflow optimization; Acoustic monitoring and predictive control.
13	T-AR 4	Technical	Equipment failure/downtime (other than compressor)	Major component failure (i.e., pumps, valves, etc.)causing heat shortfall.	3	3	9	Medium	Predictive maintenance; spares strategy; vendor quality acceptance.
14	T-P 5	Technical	Maintenance complexity	Inappropriate maintenance of air heat exchangers and piping leading to performance loss and lifetime shortening	3	3	9	Medium	Develop preventive maintenance program and include online monitoring and predictive maintenance tools; Consider service agreements with sepcialised providers.

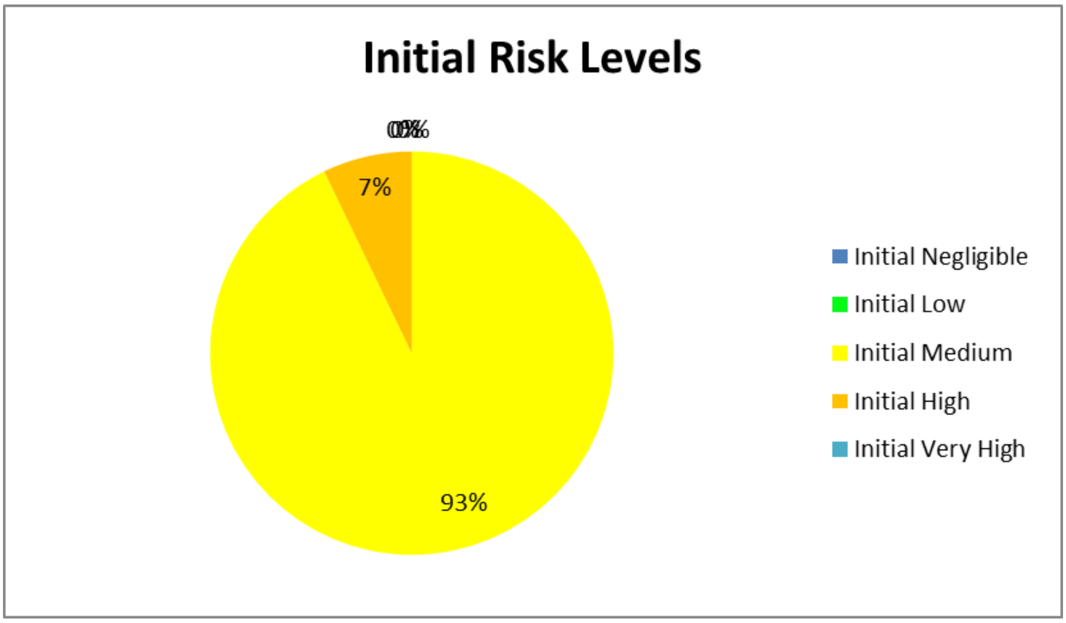

Fig. 6.8. Initial technical risk levels for the SET_HEAT_CHP project

Table. 6.25. SET_HEAT_CHP project initial technical risk heatmap

Impact ↓ / Likelihood →	1	2	3	4	5
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	9	0	0
4	0	2	1	0	0
5	0	2	0	0	0

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Table. 6.26. SET_HEAT_CHP top 5 risks (by score)

ID	Risk Name	Score	Owner	Status
T-P 4	Air heat exchanger fouling and corrosion	12	Operations	Open
T-AR 3	Compressor failures	10	Operations	Open
T-I 3	Insuficient integration with utility grid	10	Engineering Lead	Open
T-P 2	Heat pump system not working as expected	9	Operations	Open
T-P 3	Lower-than-expected COP	9	Operations	Open

Most risks identified fall into the medium-severity range, with risk scores of 8–10, indicating that project uncertainties are significant but manageable with appropriate oversight. These risks typically relate to technological integration challenges, operational uncertainties, equipment performance variability, supply-chain dependencies, and potential disruptions during commissioning or long-term operation. A notable concentration of medium-severity risks suggests that while no single threat is expected to critically jeopardise the project, the cumulative effect of several moderate risks requires continuous monitoring and proactive coordination between technical teams, suppliers, and operators.

Among the listed items, one risk stands out with a higher severity rating (score: 12), highlighted in orange in the table. This elevated score signals a threat with either a higher probability of occurrence, a greater potential impact, or both. In the context of energy-system projects, this category typically includes risks such as major equipment failure, critical delays in component delivery, incompatibility with existing district heating infrastructure, or the possibility of heat pumps exceeding allowed return temperatures, any of which could significantly affect project timelines, system reliability, or compliance requirements. The high-severity item likely requires enhanced mitigation measures, contingency planning, and stringent technical verification.

The final column of the table is dedicated to mitigation actions, signalling that the project incorporates a preventive and corrective strategy to manage risk exposure. The proposed measures include supplier quality assurance, design validation, redundancy in key components, commissioning protocols, predictive maintenance strategies, and the implementation of advanced control algorithms (e.g., MPC) to stabilise system operation under varying thermal and market conditions.

Overall, the predominance of medium-severity risks indicates that the project environment is challenging but under control, provided that mitigation actions are actively executed. The presence of a single high-severity risk underscores the need for heightened attention in specific project areas but does not undermine the overall feasibility of the hybrid heat-recovery concept. The table serves as a foundational tool for ongoing risk monitoring throughout the design, procurement, installation, and operational phases of the project.

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6.11. DH network risk analysis report

DHN risk analysis was performed on the example of the Opole DH system. Since the concept of the SET_HEAT Project is based on inductive reasoning, which would result in the creation of a plan converting the district heating system into a low-temperature 4th generation one, only one representative location was taken into consideration in this document. Additionally, due to the continuous and simultaneous implementation of D3.5 and D3.4, the district heating system in Opole was selected as the balance boundary in the analysis, and the subject of the analysis was to increase the energy efficiency of the system.

Based on the report from D3.4, detailed observations were made on a real example, which allowed the following conclusions to be drawn:

- The heating curves defined in internal formal documents do not reflect the actual operation of the district heating system;
- The highest optimisation potential characterises the period of low outdoor temperatures;
- Modelling the system at the design temperature coincides with the estimation of boundary conditions based on historical hourly data;

These conclusions allowed us to identify three reference models for the Opole system. They are differentiated by defined optimal heating curves and system configurations. Each model assumes a maximum reduction in temperature parameters at the source, a constant heat demand and the resulting mass flow from the enthalpy equation. In addition, for two models, investment tasks necessary to ensure the thermal comfort of the end user were defined:

– in terms of network reconstruction – change of pipeline diameters;

– in terms of generation infrastructure – the number of waste heat sources necessary for integration with the system.

1. Reference model 1 (M1) – a non-investment model that aims to optimise the current settings at the central heating plant:
   a. temperature parameters 115/65 ºC;
   b. mass flow in the central heating plant 3,644 t/h;
   c. no need to change pipe diameters;
   d. no waste heat sources to connect.

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2. Reference model 2 (M2) – an investment model that involves measures to optimise the temperature parameters of the network, increasing ECO's competitiveness on the heat energy market:
   a. temperature parameters 100/54.4 °C;
   b. mass flow in the central heating plant 3,290 t/h;
   c. need to change the pipe diameters from DN100/DN125 to DN150 on 320 m of the symmetrical distribution network;
   d. connection of 8 waste heat sources with a total capacity of 26.3 MW.
3. Reference model 3 (M3) – an investment model that assumes extensive measures to optimise the temperature parameters of the network, guaranteeing strong expansion of ECO on the heat energy market:
   a. temperature parameters 90/47.5 °C;
   b. mass flow in the central heating plant 3,034 t/h;
   c. need to change the diameter of pipelines from DN100 to DN125 on 152 m of the symmetrical distribution network;
   d. connection of 16 waste heat sources with a total capacity of 56.25 MW.

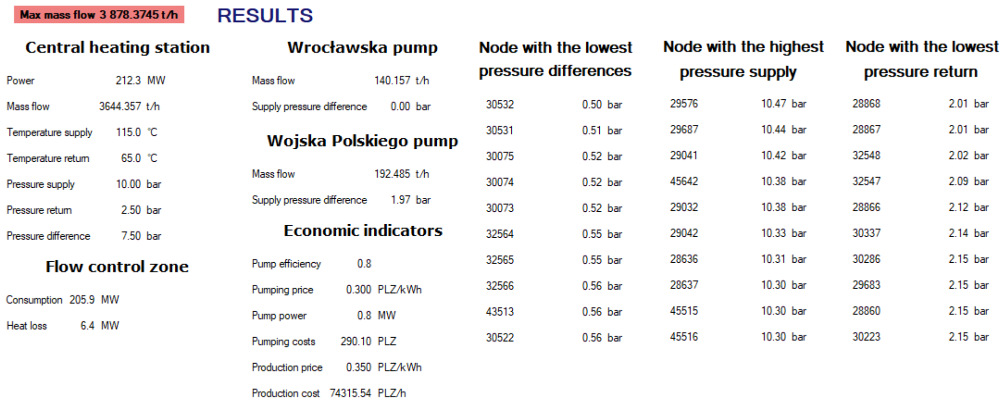
Each model represents a different heating system operation, but the primary objective of each is to maintain thermal comfort for the end user.

Reference model M1

Model M1 assumes that the system operates according to a heating curve based on average daily historical data. It illustrates the actual characteristics of the system's operation, in particular taking into account the quality of the heat substations' operation, i.e. it considers the demand side. This allows the actual return temperature to the source to be determined.

The calculation parameters are defined as 115/65 °C, which, with a maximum power demand of 212 MW, forces a flow of at the central heating plant of 3,645.7 t/h. The highest load on the network is under calculation conditions, which is why reference models are compared for these conditions.

Operation of the system in accordance with M1 requires a setting of 75 meters of lift on the circulation pumps in the source system. In addition, it is necessary to start up the network pumping station and set the supply pressure change to 1.97 bar. In this configuration, the highest supply pressure occurs in the area behind the Wojska Polskiego pumping station, while the lowest return pressure is characteristic of the node in the Zakrzów circuit. Heat losses for the given boundary conditions are 3.01%.



Max mass flow 3 878.3745 t/h

RESULTS

Central heating station

Power	212.3 MW
Mass flow	3644.357 t/h
Temperature supply	115.0 °C
Temperature return	65.0 °C
Pressure supply	10.00 bar
Pressure return	2.50 bar
Pressure difference	7.50 bar

Flow control zone

Consumption	205.9 MW
Heat loss	6.4 MW

Wrocławska pump

Mass flow	140.157 t/h
Supply pressure difference	0.00 bar

Wojska Polskiego pump

Mass flow	192.485 t/h
Supply pressure difference	1.97 bar

Economic indicators

Pump efficiency	0.8
Pumping price	0.300 PLZ/kWh
Pump power	0.8 MW
Pumping costs	290.10 PLZ
Production price	0.350 PLZ/kWh
Production cost	74315.54 PLZ/h

Node with the lowest pressure differences		Node with the highest pressure supply		Node with the lowest pressure return	
30532	0.50 bar	29576	10.47 bar	28868	2.01 bar
30531	0.51 bar	29687	10.44 bar	28867	2.01 bar
30075	0.52 bar	29041	10.42 bar	32548	2.02 bar
30074	0.52 bar	45642	10.38 bar	32547	2.09 bar
30073	0.52 bar	29032	10.38 bar	28866	2.12 bar
32564	0.55 bar	29042	10.33 bar	30337	2.14 bar
32565	0.55 bar	28636	10.31 bar	30286	2.15 bar
32566	0.56 bar	28637	10.30 bar	29683	2.15 bar
43513	0.56 bar	45515	10.30 bar	28860	2.15 bar
30522	0.56 bar	45516	10.30 bar	30223	2.15 bar

Fig. 6.9. Simulation results for M1 for an external temperature of -20 °C.

Model M1 is characterised by the highest flows on the main sections, as shown in the figure below. In addition, it shows the flow of the heating medium through the rings.

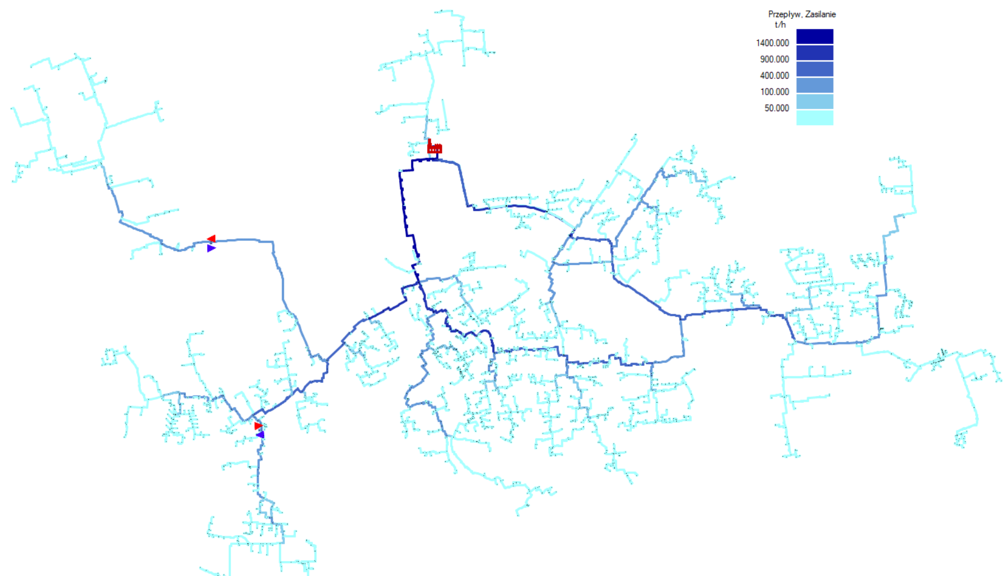


Fig. 6.10. Mass flow pattern for M1 at an external temperature of -20 °C

At high mass flows and flow velocities, bottlenecks are visible in the network. For the M1 model, three such locations can be identified:

– the heat pipe connecting the Centre circuit with Zaodrze – location 1;
– heat pipes forming a small ring behind the Wojska Polskiego pumping station – location 2;
– the heat pipeline connecting the ZWM and Malinka circuits – location 3.

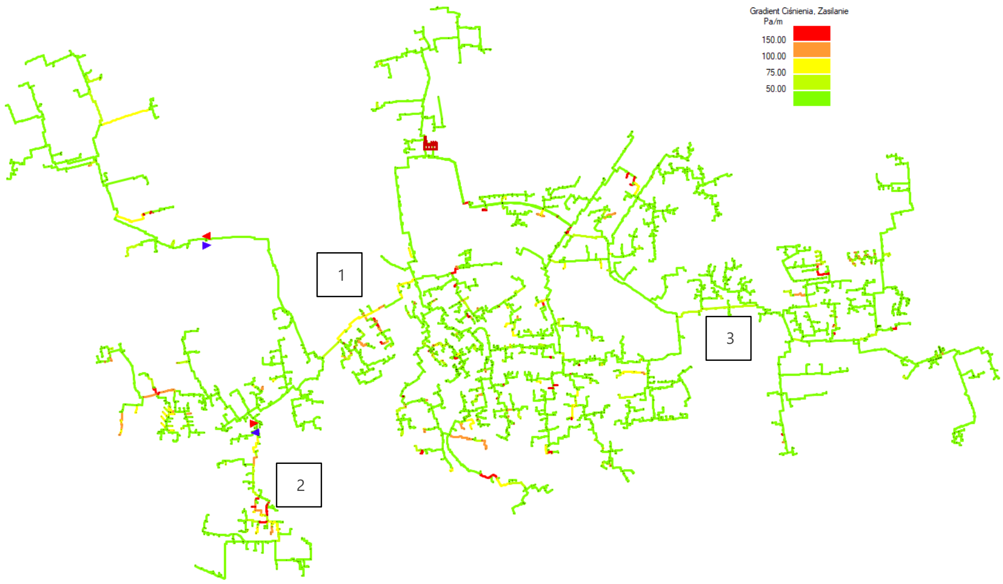


Fig. 6.11. Friction pressure gradient theme for M1, at an ambient temperature of -20 °C

The unit pressure loss values are reflected in the pressure difference theme. Namely, in the area just behind the Wojska Polskiego pumping station, we can see a rapid decrease in the pressure difference as we move away from the pumping station (a smooth transition from green to light orange). Similar colour transitions can be observed in the western part of Zaodrze. In this configuration, the most sensitive area is the eastern part of the Malinka circuit (1), as it is a bottleneck area with no pumping station to increase the pressure in this area.

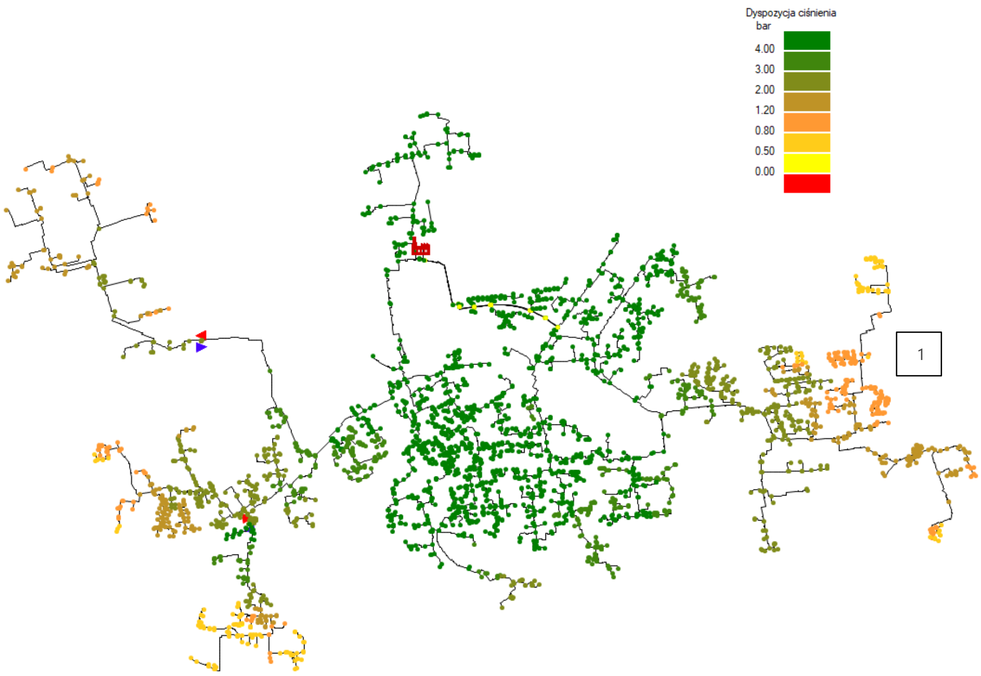


Fig. 6.12. Pressure difference theme for M1 at an ambient temperature of -20 °C

The longest transport times – over 10 hours – are characteristic of heat substations in the Głogowska area, due to low demand and high nominal diameters of DN500 pipelines. Long transport times, ranging from 4 to 7 hours, also apply to nodes in the vicinity of Kępska Street. This is due to low demand from end users. Therefore, in the event of a failure or aberration in the management of settings at the sources, these nodes are most vulnerable to potential underheating, due to the high reduction in supply temperature on the path from the source to the node.

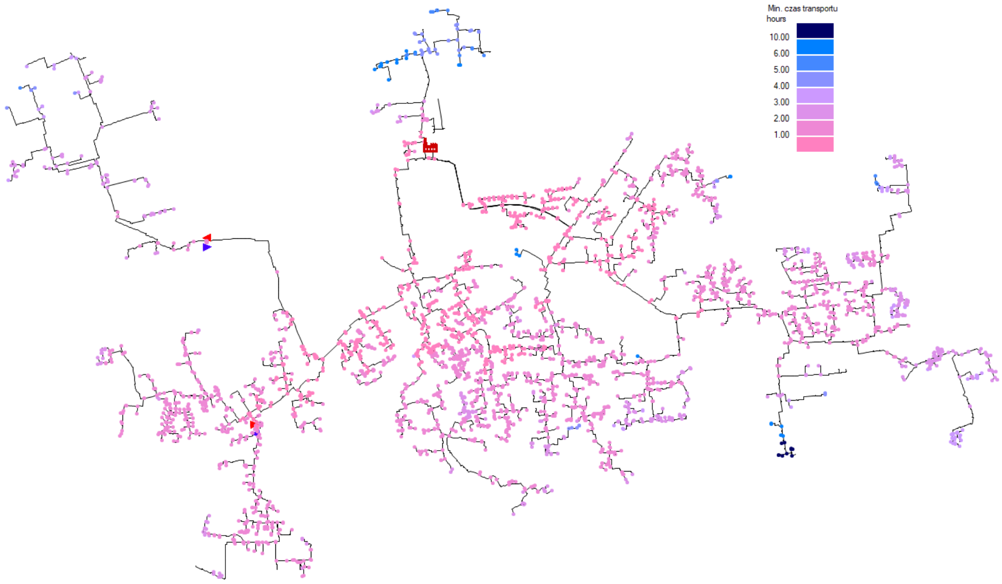


Fig. 6.13. Transport time theme for M1, at an outside temperature of -20 °C

Reference model M2

Assumes implementation of the minimum variant from Deliverable D3.4. It requires the connection of waste heat sources listed in the Table 12.1 below.

Table 12.1. Waste heat sources with a high probability of connection

Name	MW	years	long	description
Industry	5.00	50.68013	17.91410	Cement plant
Waste heat	10.00	50.67689	17.90781	BIOGAS CHP
Waste heat	1.00	50.69396	17.87458	cooling water/cooling system
Waste heat	0.60	50.66746	17.95442	cooling water/cooling system
Waste heat	0.80	50.68448	17.92037	GAS CHP lt cooling system
Waste heat	0.80	50.68414	17.91853	GAS CHP lt cooling system
Incinerator	7.00	50.6379	17.94159	Waste treatment plant
Industry	0.80	50.6915	17.86983	Process gases
Waste heat	0.40	50.68391	17.87566	Data system air/air cooling system

The sources connected to the system are listed on the map below. The total waste heat is 26.3 MW, which accounts for 11.01% of the total power volume. Additional sources are located in four zones:

– three sources, with a total capacity of 2.2 MW, are located in the industrial zone, which is very advantageous due to the distance of this zone from the central heating plant;
– three sources, with a total capacity of 16.5 MW, are located within the Odra fork, which affects the flow distribution within the large ring, increasing the load on the Chabry trunk line and the bottleneck connecting the Cantrum and Zaodrze area;

– one heat source in the western part of the Centrum area, with a capacity of 0.5 MW;
– one heat source located far from the system, with a capacity of 7 MW, which significantly reduces the time it takes for the heating medium to reach the nodes in the vicinity of Głogowska Street.

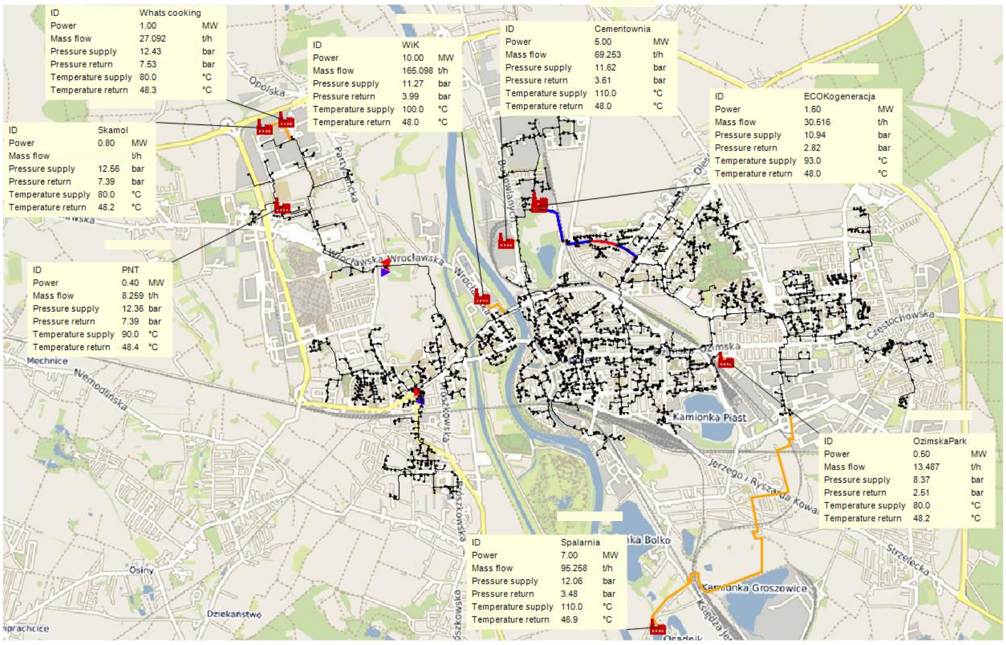


Fig. 6.14. Waste heat sources with a high probability of connection

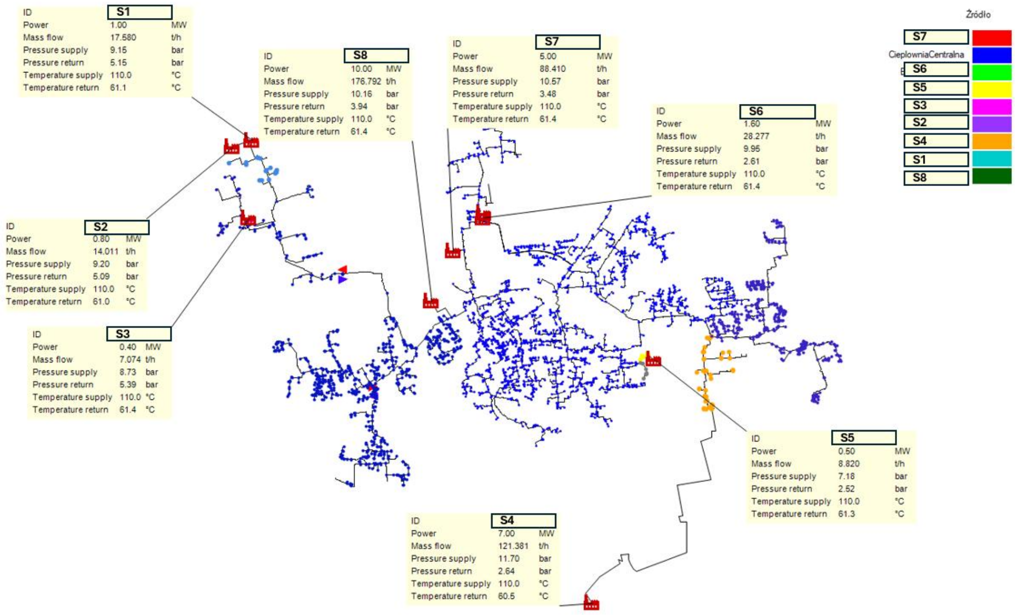


Fig. 6.15. Source range theme for parameters 100/54.5 °C at an ambient temperature of -20 °C

The necessary network investment to ensure stable operation of the system is the expansion of a 320 m symmetrical heat pipeline leading to the Przylesia housing estate. The following diameters were selected using Leanheat Network software (Table 6.27).

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Table 6.27. Proposed change in diameter for the connection to the node in the Przylesia area

ID	74827	74826	91500	71713	93935
GIS diameter	DN_125	DN_125	DN_100	DN_100	DN_125
Proposed diameter	DN_150	DN_150	DN_150	DN_150	DN_150

These investments will enable the system to operate according to the design parameters of 100/54.5 °C. The maximum power demand was set at 212 MW, with waste heat reducing production at the central heating plant to 185.37 MW, forcing an output flow of 3,500.932 t/h.

For the system to operate in accordance with M2, the circulation pumps in the source system must be set to 75 meters of head. In addition, it is necessary to start up the network pumping station and set the supply pressure change to 2.76 bar. In this configuration, the highest supply pressure occurs in the area behind the Wojska Polskiego pumping station and in the western part of the center zone, while the lowest return pressure is characteristic of the Zakrzów and ZWM areas nodes. Heat losses for the given boundary conditions are 2.72%.

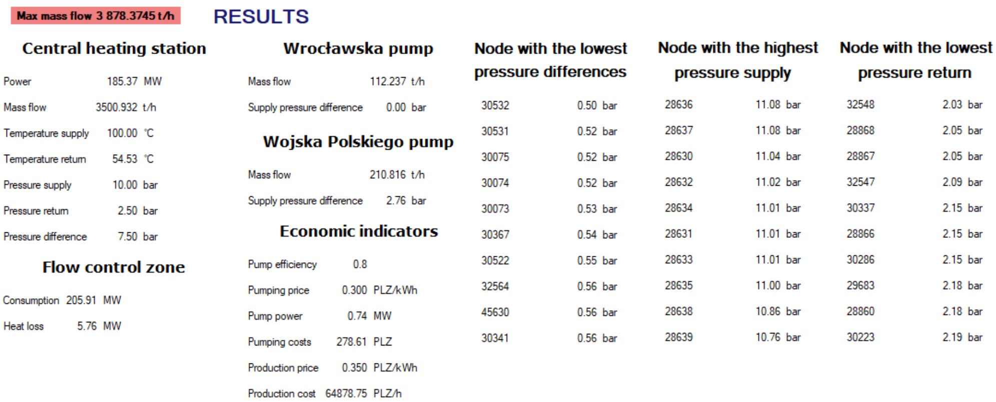

Fig. 6.16. Simulation results for parameters 100/54.5 °C for an ambient temperature of -20 °C

The area with the lowest pressure availability is the north-eastern part of the Malinka area. Compared to the M1 model, the nodes in the industrial zone are characterised by higher pressure availability. The connection of three waste heat sources in this area has a critical impact on the improvement.

The friction pressure gradient shown in the figure below illustrates that connecting sources to the network will not cause a critical increase in unit pressure losses in the industrial zone. An increase in the load on the heat pipes was observed at the point where the 10 MW source was connected (1). Connecting a 5 MW source caused a change in the flow velocity through the heat pipes within the large ring, resulting in higher unit pressure losses in the Chabry main line (2).

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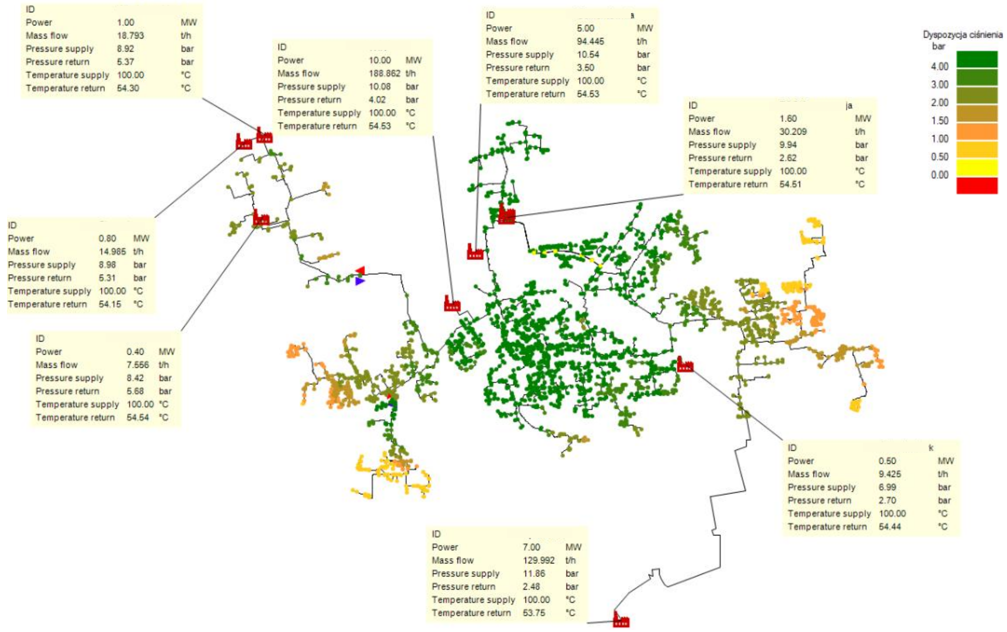

Fig. 6.17. Pressure distribution pattern for parameters 100/54.5 °C at an external temperature of -20 °C

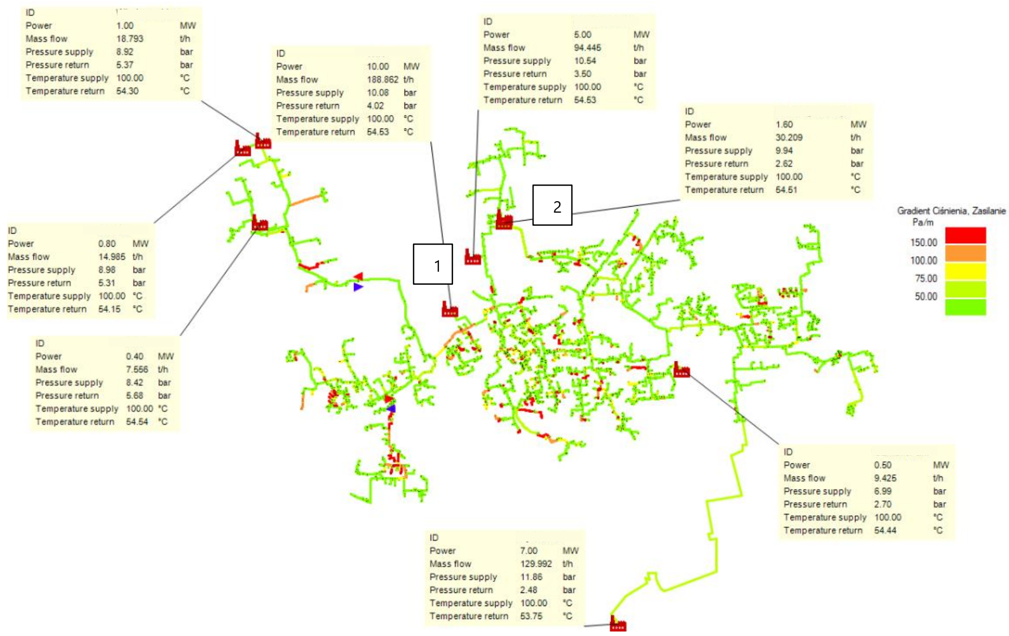

Fig. 6.18. Friction pressure gradient theme for parameters 100/54.5 °C at an ambient temperature of -20 °C

The transport time of the heating medium to the nodes in the vicinity of Głogowska Street has been significantly reduced. In this configuration, the longest supply times are characteristic of the nodes in the Zakrzów area.

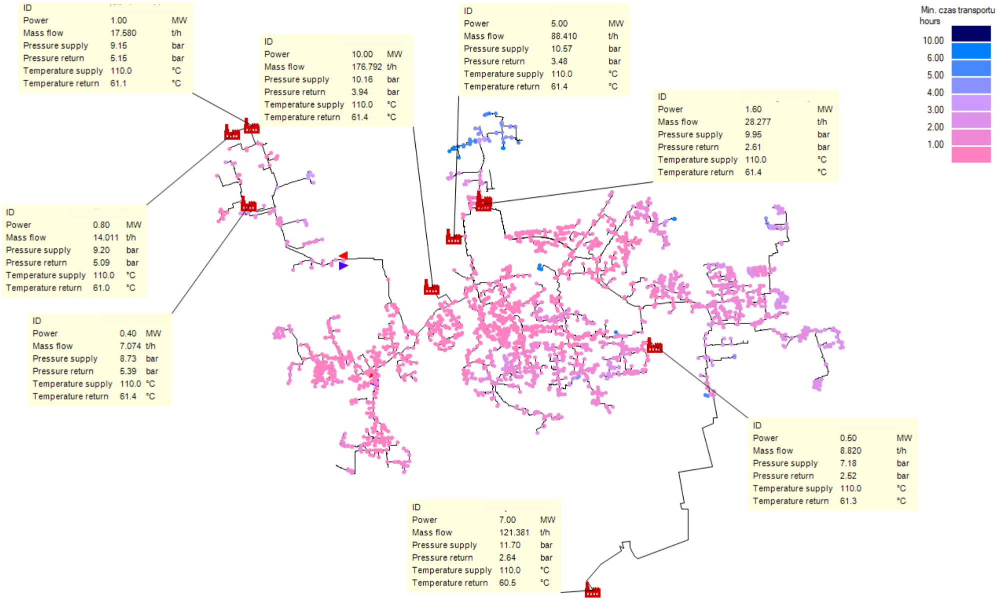

Fig. 6.19. Transport time motif for parameters 100/54.5 °C at an ambient temperature of -20 °C

Reference model M3

Assumes the implementation of the maximum variant from Deliverable D3.4. It requires the connection of waste heat sources listed in the Table 6.28 below.

Table 6.28. Waste heat sources with high and low probability of connection

Name	MW	years	long	description
Industry	15,000	50.68013	17,9141	cement plant
Industry	0.650	50.67644	17.90781	air compressors
Industry	1.150	50.67689	17.90781	BIOGAS CHP
Industry	0.100	50.67689	17.90781	BIOGAS CHP exhaust gas
Industry	0.100	50.67689	17.90781	BIOGAS CHP LT cooling system
Waste heat	3,000	50.65543	17.93358	cooling water/cooling system
Waste heat	4,000	50.66233	17.96673	cooling water/cooling system
Waste heat	2,000	50.6823	17.87811	cooling water/cooling system
Waste heat	1,000	50.69396	17.87458	cooling water/cooling system
Waste heat	0.600	50.69545	17.88128	cooling water/cooling system
Waste heat	1,000	50.66746	17.95442	cooling water/cooling system
Industry	0.300	50.66003	17.98717	cooling water/cooling system industry
Industry	0.150	50.6588	17.98781	cooling water/cooling system industry
Waste heat	0.800	50.68448	17.92037	GAS CHP lt cooling system
Waste heat	0.600	50.68448	17.92037	GAS CHP exhaust gas
Waste heat	0.800	50.68414	17.91853	GAS CHP lt cooling system
Waste heat	0.600	50.68414	17.91853	GAS CHP exhaust gas
Incinerator	7,000	50.6379	17.94159	Waste treatment plant
Incineration plant	1,000	50.63356	17.94037	BIOGAS CHP
Incinerator	0.100	50.63356	17.94037	BIOGAS CHP exhaust gas
Incinerator	0.100	50.63356	17.94037	BIOGAS CHP LT cooling system
Waste heat	0.500	50.67698	17.97564	cooling water/cooling system
Industry	0.800	50.69155	17.86983	process gases
Industry	0.400	50.68391	17.87566	date system air/air cooling system
Industry	0.500	50.68875	17.87533	gases from aluminium melting furnace
Industry	1.000	50.6901	17.87239	process gases

The sources connected to the system are shown on the map below.

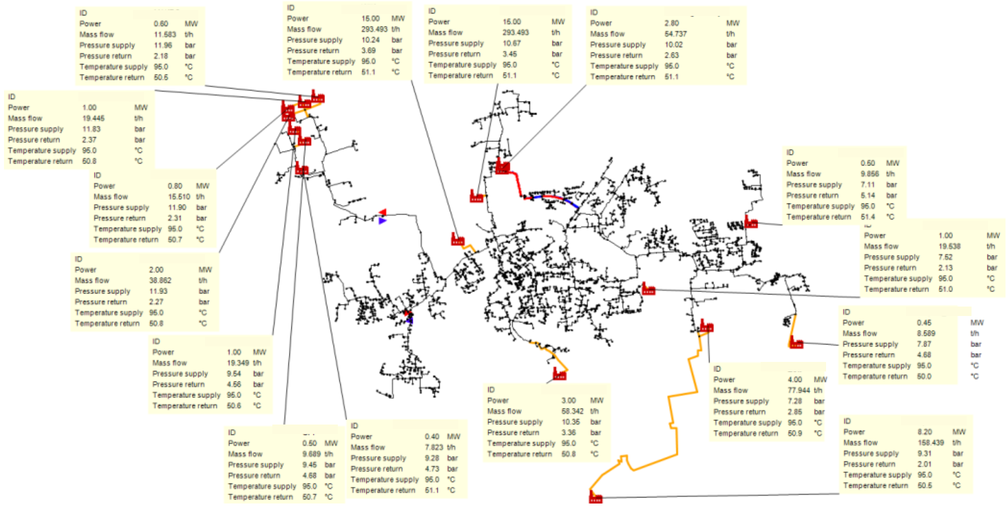

Fig. 6.20. Waste heat sources with high and low probability of connection

The total waste heat is 56.25 MW, which accounts for 21.04% of the total power volume. Additional sources are located in six zones:

– seven heat sources in the industrial zone, with a total capacity of 6.3 MW, allowed for the separation of a local balancing area, consisting of nodes in the northern part of this zone;
– three heat sources in the Odra fork area, with a total capacity of 32.8 MW, change the flow rates within a large ring, which puts more load on the Chabry main line;
– one heat source, with a capacity of 3 MW, in the vicinity of Torowa Street;
– one heat source with a capacity of 1 MW in the eastern part of the Centre area;
– two heat sources with a total capacity of 12.2 MW connected in the vicinity of Głogowska Street. This configuration significantly reduced the time it takes for the heating medium to reach the nodes in this area;
– two heat sources, with a total capacity of 0.95 MW, connected in the eastern part of the Malinka area. This configuration significantly reduced the time needed for the heating medium to reach the nodes in the vicinity of Nowowiejska Street.

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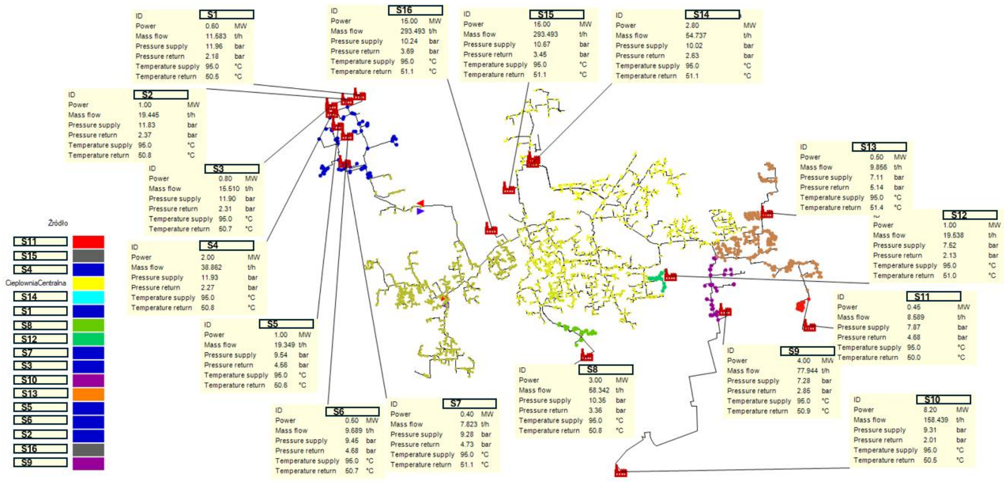

Fig. 6.2. Source range theme for parameters 90/47.5 °C at an ambient temperature of -20 °C

The necessary network investment to ensure stable operation of the system is the expansion of 152 m of symmetrical heat pipeline leading to the vicinity of Niemodlińska Street. The following diameters were selected using the Leanheat Network software:

Table 6.29. Proposed change in diameter for the connection to the vicinity of Niemodlińska Street

ID	71713	91500
Length	119.7	31.8
GIS diameter	100	100
Proposed diameter	125	125

These investments will enable the system to operate according to the design parameters of 90/47.5 ºC. The maximum power demand was set at 212 MW, with waste heat reducing production at the central heating plant to 154.83 MW, which requires an output flow of 3,122.924 t/h.

For the system to operate in accordance with M3, the circulation pumps in the source system must be set to 75 meters of head. In addition, it is necessary to start up the network pumping station and set the supply pressure change to 3.05 bar. In this configuration, the highest supply pressure occurs in the area behind the Wojska Polskiego pumping station and in the western part of the center circuit, while the lowest return pressure is characteristic of the nodes in the northern part of the industrial zone, the Zakrzów and ZWM area. Heat losses for the given boundary conditions are 2.45%.

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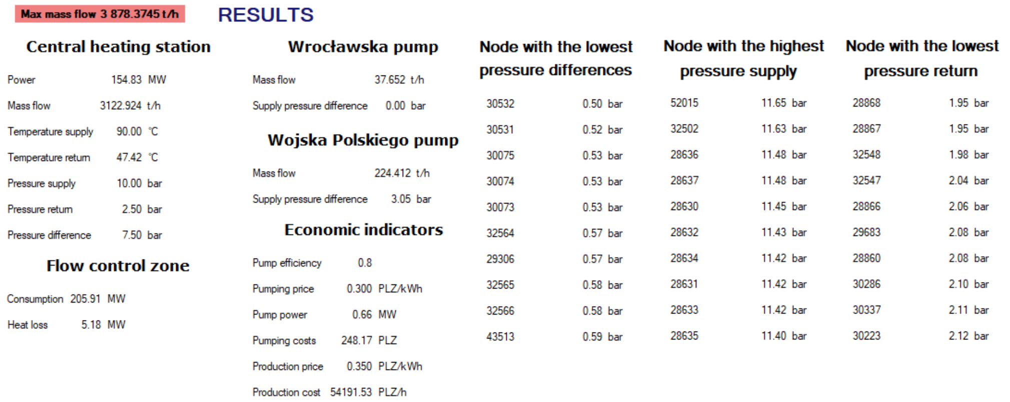

Max mass flow 3 878.3745 t/h

RESULTS

Central heating station

Power	154.83	MW
Mass flow	3122.924	t/h
Temperature supply	90.00	°C
Temperature return	47.42	°C
Pressure supply	10.00	bar
Pressure return	2.50	bar
Pressure difference	7.50	bar

Flow control zone

Consumption	205.91	MW
Heat loss	5.18	MW

Wrocławska pump

Mass flow	37.652	t/h
Supply pressure difference	0.00	bar

Wojska Polskiego pump

Mass flow	224.412	t/h
Supply pressure difference	3.05	bar

Economic indicators

Pump efficiency	0.8	
Pumping price	0.300	PLZ/kWh
Pump power	0.66	MW
Pumping costs	248.17	PLZ
Production price	0.350	PLZ/kWh
Production cost	54191.53	PLZ/h

Node with the lowest pressure differences		Node with the highest pressure supply		Node with the lowest pressure return	
30532	0.50 bar	52015	11.65 bar	28868	1.95 bar
30531	0.52 bar	32502	11.63 bar	28867	1.95 bar
30075	0.53 bar	28636	11.48 bar	32548	1.98 bar
30074	0.53 bar	28637	11.48 bar	32547	2.04 bar
30073	0.53 bar	28630	11.45 bar	28866	2.06 bar
32564	0.57 bar	28632	11.43 bar	29683	2.08 bar
29306	0.57 bar	28634	11.42 bar	28860	2.08 bar
32565	0.58 bar	28631	11.42 bar	30286	2.10 bar
32566	0.58 bar	28633	11.42 bar	30337	2.11 bar
43513	0.59 bar	28635	11.40 bar	30223	2.12 bar

Fig. 6.22. Simulation results for parameters 90/47.5 °C for an ambient temperature of -20 °C

All nodes have a pressure difference higher than 0.5 bar. The system configuration according to model M3 improves the pressure difference in the nodes in the area of Rozmarynowa Street and Nowowiejska Street, compared to model M2. This is due to the connection of two heat sources with a total capacity of 0.95 MW (1) to the system.

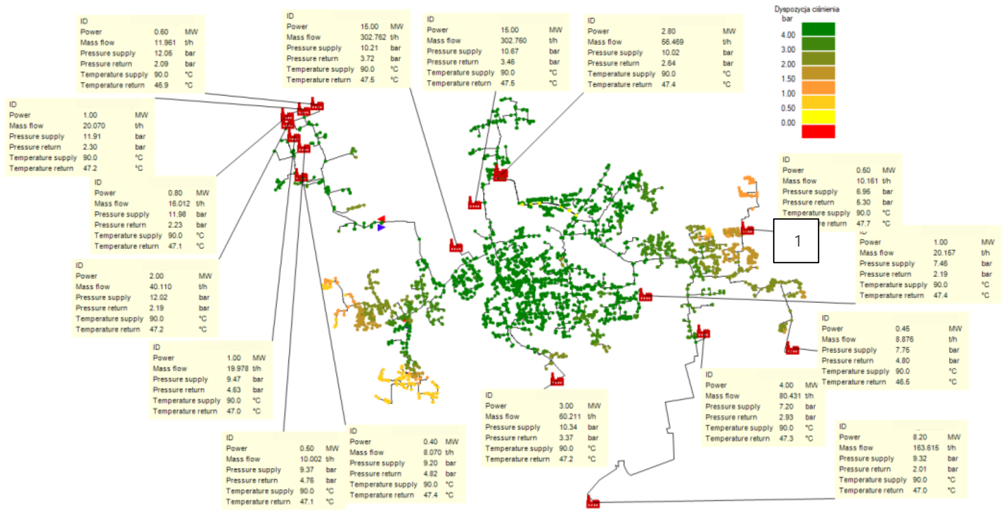

Fig. 6.23. Pressure difference theme for parameters 90/47.5 °C at an ambient temperature of -20 °C, after unchoking the pipeline

The friction pressure gradient shown in the figure below illustrates that connecting the sources to the network will increase the unit pressure losses at some connections. In particular, attention should be paid to the high unit pressure losses for pipelines in the industrial zone (1), at the source in the vicinity of Torowa Street and at the bottleneck connecting the Zaodrze and Centrum districts.

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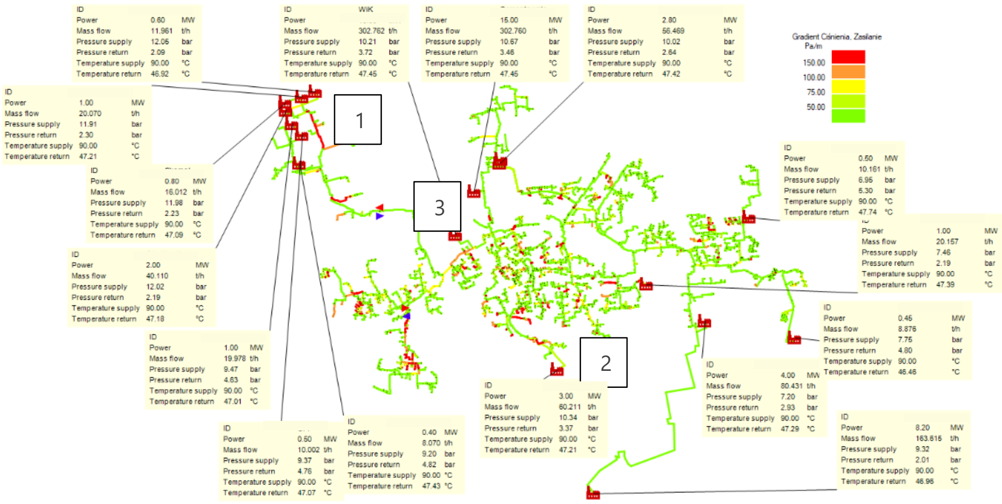

Fig. 6.24. Friction pressure gradient theme for parameters 90/47.5 °C at an ambient temperature of -20 °C

The distribution of heating medium transport time to nodes in the system has changed compared to models M1 and M2. The longest heating medium transport times are characteristic of nodes in the Zakrzów district (1) and at the boundary of the local balancing areas of the industrial zone and the central zone (2).

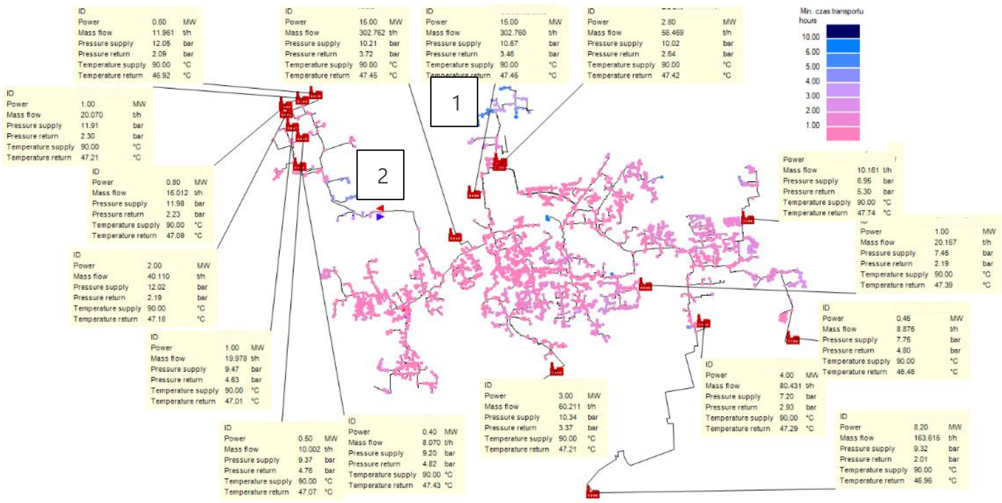

Fig. 6.25. Transport time theme for parameters 90/47.5 °C at an ambient temperature of -20 °C

In summary, the operation of the Opole heating system with parameters of 90/47.5 ºC is possible after the introduction of 17 waste heat sources with a total capacity of 56.25 MW and after changing the diameter of the connection leading to the node in the vivinity of Niemodlińska Street.

6.11.1. Network risk assessment methodology

The SWOT (Strengths, Weaknesses, Opportunities, Threats) method is a tool for identifying strengths and areas for improvement within a project and pointing out existing and potential opportunities and threats

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resulting from the impact of the external environment on a given reference model. It allows for an objective view of the issue by forcing the authors to elaborate on the subject of the analysis, both from the perspective of a person directly involved in the project and an external stakeholder.
A separate SWOT analysis is carried out for each reference model. Each of them is divided into four pillars:

- Strengths - identification of strengths from an internal perspective;
- Weaknesses - identifying unfavourable aspects from an internal perspective;
- Opportunities - identifying the positive impact of the external environment;
- Threats - predicting threats from the external environment.

The content of each pillar is based on the answers to the questions posed. Each reference model has a corresponding set of variables. Each item is assigned a weightage, and each response is scored. The research matrix created in this way will allow for a solid and reliable comparison of reference models and facilitate the correct interpretation of the results. The result of the analysis will be the selection of a reference model characterised by:

- Minimal risks associated with the implementation process;
- Maximum opportunities related to the influence of the external environment;
- Long-term protection against market and legal-formal threats.

The conclusion of the risk analysis will be recommendations regarding the choice of the company's strategy. If the opportunities and strengths prevail, it will be rational to choose an aggressive strategy. The opposite of this is to choose a defensive strategy for strongly pronounced weaknesses and threats. For companies with outstanding, favourable external prospects and visible and undeniable weaknesses, it is logical to choose a competitive strategy. In the case of numerous real external threats and solid strengths of the company, it is recommended to adopt a conservative strategy.

6.11.2. Defining the research matrix

The definition of the research matrix is a peculiar issue of SWOT analysis. The purpose of the matrix is to identify internal and external factors that determine the opportunities and limitations of ECO in the process of implementing technological and organisational changes related to the implementation of models M1, M2 and M3.

Internal factors directly related to the company's operations include the current state of technical and ICT infrastructure, including its degree of modernisation and flexibility. Formal procedures that shape the pace of

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decision-making and compliance with legal requirements are also important. Another important element is the company's management mechanisms, level of innovation and organisational culture, which can either facilitate or hinder the implementation of new solutions. It is also worth emphasising the role of staff – both technical staff, whose knowledge and skills directly affect the quality of the activities carried out, and management staff, who are responsible for strategic planning and investment decisions.

External factors include a wide range of economic, political and social conditions. These aspects are intertwined and have a critical impact on each other and on internal decisions within the company. Crucial importance here is the state's energy policy and European Union regulations, which set the legal framework, climate targets and support mechanisms for the energy transition. The competitive environment is influenced by the activities of other energy companies, which, through their innovations, marketing strategies or choice of investments, can influence the formal decisions taken within the company. The social aspect should also be taken into account, in particular, the expectations and attitudes of end users of heat, more specifically, acceptance or resistance to change has a direct impact on the pace and effectiveness of the implementation of new solutions. Macroeconomic factors such as fuel prices and the availability of EU funds for the modernisation of heating systems also play an important role.

In summary, the research matrix allows for a comprehensive understanding of both the potential within the organisation and the threats and opportunities arising from the external environment, which enables the development of realistic and long-term directions for ECO's activities. This document proposes the following variables:

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Table 6.30. SWOT analysis research matrix

Pillar	*Variable*
Strengths	Potential financial savings resulting from the reduction of heat losses during transmission through the implementation of a new heating curve.
	Experience and qualifications of operating staff in empirically lowering network curves.
	The ability to maintain the reliability of heat supply to end users with the system configuration indicated in the model.
	Experience and qualifications of engineers in making decisions related to interference with technical infrastructure.
	Level of digitisation and digitalisation of the heating system, enabling the implementation of monitoring and optimisation tools.
Weaknesses	The need to invest in the infrastructure of generation units and the network.
	The need to carry out organisational and investment activities on the demand side.
	Limited flexibility of part of the existing infrastructure – whether the heat pipelines are fully adapted to the proposed configurations of the generation units.
	Risk of unstable heat supply in the event of a heat pipeline failure.
	Lack of regulations supporting zone balancing solutions, which generates high system stabilisation costs.
	Potential technological limitations in the integration of waste heat and the use of new energy sources.

Opportunities	Gradual transition to 4th and 5th generation district heating systems, in line with European trends. Increased economic resilience due to the system's lower sensitivity to changes in fossil fuel prices and greenhouse gas emission regulations. Strengthening of competitive position by maintaining ESC status and increasing energy efficiency. Expansion of access to financing – possibility of obtaining national and EU funds for system modernisation. Consistency with strategic documents (SOR, KPD, PEP2040) that support the development of the heat energy sector. Potential to increase the recognizability and attractiveness of the Opole heating system on the international stage.
Threats	Strong dependence of the formal implementation of the new curve on cooperation with external stakeholders (including local governments, housing communities, individual consumers) and the risk of lack of public acceptance. Risk of costly technical interventions in the existing infrastructure for the integration of waste heat. Dependence on external district heating suppliers, which limits the independence of the production schedule of generating units. Lack of stable and long-term formal and legal regulations on energy transition and heat recovery development at the national level. Potential threats resulting from the volatility of energy and climate policy at national and EU level.

Strengths

The Strengths pillar is particularly focused on the specific nature of ECO and its experience in managing the heating system. Lowering the regulatory tables, i.e. gradually reducing the supply temperature of the network, is a task that requires both technical knowledge and organisational skills. This process entails the need to increase the mass flow at the source to meet the demand for heat power. This requires active

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cooperation between operational, engineering and analytical teams, which in the case of ECO already have empirical knowledge in this area.

In addition to the source aspect, elements related to the network and demand side are also important. In this regard, the strengths are:

- A digital network model, which allows bottlenecks to be identified and eliminated at the design stage and enables flexible reconfiguration of network connections.
- Awareness of technical limitations at the level of heat distribution centres, including a reliable inventory of heat distribution centres, allows for systematic and rational planning of modernisation measures, such as the replacement of poorly dimensioned heat exchangers, pumps or obsolete control and measurement equipment.

Another extremely important advantage is the advanced degree of digitisation and digitalisation of the heating system, which provides a foundation for reactive action in the event of anomalies and disruptions in heat supply. In recent years, the company has carried out a number of investments and implementations in this area, including:

- Expansion of telemetry systems by increasing the number of nodes covered by monitoring and equipping them with additional temperature and pressure detectors, enabling ongoing supervision of network parameters.
- Development of pre-insulated network detection systems, enabling early detection of failures and leaks, which significantly increases the safety and reliability of network infrastructure operation.
- Implementation of solutions based on artificial intelligence elements, which enable optimisation of heat consumption on the part of end users and better adjustment of heating curves to the actual needs of users.
- Implementation of a digital twin of the heating system, which allows for complex analyses to be performed, both for the current technical condition of the system and for the system after infrastructure modernisation.

Additionally, the following can be considered strengths:

- Human capital – highly qualified technical and engineering staff, supported by an experienced management team, ensuring flexibility in decision-making and effective implementation of innovative solutions.

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- Experience in the implementation of investment projects financed from national and EU funds, which increases the company's ability to further modernise the system.
- An organisational culture conducive to innovation, in which solutions are actively sought to improve DH system management and end-user comfort.

Each of the aspects described is important for the effective implementation of reduced regulatory tables and the management of generation units, which can be considered a competitive advantage for ECO. These aspects have been grouped into five variables, each of which has been assigned a weight reflecting its impact on the efficiency and effectiveness of the implementation of reference models.

Table 6.31. Assigning weights to variables in Strengths

Variable	Weight
Potential financial savings resulting from the reduction of heat losses during transmission through the implementation of a new heating curve.	0.225
Experience and qualifications of operating staff in empirically lowering network curves.	0.1
The ability to maintain the reliability of heat supply to end users with the system configuration indicated in the model.	0.25
Experience and qualifications of engineers in making decisions related to interference with technical infrastructure.	0.175
Level of digitisation and digitalisation of the heating system, enabling the implementation of monitoring and optimisation tools.	0.25
TOTAL	1

Weaknesses

The pillar of weaknesses, like that of strengths, is closely related to the specific nature of ECO's operations. Although the staff has experience in lowering temperature tables and has the necessary engineering skills, the main weaknesses stem primarily from the conditions of the system's infrastructure.

- Source infrastructure limitations

ECO currently operates various types of heat sources (gas and coal boilers and cogeneration systems) located at a single central heating plant. The operating schedule of the generating units is mainly determined by economic balances resulting from the correlation between the electricity and heat markets. This location is flexible in technical terms and does not require consideration of the network hydraulics. An additional challenge in the management of generation units is the integration of waste heat sources located at the extreme points of the network. This requires not only cost optimisation, but also consideration of hydraulic conditions, which increases the complexity of system balancing. This requires a transition from global balancing to local balancing.

- Network infrastructure limitations

The introduction of new sources at the end of the network will increase the flow of heating medium at the terminal connections, which may reveal the undersizing of these parts of the network. Increasing the diameters in these areas requires significant investment.

- Insufficient monitoring and observability

Before the implementation of the M2 and M3 reference models, the Opole system could be balanced globally, for which the current level of system digitalisation was adapted. The connection of new sources at the network terminals implies a change in the supply areas of the heat substations. In this configuration, it may be necessary to increase the number of metered heat substations, in particular pressure detectors. In addition, there are weaknesses in the area of monitoring:

✓ The lack of complete telemetry modules at third-party nodes implies the inability to fully balance energy in real time.

✓ In the case of battery-powered telemetry modules, delays in making detectors data available for analysis implies the inability to take preventive action in the event of anomalies in heat supply to a given node.

- Risk of deterioration in supply quality

Changes in the supply range of heat sources directly affect the transport time of the heating medium to individual nodes. The integration of waste heat in locations distant from the Central Heating Plant significantly reduces the transport time of the medium for nodes located near the waste source. However, in situations where there is no consumption from these sources and it is necessary to supply the nodes from the Central Heating Plant, the transport time is significantly extended. This results in a significant drop in temperature along the transmission route,

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which directly translates into a risk of not ensuring thermal comfort for end users.

- Organisational and financial constraints

Skillful balancing of local supply areas and rational flow management is a challenge that requires a high level of real-time system coordination using advanced decision support tools. However, in the perspective of implementing reference models, organisational measures alone may prove insufficient. Interference with the network infrastructure may be necessary, which entails significant, urgent and difficult to postpone capital expenditure. The high cost of infrastructure modernisation, combined with time pressure, is one of the most critical weaknesses limiting the pace and scope of reference model implementation.

The above-identified risks have been compiled in a table and assigned weights depending on their impact on the success of the reference model implementation.

Table 6.32. Assigning weights to variables in Weaknesses

Variable	Weight
The need to carry out investment activities in network infrastructure.	0.25
The need to implement organisational and investment measures on the demand side.	0.125
Limited flexibility of part of the existing infrastructure – whether the heat pipelines are fully adapted to the proposed configurations of the generating units.	0.225
Risk of unstable heat supply in the event of a heat pipeline failure.	0.125
Lack of regulations supporting zone balancing solutions, which generates high system stabilisation costs.	0.125
Potential technological limitations in the integration of waste heat and the use of new energy sources.	0.15
TOTAL	1

Opportunities

This pillar covers external aspects, both domestic and European, which ECO should take into account in its development plans. The key

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direction is to strive to increase energy efficiency, which is one of the main priorities of the climate policy of the European Union, including Poland. In practice, this means maximising energy use while reducing losses, which in the case of heating translates not only into the modernisation of source infrastructure, but also into improved network efficiency.

Energy efficiency forces companies to invest in modern technical solutions, such as pre-insulated pipelines, duo pipe systems with lower unit losses compared to two separate supply + return pipelines, or energy-efficient high-class fittings. Advanced ICT systems are also of key importance – meters, sensors and transducers configured with modern controllers and a central telemetry system. Their implementation provides a real-time overview of network and node parameters, eliminates signal duplication and enables remote control of the system. An additional driving force for improving efficiency is the gradual reduction of temperature parameters, not only in design conditions, but also in transitional periods, which effectively reduces transmission losses and thus generates financial benefits.

An important element of the heating sector is the pursuit of obtaining/maintaining the status of an Efficient Heating and Cooling System (ESC), which defines the minimum requirements for the share of energy from renewable sources, high-efficiency cogeneration and waste heat in the total production volume. Maintaining this status not only strengthens the company's image as a leader in energy transition, but is also sometimes a prerequisite for obtaining national and EU funds. The lack of ESC status closes the door to many sources of financing. In this context, programmes such as FENIX, the digitisation of heating networks and local initiatives such as County Cogeneration are of particular importance.

The volatile geopolitical situation has a strong impact on the fossil fuel market, creating additional incentives for transformation. High natural gas prices and uncertain supplies, high coal prices, and the low profitability of domestic mines are increasing pressure to reduce dependence on fossil fuels. An additional factor is the increase in CO_2 emission allowance prices under the EU ETS, which directly translates into tariff costs for heating companies. The IED Directive, in turn, imposes strict emission limits on installations with a capacity of more than 50 MW, forcing further modernisation and reduction of emissions of dust, nitrogen oxides, carbon dioxide and sulphur.

National strategic documents, such as *the Strategy for Responsible Development (SOR)*, *the National Renewable Energy Action Plan (KPD)* and

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Poland's Energy Policy until 2040 (PEP2040), clearly indicate the direction of development towards low-carbon systems and improved efficiency of heat generation and distribution processes.

The implementation of the M2 and M3 reference models contributes both to the reduction of CO_2 emissions, and thus to the reduction of EU ETS allowance purchase costs, as well as to an increase in the share of waste heat in the total production balance. Combining these measures with lowering the temperature in the heating network allows the company to move towards 4th and 5th generation systems, in line with modern European standards.

The implementation of reference models also improves the company's image and internationalisation. ECO's branding as an innovative and sustainable company increases opportunities for international cooperation, provides wider access to new technologies and facilitates the exchange of good heating practices. The growing interest in "green" solutions in the energy sector may also translate into positive public perception and better cooperation with local and national stakeholders.

Table 6.33. Assigning weightages to variables in Opportunities

Variable	Weight
Gradual transition to 4th and 5th generation heating systems, in line with European trends.	0.125
Increased economic resilience due to the system's lower sensitivity to changes in fossil fuel prices and greenhouse gas emission regulations.	0.225
Strengthening competitive position by maintaining ESC status and increasing energy efficiency.	0.25
Expanding access to financing – the possibility of obtaining national and EU funds for system modernisation.	0.25
Consistency with strategic documents (SOR, KPD, PEP2040) that support the development of the heat energy sector.	0.075
Potential to increase the recognition and attractiveness of the Opole heating system on the international stage.	0.075
TOTAL	1

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Threats

Threats mainly include external factors that may significantly limit or even block the implementation of reference models M2 and M3. They result from social, technical, regulatory and legal conditions.

Social aspect

Lowering temperature tables requires close cooperation with end users, who must accept lower system operating parameters. Lack of public acceptance is one of the most serious threats, especially when the actual involvement of users does not match their declared support for measures to improve energy efficiency. Limited trust, scepticism towards modern solutions or active opposition from stakeholder groups can significantly hinder the formal implementation of changes. Another problem may be insufficient energy awareness among the public and a lack of willingness to bear the potential costs of modernisation. Nevertheless, the growing level of acceptance for environmental protection among citizens, businesses and public administration provides an opportunity to mitigate these barriers through education and communication activities.

Technical aspect

A significant risk is the lack of compatibility between the production profiles of waste heat suppliers and the ECO heating system. Industrial and service plants often have variable, cyclical production profiles, while the operation of heating plants is regulated by weather conditions. These differences can lead to a situation where the peak surplus of waste heat to be transferred to the system from the plants will not coincide with the peak heat demand in the system. This threatens to leave the potential of the installation unused. An additional risk is the division of responsibility for the maintenance and operation of installation components at the boundary between the plant and the heating system, which may give rise to technical and financial disputes. Furthermore, new regulations or regulatory changes may require costly technological adjustments, limiting the flexibility and stability of the system.

Regulatory and legal aspects

The lack of stable and long-term legal regulations in the field of energy transition poses a significant threat to strategic planning. Legislative uncertainty concerning, among other things, the EU ETS system, environmental directives and national regulations may lead to difficulties in assessing the profitability of investments and increase the financial risk of projects. Too frequent or sudden changes in the law may also cause

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delays in the implementation of projects and the need for unforeseen adjustments.

In all of the areas identified, ECO can only implement mitigating measures, such as dialogue with consumers, public education, negotiations with industrial partners and flexible technical planning. Nevertheless, it should be emphasised that some of the risks are random in nature and cannot be completely eliminated. It is therefore essential to systematically monitor the environment and respond quickly to emerging challenges.

Potential difficulties have been summarised in the table below and assigned weights reflecting their impact on the successful implementation of reference models:

Table 6.34. Assigning weights to variables in Risks

Variable	Weight
Strong dependence of the formal implementation of the new curve on cooperation with external stakeholders (including local governments, housing communities, individual consumers) and the risk of lack of public acceptance.	0.275
Risk of costly technical interventions in existing infrastructure for the integration of waste heat.	0.225
Dependence on external district heating suppliers, which limits independence in scheduling the production of generating units.	0.225
Lack of stable and long-term formal and legal regulations on energy transition and the development of waste heat recovery at the national level.	0.15
Potential risks arising from the volatility of energy and climate policy at EU level.	0.125
TOTAL	**1**

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6.11.3. Risk analysis

The risk analysis consists of assigning points on a scale from -5 to +5 to each variable. Depending on the pillar, the following scores are assigned:

– in the range from 0 to +5 for strengths and opportunities, where 0 means that the variable does not apply to the model, and +5 means that the implementation of the model fully corresponds to the variable's thesis;

– from -5 to 0 for weaknesses and threats, where 0 means that the variable does not apply to the model, and -5 means that the model fully corresponds to the variable's thesis.

Each variable of the four pillars was assigned a score. The results are summarised in the Table 6.35 below.

Table 6.35. Assigning points to variables in SWOT analysis

Strengths		**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
Variable	**Weight**	**Points**	**Points**	**Points**	**Share**	**Share**	**Share**
Potential financial savings resulting from the reduction of heat loss during transmission through the implementation of a new heating curve.	0.225	1	3	5	0.225	0.675	1.125
Experience and qualifications of operating personnel in empirical reduction of network curves.	0.1	3	3	3	0.300	0.300	0.300
The ability to maintain the reliability of heat supply to end users with the system configuration indicated in the model.	0.25	3	3	3	0.750	0.750	0.750
Experience and qualifications of engineers in making decisions related to interference with technical infrastructure.	0.175	4	2	1	0.70	0.350	0.175
Level of digitisation and digitalisation of the heating system, enabling the implementation of monitoring and optimisation tools.	0.25	4	2	1	1.00	0.500	0.25
TOTAL	1	15	13	13	2,975	2,575	2,600
MAXIMUM NUMBER OF POINTS	5						
Weaknesses		**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
Variable	**Weight**	**Points**	**Points**	**Points**	**Share**	**Share**	**Share**
The need to carry out investment activities in network infrastructure.	0.25	0	-5	-3	0.000	-1.250	-0.750
The need to implement organisational and investment measures on the demand side.	0.125	-3	-4	-5	-0.375	-0.5	-0.625

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Limited flexibility of existing infrastructure – are the heat pipelines fully adapted to the proposed configurations of the generating units?	0.225	-1	-	-4	-0.225	-0.450	-0.900
Risk of unstable heat supply in the event of a heat pipeline failure.	0.125	-5	-5	-5	-0.625	-0.625	-0.625
No regulations supporting zone balancing solutions, which generates high system stabilisation costs.	0.125	0	-2	-4	0.000	-0.250	-0.500
Potential technological limitations in the integration of waste heat and the use of new energy sources.	0.15	0	-2	-4	0.000	-0.30	-0.600
TOTAL	1	-9	-20	-25	-1,225	-3,375	-4,000
MAXIMUM NUMBER OF POINTS	-5						
Odds		**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
Variable	**Weight**	**Points**	**Points**	**Points**	**Share**	**Share**	**Share**
Gradual transition to 4th and 5th generation district heating systems in line with European trends.	0.125	0	0	5	0	0	0.625
Increased economic resilience due to reduced sensitivity of the system to changes in fossil fuel prices and greenhouse gas emission regulations.	0.225	1	3	4	0.225	0.675	0.900
Strengthening competitive position by maintaining ESC status and increasing energy efficiency.	0.25	1	5	5	0.250	1.250	1.250
Expanding access to financing – the possibility of obtaining national and EU funds for system modernisation.	0.25	1	5	5	0.250	1.250	1.000
Consistency with strategic documents (SOR. KPD. PEP2040) that support the development of the heat energy sector.	0.075	3	5	5	0.225	0.375	0.375
Potential to increase the recognition and attractiveness of the Opole heating system on the international stage.	0.075	0	3	4	0.000	0.225	0.300
TOTAL	1	6	21	28	0.950	3.775	4.700
MAXIMUM NUMBER OF POINTS	5						
Threats		**M1**	**M2**	**M3**	**M1**	**M2**	**M3**
Variable	**Weight**	**Points**	**Points**	**Points**	**Share**	**Share**	**Share**
Strong dependence of the formal implementation of the new curve on cooperation with external stakeholders (including local governments, housing communities, individual consumers) and the risk of lack of public acceptance.	0.275	-3	-4	-5	-0.825	-1.100	-1.375
Risk of costly technical interventions in existing infrastructure for the integration of waste heat.	0.225	0	-2	-4	0.000	-0.450	-0.9
Dependence on external suppliers of district heating, which limits independence in scheduling the production of generating units.	0.225	0	-	-5	0.000	-0.450	-1.125

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Lack of stable and long-term formal and legal regulations regarding energy transition and the development of waste heat recovery at the national level	0.15	-1	-	-	-0.150	-0.300	-0.450
Potential risks arising from volatility in energy and climate policy at EU level.	0.125	0	-1	-2	0.000	-0.125	-0.250
TOTAL	1	-4	-11	-18	-0.975	-2.425	-4.100
MAXIMUM NUMBER OF POINTS	-5						

The assigned scores are justified as follows.

Table 6.36. Justification for assigning points to variables in the SWOT analysis

Strengths	
Variable	**Justification**
Potential financial savings resulting from the reduction of heat losses during transmission through the implementation of a new heating curve.	Lowering the temperature parameters implies a reduction in heat loss during transmission, which is assumed in the implementation of each of the reference models, therefore the score is positive in all cases. Model M3 assumes the deepest reduction in parameters, so it has the most points, and model M1 assumes the mildest reduction in parameters, so it has the fewest points.
Experience and qualifications of operating staff in empirical reduction of network curves.	It is assumed that the reference models are implemented by the same staff, so the number of points in this variable is the same for all models.
The ability to maintain the reliability of heat supply to end users with the system configuration indicated in the model.	Assuming a steady state and correct operating parameters of the heating plant, the same possibilities for maintaining the thermal comfort of the end user are assumed for all reference models.
Experience and qualifications of engineers in making decisions related to interference with technical infrastructure.	The dispersion of points between models is determined by the system configuration. In model M1, there are no additional heat sources, other locations or local balancing areas, which determines the high level of experience of the staff in making technical interventions. An antagonistic situation occurs for models M2 and M3.
The level of digitisation and digitalisation of the heating system, enabling the implementation of monitoring and optimisation tools.	In the case of this variable, the distribution of points between models is also dictated by the system configuration. Models M2 and M3, unlike model M1, have moving supply areas, which means that in some locations on the network, the current ICT status might be insufficient.
Weaknesses	
Variable	**Justification**
The need to invest in network infrastructure.	Due to the lack of necessity to rebuild heat pipelines in the M1 model, the variable is outside the balance sheet of the model and the score is 0. The reconstruction of the longest section of pipelines assumes the implementation of the M2 model, which determines the assignment of a score of -5.
The need to carry out organisational and investment activities on the demand side.	This variable assumes the implementation of minor tasks at nodes, such as flushing exchangers or replacing regulators. The dispersion of scores here reflects the depth of the reduction in temperature parameters in the network.
Limited flexibility of part of the existing infrastructure – whether the heat pipelines are fully adapted to the proposed configurations of the generating units.	This variable determines the correct selection of pipe diameters. The M1 model was assigned -1 points due to the presence of three bottlenecks in the network. The M2 model was assigned -2 points due to increased unit pressure losses in pipelines at bottlenecks compared to the M1 model. The M3 model

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	was assigned -4 points due to a significant increase in unit pressure losses at connections in the vicinity of waste heat sources.
Risk of unstable heat supply in the event of a heat pipeline failure.	Each model assumes that the system operates at minimum supply temperature with a hydraulically open network configuration. A pipeline failure forces a change in the flow distribution in the ring. This change requires an increase in temperature parameters in order to guarantee stable heat supply.
Lack of regulations supporting zone balancing solutions, which generates high system stabilisation costs.	Model M1 has a centrally located source, so there are no local balancing areas, hence the score is 0. In model M3, there are more local balancing areas than in model M2, which determines the assigned score.
Potential technological limitations in the integration of waste heat and the use of new energy sources.	Model M1 has no connected waste heat sources, so the assigned score is 0. Model M3 assumes a greater number of connected waste heat sources than in model M2, which determines the assigned score.
Chances	
Variable	**Importance**
Gradual transition to 4th and 5th generation district heating systems in line with European trends.	The proposed supply temperature in models M1 and M2 does not fit into the concepts of 4th or 5th generation systems, so the assigned score is 0. Model M3 assumes a supply temperature at the source that fits into the framework of a 4th generation system.
Increased economic resilience due to the system's lower sensitivity to changes in fossil fuel prices and greenhouse gas emission regulations.	Model M1 assumes an increase in energy efficiency by reducing heat losses during transmission, thereby reducing greenhouse gas emissions. Models M2 and M3, in addition to reducing heat losses during transmission, assume a reduction in production by the central heating plant at the expense of purchasing waste heat, which allows for a reduction in the share of heat from fossil fuels.
Strengthening the competitive position by maintaining ESC status and increasing energy efficiency.	Model M1 assumes an increase in energy efficiency, which does not hinder the maintenance of ESC status. Models M2 and M3, particularly in view of the 2035 standards, will provide ECO guarantees for maintaining ESC status.
Expanding access to financing – the possibility of obtaining national and EU funds for system modernisation.	Improving energy efficiency and maintaining ESC status is often linked to the availability of national funds, which means that the dispersion of points between models is the same as in the case of the variable above.
Consistency with strategic documents (SOR. KPD. PEP2040) that support the development of the heat energy sector.	These documents guide companies towards improving energy efficiency, which is ensured by the implementation of all reference models, therefore all models are assigned positive points. In addition, models M2 and M3 assume an increase in the share of waste heat in the production volume, which determined the assignment of 5 points for this variable.
Potential to increase the recognition and attractiveness of the Opole heating system on the international stage.	The implementation of model M1 assumes standard activities of energy companies, so 0 points were assigned to this variable. The implementation of model M2 assumes the connection of waste heat, including prosumer points, which is an innovative approach to the functioning of the heating system, so 3 points were assigned to this variable. The implementation of model M3, compared to model M2, additionally assumes a transition to a 4th generation system, which increases the attractiveness of Opole as a modern system.
Threats	
Variable	**Weight**
Strong dependence of the formal implementation of the new curve on cooperation with external stakeholders (including local governments, housing communities, individual consumers) and the risk of lack of public acceptance.	Changing the normative parameters requires interference in heat supply contracts and, therefore, the written consent of end users. Lowering the heating curve is often met with a negative response. As justification for this attitude, users cite the possible underheating of buildings. The greater the reduction in the heating curve compared to the current one, the more intense the negative attitude of stakeholders.

Risk of costly technical interventions in existing infrastructure for the integration of waste heat.	Model M1 does not assume the connection of waste heat sources, so 0 points were assigned to the variable. Models M2 and M3 assume such integration. Due to the pioneering nature of these activities, the risk is seen in the precise specification of the ownership boundary of the technical infrastructure and the associated need for repairs in emergency situations. The more waste heat sources there are, the higher the risk of repair costs.
Dependence on external suppliers of district heating, which limits independence in scheduling the production of generating units.	Model M1 does not assume any interference with the generating units, so it does not assume any changes in the methodology of planning the production schedule of the sources; 0 points were assigned to the variable. Models M2 and M3 assume the connection of waste heat sources with a different production profile than the heating plant (periodic regulation vs. weather-based regulation), which significantly complicates the methodology of generating the production schedule, especially in the long term. The more waste heat sources there are, the greater the difficulty.
Lack of stable and long-term formal and legal regulations on energy transition and the development of waste heat recovery at national level	Model M1 only assumes a reduction in temperature parameters, which is strongly recommended in the long term. However, these measures may prove insufficient in the future. Models M2 and M3 assume an increase in the share of waste heat in the production volume. However, formal and legal regulations currently focus on the development of heat from renewable energy sources.
Potential risks resulting from the volatility of energy and climate policy at the EU level.	The dispersion of scores between the reference models is analogous to that for the variable above, with the difference that the volatility of EU energy law has a milder impact on the strategic decisions of the Polish company than the volatility of national law.

The summary of points for the reference models is presented in the table below.

Table 6.37. table Summary results of the SWOT analysis for models M1, M2, M3

	M1	***M2***	***M3***
S+O	3,925	6,350	7,300
W+T	-2,200	-5,800	-8,100
W+O	-0.275	0.400	0.700
S+T	2.000	0.150	-1,500
S+W	1,750	-0.800	-1,400
O+T	-0.025	1,350	0.600
Balance	**1.725**	**0.550**	**-0.800**

The M3 model is characterised by a negative risk balance, which means that the weaknesses and threats (W+T) outweigh the strengths and opportunities (S+O). When analysing the sources of these factors, it can be visible that in this model, the positive balance relates to external elements (O+T), while internal factors show a negative balance (S+W). The implementation of the M3 model would involve a high risk resulting from the incompatibility of the current technical infrastructure with 17 waste heat sources at standard temperature parameters of 90/47.5 °C under design conditions. At the same time, the potential opportunities arising from the external environment are relatively limited. Consequently, the adoption of this model could force ECO to implement a

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competitive strategy focused on reducing losses and minimising risks in order to ensure the stable operation of the company.

In contrast, models M1 and M2 show a positive risk balance, which means that the benefits outweigh the potential negative consequences. In the case of M2, despite the existing risk associated with incomplete technical infrastructure (S+W), the balance of external factors is clearly positive (O+T). This means that the opportunities associated with the environment outweigh the internal weaknesses (O+W). Adopting the M2 model could force ECO to pursue an aggressive strategy focused on the dynamic exploitation of favourable external conditions. The M1 model, on the other hand, is characterised by a positive balance of internal factors (S+W), which suggests that the current technical infrastructure is well prepared for its implementation. However, the limited benefits of the external environment do not outweigh the risks (O+T), especially those of a social nature. As a result, choosing this model would involve implementing a conservative strategy focused on stability and the utilisation of existing potential.

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6.11.4. Selecting an appropriate strategy

Choosing a business development strategy is a key task for management. We distinguish four types of strategies:

- Aggressive, characterised by a positive balance of external and internal factors;
- Competitive, characterised by a positive balance of external factors with notable weaknesses;
- Conservative, with a negative balance of external factors and no significant strengths;
- Defensive, characterised by a negative balance of external and internal factors.

Each of the reference models assumes a different strategy.

- Model M1 – Conservative strategy

In the M1 model, internal factors gain the upper hand, indicating that the technical infrastructure is well suited to implementing the model, while at the same time limiting the benefits of external opportunities and significant external threats. The threats are primarily social in nature. The aim of this profile is to use the organisation's strengths to counteract adverse external factors. In practice, this would mean that ECO focuses on stability, exploits its technical potential, but takes cautious, defensive action in relation to the socio-economic environment. This choice limits expansion but ensures operational security.

- Model M2 – Aggressive strategy

The risk balance in the M2 model is positive, and the opportunities arising from the environment clearly outweigh internal weaknesses. This points to the use of an aggressive strategy, appropriate for situations where the company can exploit the advantage of external factors and strive for dynamic growth. Although there is a risk of insufficient technical infrastructure, the favourable external conditions (O > T) provide a basis for strong expansion. Thanks to this model, ECO could pursue offensive development activities, investing in technology adaptation and strengthening its position on the international arena as a highly innovative company.

- Model M3 – Competitive strategy

Despite its negative risk balance, the M3 model can be interpreted in the context of a competitive strategy. This means that although weaknesses and risks outweigh strengths, the opportunities available in the external environment may create space for improving the internal situation. In practice, this means that ECO, when implementing the M3 model, should focus on exploiting market and regulatory opportunities (e.g. available waste heat sources, energy efficiency initiatives) in order to simultaneously overcome its technical limitations. Existing infrastructure weaknesses – in particular the lack of adaptation to work with heat sources at 90/47.5 °C – could be gradually reduced through external support, partnerships or investments driven by favourable environmental conditions. In this sense, M3 would not lead to a defensive strategy, but to competitive actions that require consistent and intensive efforts and investments to take advantage of favourable external circumstances to improve the internal side and increase the flexibility of the company.

In summary, based on this document, it is recommended to implement the M2 reference model, as it allows a favourable environment to be used for intensive development and strengthening of ECO's position as an innovative heating plant of the future. However, a prerequisite would be the appropriate preparation of the technical infrastructure to mitigate internal risks.

7. Summary and conclusions

The work in WP3 was carried out with the recognition of the profound changes affecting the DH sector. Traditional systems built around centralised heat generation are evolving into multi-source networks that integrate wastewater heat, ambient heat, solar energy, lake and river water, low-temperature industrial waste heat, and seasonal thermal storage. This transition introduces technical, operational, and organisational challenges that extend far beyond standard boiler replacement or incremental efficiency improvement. At the same time, rising volatility in electricity markets, stricter environmental regulations, and increasing pressure to reduce supply temperatures amplify the complexity of system design and long-term planning.

The findings highlight both the transformative potential of renewable and waste-heat technologies and the technical challenges that arise when integrating these solutions into existing DH infrastructure.

Across the eight SET_HEAT model projects, covering wastewater heat recovery, supermarket waste-heat utilisation, river and lake water heat pumps, air-source heat pumps, solar thermal systems, seasonal pit thermal energy storage (PTES), and CHP-waste-heat recovery, the assessment identifies predominantly medium to high risk levels. These do not stem from fundamental technical infeasibility but from integration complexity, site-specific conditions, and operational uncertainties.

Projects such as SET_HEAT_RETAIL and SET_HEAT_SEWAGE demonstrate moderate, well-understood risks, primarily related to system integration and the stability of low-temperature heat sources. River-source

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heat pumps show similarly manageable risk profiles, provided that seasonal water-temperature fluctuations and intake-infrastructure reliability are addressed. By contrast, lake-source heat pumps and industrial air-source heat pumps are associated with higher risk concentration, reflecting performance sensitivity to environmental conditions, electrical-grid constraints, and the use of high-temperature refrigerants.

The SET_HEAT_SOLAR project reveals that solar thermal integration is viable but vulnerable to structural, environmental and hydraulic issues requiring strong design and commissioning practices. The PTES concept carries the highest inherent technical risks, especially regarding geotechnical stability and storage-system performance, underscoring the need for extensive site investigations and rigorous engineering validation.

The analysis of the Opole DH network illustrates the systemic risks associated with transitioning to lower-temperature, fourth-generation operation. Bottlenecks, pressure distribution changes, and transport-time effects emerge as key considerations, necessitating targeted pipe upgrades and smart integration of waste-heat sources.

Overall, the report concludes that while DH decarbonisation carries moderate-to-high technical risk, all risks are manageable through robust engineering, stakeholder coordination, and continuous risk governance, supporting the feasibility of a low-carbon DH transition.
The analysis of the SET_HEAT model projects reveals a broad but ultimately manageable set of risks. Projects like wastewater heat recovery (SET_HEAT_SEWAGE) and supermarket waste-heat utilisation (SET_HEAT_RETAIL) demonstrate moderate risk profiles, largely governed by integration issues, operator competence, and variability of heat supply. Renewable heat from rivers and lakes introduces additional uncertainties, especially related to seasonal water temperatures, intake structures, and the performance of large industrial heat pumps. The lake-source system, in particular, exhibits a higher concentration of severe risks due to the scale and novelty of the CO_2 heat-pump technology as well as the challenge of connecting large-capacity units to an existing, high-temperature DH infrastructure.

Air-source heat pumps show another dimension of risk, arising primarily from climatic sensitivity, frosting and defrost cycles, electrical-grid constraints, and the need for stringent safety measures when high-temperature refrigerants are used. Solar-thermal systems, although well-established, face structural and environmental risks such as hail, wind loads and stagnation, and require meticulous quality assurance during installation and commissioning. The Pit Thermal Energy Storage (PTES) project stands out as the technology with the highest inherent risk, due in large part to its geotechnical dependency and the engineering uncertainty surrounding large-scale seasonal thermal storage. Nevertheless,

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even here, the analysis concludes that proactive site investigations, rigorous engineering and iterative risk management can keep the technology within acceptable boundaries.

In addition to technology-specific assessments, the report offers an in-depth examination of the Opole district-heating network as a representative example of the system-level risks associated with transitioning to fourth-generation, low-temperature operation. Three reference models are analysed, each reflecting different temperature regimes and degrees of investment. The analysis highlights hydraulic bottlenecks, changes in pressure distribution, transport-time implications, and the effect of integrating multiple waste-heat sources. A structured SWOT analysis further evaluates the strategic risks and opportunities associated with each transition pathway, emphasising the importance of coordinated planning, infrastructure reinforcement, and engagement with external stakeholders.

Taken together, the findings portray an energy-transition environment characterised by moderate-to-high technical risk. This level is neither surprising nor prohibitive; rather, it reflects the introduction of new technologies, the complexity of legacy networks, and the dynamic interplay between heat supply, electricity markets and environmental conditions. Crucially, the report demonstrates that none of these risks is unmanageable. Where high-severity risks do appear, such as those linked to PTES geotechnics, high-temperature refrigerants, or large-scale system integration, they can be systematically reduced through rigorous engineering design, comprehensive feasibility work, advanced control strategies, redundancy, and robust monitoring practices.

Thus, the overall conclusion emerging from the analysis is cautiously optimistic. While district-heating decarbonisation does entail significant uncertainties, these risks are acceptable and controllable when approached through disciplined planning and structured mitigation. The transition to low-temperature, multi-source, renewable-integrated district-heating systems is both feasible and strategically advantageous, provided that risk management remains a continuous and central element of the development process. The SET_HEAT risk assessments serve as evidence that with proper governance, the sector can successfully navigate the complexities of decarbonisation and implement resilient, future-proof heating systems for European cities..

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