D3.4

Case study definition guide

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List of Acronyms and Abbreviations

Abbreviation	Definition
L2HDH	Low2HighDH
EU	European Union
WP	Work Package
DH	District Heating
DHC	District Heating and Cooling
GHG	Greenhouse gases
LGRES	Low-Grade Renewable Energy Sources
RES	Renewable Energy Sources
HT	High Temperature
IH	Individual Heating

EXECUTIVE SUMMARY

Low2HighDH is a 3-year project supporting 30 high-temperature district heating sites (HT DHC) in Lithuania, Poland, and Slovakia in implementing low-grade or waste heat technologies. It promotes the advantages of these energy sources and provides them with an investment plan to fulfil the proposed criteria for 'efficient district heating and cooling' from the Energy Efficiency Directive (EU) 2023/1791 within a 10-year timeframe.

The document D3.4 Case Study Definition Guide has been developed to outline guidelines for a comprehensive case study definition. It explains the most relevant aspects to focus on (supply, alternatives, network costs, financing options) and how to organise the information for the next steps of the investment plans. As this deliverable is considered a relevant project output, it will be translated within the project's capabilities (Polish, Lithuanian, Slovak) to foster dissemination.

Low-grade RES technologies to be explored will consist of at least solar thermal, low-temperature geothermal and heat pumps. The latter will be considered "the enabling technology" to harness low-grade heat sources and use waste heat. As electrically driven systems, heat pumps can operate using renewable electricity, such as that generated from wind or photovoltaic sources. The project will generate and disseminate capacity-building materials to be used by other HT DHC sites or stakeholders, including a portfolio of technical and financial solutions that fit the most abundant situations. An active engagement, dissemination and replication phase will be enabled by creating a vast network of stakeholders across the 3 case study countries and beyond – 3 national stakeholder communities, 30 local liaison groups, and a project-wide Ambassador community.

The project is expected to trigger EUR 454 million in investments in sustainable energy (thermal RES technologies + waste heat), replacing 1 TWh/year of fossil fuels with and abating 291 thousand tons of CO_2 emissions.

As mentioned, the activities envisaged by the L2HDH project are in accordance with the requirements of the new Energy Efficiency Directive (EU) 2023/1791 for the district heating sector.

Changes from the previous directives 2018/2002 and 2012/27/EU include the following:

1. It is establishing a legally binding EU target to reduce the EU's final energy consumption by 11.7% by 2030 (relative to the 2020 reference scenario). This includes each Member State's requirement to set its indicative national contribution based on objective criteria reflecting national circumstances. The Commission applies an ambition gap mechanism if the national contributions do not meet the EU target.
2. Increasing annual energy savings from 0.8% (at present) to 1.3% (2024-2025), then 1.5% (2026-2027) and 1.9% from 2028 onwards. That's an average of 1.49% of new annual savings from 2024-2030.
3. Obliging Member States to prioritise vulnerable customers and social housing within the scope of their energy savings measures.
4. Introducing an annual energy consumption reduction target of 1.9% for the public sector.

5. Extending the annual 3% building renovation obligation to all levels of public administration.
6. Introducing a different approach based on energy consumption allows businesses to have an energy management system or carry out energy audits.
7. Bringing in a new obligation to monitor the energy performance of data centres, with an EU-level database collecting and publishing data.
8. Promoting local heating & cooling plans in larger municipalities.
9. Progressively increasing the efficient energy consumption in heat or cold supply, also in district heating.

INTRODUCTION

To achieve the aim of L2HDH, the project requires active engagement from HT DHC sites. Additionally, prospective participants will be assessed through a Call for Applications, structured into three phases:

1. Application
2. Selection
3. Project definition

This document provides guidelines for a correct case study definition, detailing the third step. It outlines the key aspects to consider—such as supply, alternatives, network costs, and financing options—and guides the preparation of information for the subsequent steps of the investment plans.

A comprehensive selection process with appropriately broad participation criteria will be established to identify 10 district heating (DH) operators in Lithuania, Poland, and Slovakia to receive full consulting support from the project consortium. The selection will be done through a two-step call for applications process to guarantee the highest implementation probability. The parameters - scope, objectives, timeline, expected results, and specifications – of the suitable technical solution for each beneficiary will then be defined based on local economic, technical, regulatory, legal, and societal conditions of the energy market. These will be simultaneously case-specific and sufficiently holistic to be easily adaptable and replicable to other EU-wide operators with similar situations. Lighter support will be carried out to 20 other DH operators ("replicant sites") primarily through group training and/or coaching sessions and other forms of individual and collective advice/assistance.

The objectives of the case study for the decarbonisation of the DH should:

1. Implement the goals and measures of the DH plan specified in the national DH development program and other legally valid European Union and national energy strategic documents and legislation.

2. Carry out long-term planning of investments in district heating systems, providing for the replacement and modernisation of worn-out or non-compliant installations or infrastructure to reduce the harmful effects of heat supply on the environment, economic efficiency, and technological reliability.

3. Explore the possibilities of using a lower-temperature heat supply on the heat consumption side and develop an assessment of potential DH temperature reduction in the entire DH network or individual zones.

4. Maximise the potential of local renewable energy sources and environmental and waste (residual) heat to achieve national targets and allow for competitive heat prices and security of supply.

5. Provide for modernising the heating substations and heating systems of buildings connected to DH to implement mandatory requirements. In the proposals to modernise the heating substations, evaluate the possibilities of reducing the temperature of the supplied heat.

6. Assess changes in local pollution and GHG emissions as part of the plan's solutions.
7. The cost-benefit analysis should be based on the selected planned investments with alternatives, modelling the volume of implementation in individual periods and indicating possible sources of financing.
8. Expand and further develop new sustainable heat supply and other related services.
9. Contribute to research, innovations and experimental development in the DH sector.
10. Get acquainted with and test the latest technical and digital solutions offered to the heat supply industry.
11. Analysis and assessment of the applicability of good practices from other countries.

1. Key Components of a Case Study Definition

1.1 Selection process

The selection criteria have been carefully designed to evaluate applications on various essential aspects that reflect their potential to benefit from and contribute to the project's goals. These criteria are divided into two main categories:

1. Knock-out criteria are essential for all applicants to be considered for further evaluation. These criteria serve as preliminary filters to ensure only qualified applicants are assessed during the evaluative criteria.

Availability of free ground next to the DH system or distance from possible waste heat sources	Consider if the DH has available space (ground or roof) or if the DH system is close to potential waste heat sources.
Availability of technical and economic data	Having enough data available is crucial in triggering the process.
Availability of qualified personnel	Having the required staff to support the project is essential to make the project a success.

2. Once applicants have passed the Knock-Out stage, they are assessed based on more detailed Evaluative Criteria, which rank them based on ease of implementation and technical, financial, and regulatory aspects.

Ease of implementation	
Ownership of the DH system	Evaluates the type of ownership of the DH system. Ownership types such as private, public, or public-private partnerships are considered. This helps in understanding the governance structure and potential decision-making processes, which can impact the implementation and sustainability of the project.
Motivation for installing RES technologies	Assesses the primary motivation for installing RES technologies. This includes motivations for reducing CO_2 emissions, cost savings, regulatory compliance, and other potential reasons. Understanding the motivation behind adopting RES technologies provides insight into the applicant's priorities and alignment with project goals.
Existing plans for DH system improvement	Looks at the current state of plans for improving or upgrading the DH system. This helps assess the

	applicant's readiness and strategic vision for future development.
Room availability for new equipment	Evaluates the availability of space within the heat source building for installing new equipment (e.g., heat pumps). Knowing the available space is essential for integrating new technologies' feasibility.
Technical criteria	
Working temperatures	Examines the operating temperatures of the DH system. Different temperature ranges are considered to evaluate the system's efficiency and suitability. This helps identify the current efficiency levels and the potential for integrating advanced technologies requiring specific temperature conditions.
Working pressures	Analyses the pressure levels within the DH system. Various pressure levels (to be defined) are evaluated for system performance and safety.
Current heat technology used	Assesses the current state of the heat technology in use. Evaluating the existing heat technology provides a baseline for planning upgrades and improvements that align with the project's objectives.
Current fuel mix of DH system	It looks at the type of fuel and its percentages. This helps understand the current energy mix and identify opportunities for transitioning to more sustainable fuel sources.
Financial criteria	
Available financial resources	Assesses the amount of financial resources available for investment. This criterion examines the applicant's financial capacity to support the project, indicating their ability to fund a potential investment.
Annual revenues over the last 3 years	Looks at the annual revenues generated over the last three years. This helps understand the applicant's economic evolution, which is essential to building an attractive investment case.

Average annual cash generation	Evaluates the average annual cash generation. This metric provides insight into the capacity of the applicant to repay the investment.
Regulatory criteria	
Availability of subsidies or financial support	This could be crucial to build an attractive investment case.

1.2 Decarbonization of DH and implementation: Case study composition

This section outlines the comprehensive approach taken to evaluate and implement low-grade and waste heat technologies in existing DH networks. By examining market conditions, technical capabilities, and financial viability, the project aims to create a robust framework for integrating sustainable heating solutions. The following sub-sections provide detailed analyses in key areas essential for the successful decarbonization and implementation of these technologies:

- Market Analysis: This analysis aids in evaluating the feasibility and potential impact of the project by considering the current conditions and anticipated developments in Lithuania, Poland, and Slovakia. It identifies emerging market trends, examines the competitive landscape, evaluates energy prices and costs, and considers regulatory factors that could influence the project's success.

  To develop a comprehensive case study on the modernization and expansion of DH, the market analysis should start with a contextual analysis. This includes examining the heat supply market, the legal regulatory environment, economic development trends, demographic situation, and all available public information related to energy supply and consumption. Additionally, it is important to categorize DH installations by their systems, functional purpose ownership and legislative compliance.

- Technical Analysis: The focus is on assessing the existing infrastructure and identifying the most suitable technologies for integrating low-grade and waste heat into DH systems. This analysis includes detailed evaluations of current systems, the potential for technological upgrades, and the use of advanced modelling and simulation tools like nPro. By understanding the technical capabilities and limitations, the project can develop effective strategies to enhance efficiency and sustainability in DH networks.

  A thorough current status analysis is essential, providing data on current heat consumers, their demand, heating networks, existing losses, and heat sources in the integrated network. This includes assessing the capacity and utilization of heat production sources, the condition of transfer pipes, and the overall technical state of the infrastructure. Furthermore, a production and consumption evaluation should be conducted, detailing annual heat production and consumption schedules, fuel use, electricity and water consumption, performance indicators, and other relevant data.

- Financial Analysis: The financial analysis examines the economic viability and funding opportunities for the L2HDH project. This section analyses economic and financial data to assess the project's cost-effectiveness and potential return on investment. It also explores various funding sources and management solutions to ensure the project's financial sustainability. By evaluating the economic impact and identifying feasible financial strategies, the project aims to secure the necessary resources for successful implementation.

  To plan the modernization and development of the DH system, the financial analysis should include a detailed plan for the modernization and development of the heat supply system, identifying perspective zones for improvement. This involves planned investments based on cost-benefit analysis, implementation deadlines, and potential financing sources. Additionally, forecasts of energy resource demand by fuel type, the need for new heat generation facilities, and plans to increase energy efficiency and reduce heat consumption demand should be included. The analysis should also cover the viability of integration of renewable energy sources and heat storage solutions.

  A review of current plans for upgrading the DH system led us to the conclusion that space requirements for new equipment, along with land availability and proximity to waste heat sources are also key considerations. For effective DH system implementation, it is essential to have technical and economic data, qualified personnel, and adequate financial resources, as indicated by annual revenues and cash flow. Collecting this comprehensive data will enable a well-informed selection of DH case studies tailored to the project's objectives.

  In collaboration with electricity distribution system operators, heat providers should evaluate the possibility of using efficient DH systems to provide flexibility services to the electricity system, such as demand management and storage of excess electricity from renewable sources. All documentation and content of these case studies must comply with regulations approved by the National Energy Regulator or other relevant national entities.

3. Market Analysis

3.1 Analysis of historical trends and local context

Understanding the local trends and context is essential for evaluating the feasibility and impact of integrating low-grade and waste heat technologies into DH systems. This analysis involves examining political, economic, and technological trends that influence heat demand in Lithuania, Poland, and Slovakia. The political landscape, including regulations and policies aimed at reducing carbon emissions, plays a significant role in shaping the heat demand. Economic factors such as regional development trends, population growth, and urbanization also impact the demand for DH. Technological advancements, particularly in renewable energy sources and energy efficiency, are crucial for modernizing DH systems and reducing reliance on fossil fuels.

Analysing the trends in DH usage involves studying the historical and projected heat demand in each city within the target countries. This includes assessing the impact of network expansion programs, which aim to increase the coverage and efficiency of DH systems. Population density and local strategies for urban development also influence the evolution of DH usage. The number of DH consumers has evolved over time due to various factors such as network expansion, economic growth, and changes in population density. Evaluating these changes helps understanding the current and future demand for DH. Local strategies aimed at increasing the adoption of DH systems, such as incentives for network connections, also play a crucial role.

Evaluating changes in average consumption per consumer involves analysing trends in energy efficiency improvements and building modernization efforts. Energy efficiency measures, such as better insulation and more efficient heating systems, can significantly reduce heat consumption. Additionally, changes in consumption habits, driven by increased awareness of energy conservation and the adoption of smart technologies, also impact the average heat demand per consumer. By comprehensively analysing these factors, the project can develop a well-informed strategy for integrating low-grade and waste heat technologies into existing DH systems, ensuring their sustainability and efficiency.

3.2 Retail Prices Analysis

This analysis begins with a review of the current national, regional, and local regulatory frameworks that affect energy tariffs in Lithuania, Poland, and Slovakia. These regulations play a significant role in determining the cost structure and pricing mechanisms for energy, influencing both the supply and demand sides of the market.

Assessing the historical evolution of electricity and fuel costs is essential to identify trends and predict future patterns. By examining past data, we can understand how prices have fluctuated due to various factors such as market dynamics, geopolitical events, and policy changes. This historical perspective helps in forecasting future price movements and preparing for potential economic impacts.

A detailed breakdown of retail heat price components is necessary to understand the various elements that contribute to the final cost paid by consumers. These components typically include the cost of energy production, transportation, maintenance, and taxes. Each of these elements can vary significantly depending on the regulatory environment and market conditions in each country.

Explaining and commenting on historical price developments involves analysing the economic, political, and technical factors that have influenced price changes over time. Economic factors might include inflation rates, changes in fuel prices, and shifts in supply and demand. Political factors could involve regulatory changes, government policies, and international agreements. Technical factors might encompass advancements in energy production technologies, improvements in energy efficiency, and changes in infrastructure.

By comprehensively analysing these aspects, the project can develop a robust understanding of the retail energy prices landscape. This understanding is crucial for making informed decisions about integrating low-grade and waste heat technologies into existing DH systems, ensuring that the solutions are economically viable and sustainable in the long term.

3.3 Competitor Study and Alternative Heat Sources

The transition from Individual Heating (IH) systems to DH is a key aspect for achieving a more efficient and sustainable heating sector. IH systems, which include gas boilers, electric heaters, and heat pumps, are widely used due to their flexibility and relatively low upfront costs. However, their decentralized nature often results in higher energy consumption and increased greenhouse gas emissions, particularly when fossil fuels are the primary energy source. In contrast, DH enables a centralized approach that improves energy efficiency and facilitates the integration of renewable energy sources and waste heat recovery.

Comparing the two heating modes, DH systems generally require less energy than IH systems to provide the same level of thermal comfort. This is primarily because DH allows for sector coupling, where surplus electricity from renewable sources can be used for heating, reducing reliance on fossil fuels. Additionally, DH networks are more effective in densely populated areas where infrastructure can be fully utilized, while IH systems remain a more viable option in sparsely populated regions where the installation of DH infrastructure would be economically challenging.

The competitiveness of DH is further enhanced by its ability to integrate waste heat sources from industrial facilities, data centers, and other urban infrastructure. Unlike IH systems, which often waste excess heat, DH networks can efficiently capture and redistribute this energy, improving overall system efficiency. Moreover, renewable energy integration into DH, such as solar thermal, biomass, and geothermal sources, offers a pathway to decarbonization while maintaining heating reliability. In contrast, IH systems, particularly those reliant on natural gas or direct electricity consumption, remain highly susceptible to fuel price volatility and supply chain disruptions.

Future trends in heating systems indicate a growing shift toward low-temperature DH networks that further optimize energy use by reducing heat losses and enhancing the compatibility with renewable energy technologies. Electrification through heat pumps is also emerging as a complementary strategy, where DH and decentralized solutions can coexist, leveraging local renewable energy production to balance supply and demand.

A comprehensive competitor analysis highlights the strengths of DH in terms of efficiency, emissions reduction, and integration of alternative heat sources. However, the feasibility of DH expansion depends on local conditions, including population density, regulatory support, and the availability of waste heat and renewable energy sources. While IH remains a flexible solution for certain applications, DH presents a clear advantage in urban environments where centralized energy management can be optimized to achieve long-term sustainability goals.

3.4 Regulatory Framework and Compliance Requirements

The study should consider the requirements for district heating systems set out in Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (the 'EED Directive'), including the requirements on maximum GHG emissions per unit of heat supplied to consumers (g/kWh). Articles 26 (1) and (2) of the EED Directive provide for sustainability criteria for an effective DH system:

1. An efficient DHC system shall meet the criteria to achieve greater primary energy efficiency and increase the share of renewable energy supplied to the grid in the heating and cooling sector.
2. In addition to the criteria set out in paragraph 1 of this Article, Member States may also choose sustainability performance criteria based on GHG emissions from DHC systems per unit of heat or cooling supplied to consumers, considering measures implemented to fulfil an obligation under Article 24 (4) of Directive (EU) 2018/2001.

The plan's solutions also consider other existing and future regulatory provisions of the EU, including, but not limited to:

- The Directive on the promotion of the use of energy from renewable sources, Directive (EU) 2023/2413.
- The Directive to further reduce emissions cost-effectively and to incentivise investment in low carbon technologies, Directive 2003/87/EC.
- The Directive on the limitation of emissions of certain pollutants into the air from medium combustion plants, Directive (EU) 2015/2193.
- The Directive on the energy performance of buildings. The main legislation is Directive (EU) 2010/31, with updates introduced in Directive (EU) 2018/844 to enhance energy efficiency in buildings.

It is important that long-term investments consider legal requirements that may come into force during the lifetime of the equipment.

The heat sector development plan should consider the requirements for efficient district heating systems laid down in Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955[1] (hereinafter referred to as the

[1] Energy Efficiency Directive: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L1791

Directive), including the requirements on maximum GHG emissions per unit of heat supplied to consumers (g/kWh). Article 26 (1) and (2) of the Directive lays down sustainability criteria for an effective DH system:

Period	***Efficiency criteria for the district heating and cooling system***	***GHG emissions from DHC systems per unit of heating or cooling supplied to consumers***
Until 31 December 2027	- At least 50% of the energy consumed is from renewable sources, **or** - 50% waste heat, **or** - 75% heat from cogeneration, **or** - 50% a combination of these sources.	*200 grams/kWh*
From 1 January 2028	- At least 50% energy from renewable sources, **or** - 50% waste heat, **or** - 50% renewable energy and waste heat, **or** - 80% heat from high-efficiency cogeneration, **or** - At least 5% renewable energy and 50% combined share of renewable energy, waste heat, or heat from high-efficiency cogeneration.	*N/A*
From 1 January 2035	- At least 50% energy from renewable sources, **or** - 50% waste heat, **or** - 50% renewable energy and waste heat, **or** - 80% combined share of renewable energy, waste heat, or heat from high-efficiency cogeneration, and at least 35% renewable energy or waste heat.	*100 grams/kWh*
From 1 January 2040	- At least 75% energy from renewable sources, **or** - 75% waste heat, **or** - 75% renewable energy and waste heat, **or** - 95% combined share of renewable energy, waste heat, and heat from high-efficiency cogeneration, and at least 35% renewable energy or waste heat.	*100 grams/kWh*
From 1 January 2045	- At least 75% energy from renewable sources, **or** - 75% waste heat, **or** - 75% renewable energy and waste heat.	*50 grams/kWh*
From 1 January 2050	- Exclusive use of energy from renewable sources, waste heat, or a combination of both.	*0 grams/kWh*

The plan's solutions also take into account other existing and future regulatory provisions of the EU, including, but not limited to, the Directive on the promotion of the use of energy from renewable sources, the Directive to further reduce emissions of pollutants cost-effectively and to incentivise investment in low-carbon technologies, the Directive on emissions into the air from medium combustion plants, quantity limitation, the Directive on the energy performance of buildings, etc. For example, when planning long-term investments, it is also necessary to evaluate new legal requirements that will come into force during the lifetime of the equipment. Among them, the following are more important:

1. Limitation of emissions from combustion plants under EU Directive 2015/2193 on the limitation of emissions of certain pollutants into the air from medium combustion plants[2].
2. EU directive 2010/31/EU on the energy efficiency of buildings[3].

3.5 Demand forecasting and Prices

Accurate demand forecasting and price analysis are essential for planning the integration of low-grade and waste heat technologies into DH systems. This process begins with identifying the key drivers that influence future demand projections. Factors such as population growth, urbanization, and overall energy consumption play a significant role in shaping the demand for district heating. As urban areas expand and population increases, the need for efficient and sustainable heating solutions becomes more critical. Additionally, changes in energy consumption patterns, driven by technological advancements and shifts in consumer behaviour, must be considered.

Developing quantitative projections involves using expert criteria and analysing long-term trends to predict future demand accurately. This includes examining historical data and identifying patterns that can inform future projections. By leveraging statistical models and forecasting techniques, it is possible to estimate the future demand for district heating with a high degree of accuracy. These projections must account for various scenarios, including potential changes in regulatory frameworks, economic conditions, and technological advancements.

Understanding the historical evolution of electricity and fuel costs is also crucial for demand forecasting and price analysis. By assessing past trends, it is possible to identify patterns and predict future price movements. This analysis helps in understanding the economic factors that influence energy prices and their impact on the overall cost of district heating. Additionally, a detailed breakdown of retail heat price components, such as energy production, transportation, maintenance, and taxes, provides insights into the cost structure and helps in identifying areas for potential cost savings.

By comprehensively analysing these factors, the project can develop robust demand forecasts and price projections that support the sustainable integration of low-grade and waste heat technologies into existing DH systems. This approach ensures that the solutions are economically viable and capable of meeting future demand efficiently.

3.6 Social responsibility

3.6.1 Relationships with stakeholders

Establishing and maintaining solid stakeholder relationships ensures their support and alignment with project objectives, facilitates more straightforward implementation, and helps achieve the desired goals.

[2] directive https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32015L2193
[3] The Energy Efficiency of Buildings Directive: https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0031

This process effectively manages their expectations and needs, ensuring their diverse perspectives are considered. By implementing appropriate communication and collaboration strategies, risks are minimised, and support for the project is maximised.

Effective engagement helps build trust and align the interests of all key stakeholders, which contributes significantly to the project's success and sustainability.

3.6.2 Measures to improve Clients' Management and Reduce Heat Energy Poverty

Measures to reduce heat energy poverty increase efficiency and reliability of heat supply and increase competition.

Considering the capabilities of heat suppliers, it makes sense to constantly analyse consumers' payments for heating and hot water and inform them about the reasons that determine the size of payments. To this end, a system could be developed, simply and systematically informing consumers about the energy efficiency indicators of their building and comparing them with analogous renovated and new energy-efficient buildings. Among such indicators could be the following parameters:

- Cost indicators: heat price (ct/kWh), heating payments (EUR/month), consumption (kWh/month for an apartment, kWh/m^3) and other indicators.
- Consumers are systematically provided with information on the possibilities and methods of renovating buildings and heating systems in buildings.
- Publishing expected heating payments would help consumers better plan cash, apply for compensation, or otherwise solve problems with heating availability.

The heat supplier should constantly monitor the prices of alternative heating methods and compare the competitiveness of its service.

4. Technical Aspects of Case Study Definition

4.1 Infrastructure and Network analysis

When preparing and updating the investment plan for the development of the heat sector, the heat supplier predicts the volume, structure, annual schedules, necessary parameters, etc of heat production, supply, and consumption, we need to base our plan on the available data.

To achieve a more even and efficient development of RES throughout the city/district, predicting the renovation (modernisation) of buildings and the reduction (increase) of the need for thermal energy, it is appropriate to ensure proper planning of DH systems. To assess future developments in the sector and to make technological and investment decisions that would allow reducing the parameters of heat supply and ensuring the adequacy of heat consumption and supply, using waste and environmental heat, the potential of indigenous and RES.

4.2 Identification of new heat sources and technologies to be used

4.2.1 Heat sources and means of their integration in the heat supply in the long term

To that end, existing waste heat streams, the use of ambient heat in nearby areas that are not yet in use, and the reduction of heat temperatures supplied to consumers should be examined. The investments, costs, and other circumstances should be assessed. An integrated assessment of total costs would reveal the feasibility in the long term.

After the formation and selection of targeted measures for the selected facilities, it is possible to predict and plan the need for primary energy resources in the long term. When designing the further need for means of production and energy resources, the following items should be considered:

1. Projections of the demand for energy sources by fuel while striving for the abandonment of fossil fuels and the transition to the full use of renewables and waste heat.
2. Predicted heat production by source, meeting new heat base and peak needs and ensuring the necessary backup.
3. Other planned alternative sources of heat production from RES include the need for new sustainable heat production facilities (capacity (MW), the location of the connection to the district heating system, and the planned start of operation) and prioritising technologies that reduce greenhouse gas emissions.
4. Assessment of GHG from the planned sources of heat.

4.2.2 Need for new generation facilities and connection to DH systems

By assessing the requirements of the legislation for reliable heat supply and restoration of supply after incidents and taking into account the unique conditions of DH systems (changes in heat consumption, configuration, permeability, etc.), the compliance of the current situation with the requirements is determined and, accordingly, proposals for the construction of new heat generating equipment for their placement, parameters and schedule of entry into operation are prepared. Priority is given to technologies that reduce GHG emissions and the lowest costs in the long term.

Heat suppliers could assess the possibility of using an efficient DH system to provide flexibility services for the electricity system, where this involves the use of electricity demand management, the storage of excess electricity produced from RES, as well as an assessment of the economic benefits of providing these services. When drawing up an investment plan for the development of the heat sector, heat suppliers should consider the results of assessing the feasibility of offering flexibility services for the electricity system.

To that end, waste heat flows still need to be used in nearby areas, and the investments, costs, and other circumstances necessary for their recovery should be assessed. An integrated assessment of total costs would reveal the practicality of their use in the long term.

It is necessary to analyse prospective spatial development plans and predict possible new sources of DH systems with waste or low potential.

The heat supplier should assess and describe the measures and the possible plan for their implementation, including the timing schedule, to modernise the serviced buildings' heating systems and improve the energy efficiency of public buildings. To this end, using an available database, the heat provider identifies energy-inefficient buildings and describes the possible causes of poor efficiency. The expected need for heat consumption and characteristic graphs of consumption.

In turn, the heat supplier develops and implements technological solutions for the installation of monitoring systems and smart metering devices, efficient network management, examines and, if expediently, implements thermohydraulic modelling programs and implements other measures that increase the adequacy of heat supply and consumption and improve the overall energy and economic efficiency of the DH system. At the same time, measures are being studied and recommended for optimising heat supply modes to reduce the water temperatures in the network and the operating pressure used. According to the intensity of heat consumption and the relative load on heat networks, it is necessary to evaluate the partial decentralisation of the heat supply system.

In line with the above assumptions and the measures in place, it is necessary to link how the manufacturing sector will develop with long-term plans to increase energy efficiency and reduce the demand for heat consumption.

4.2.3 Current network status

In the description of the current situation, it is appropriate to describe the general infrastructure and objects managed by the heat supplier system and the external heat producers, DH network and consumers, indicating the available information on their main technical characteristics, to describe, as far as possible, their technical standing, degree of wear, potential period of operation, needs for renewal or modernisation, etc. System objects, according to their functional purpose and characteristics, could be structured, for example, according to the following list:

1. Heat transfer system. The principled geometric scheme, trunk and distribution pipelines, configuration, and locations of internal and external heat sources and consumers.
2. Pipelines (or their groups). Inventory by year of the last laying, technological type, diameter, design pressure, technical condition, when the year of their replacement would be expected, and so on.
3. Heat and power installations (boiler rooms, power plants, other heat sources: possible additional sources of use of renewable energy, heat storage systems, ambient and waste heat, etc.) and related buildings, chimneys, fuel depots and other structures of high value. Fuel used by the central installations, nominal/minimum operating power, other essential parameters, expected remaining operating resources, etc.
4. Heat substations in buildings, a list with the essential characteristics: technological type, property owner (DH company, consumers, etc.), thermal power, main parameters, expected operating resource (period), degree of digitisation, etc.

To provide general data on existing heat consumers, their current heat demand, general information about heat networks, and existing losses in the networks, describe and provide information about existing heat sources in the integrated heat network. Provide an annual heat production and consumption schedule, with the help of which to assess the adequacy of heat production and consumption. Provide aggregated yearly data on the total fuel structure, electricity and water consumption, benchmarks and their compliance with the established indicators, temperature regimes of the supplied and returned water provided by the heating networks, water replenishment, etc.

4.3 Modelling and simulation with nPro

This process begins with creating a baseline model of the existing DH system, which includes detailed representations of generation plants and distribution networks. By establishing this baseline, we can accurately assess the current state of the system and identify areas for improvement.

Once the baseline model is established, various simulations are developed to demonstrate the integration of selected technologies into real DH scenarios. These simulations allow us to explore how different technologies, such as renewable energy sources and advanced heat recovery systems, can be incorporated into the existing infrastructure. By running these simulations, we can evaluate the performance of each technology under different conditions and identify the most effective solutions.

Optimizing the system design is another critical aspect of this process. The goal is to maximize energy efficiency and cost-effectiveness by fine-tuning the configuration of the DH system. This involves adjusting parameters such as the capacity of generation units, the layout of distribution networks, and the operational strategies to achieve the best possible performance. The nPro tool provides advanced optimization algorithms that help in identifying the optimal design configurations from thousands of possible options.

Comparing different scenarios is essential for understanding the potential impacts of various design choices. By creating multiple scenarios and comparing their outcomes, we can assess the trade-offs between different approaches and select the most suitable one for implementation. This comparison includes evaluating technical performance, economic viability, and environmental benefits. The ability to directly compare scenarios within nPro makes it easier to visualize the effects of different strategies and make informed decisions.

By leveraging the capabilities of nPro for modelling, simulation, and optimization, the project can develop a robust and efficient DH system that integrates low-grade and waste heat technologies effectively. This approach ensures that the solutions are not only technically feasible but also economically viable and environmentally sustainable.

4.4 Results: Economic and CO2 emissions impact

Analysing the economic and CO_2 emissions impact of integrating low-grade and waste heat technologies into district heating (DH) systems is crucial. This begins with comparing the capital expenditures (CAPEX) and operational expenditures (OPEX) of the proposed solutions against traditional fossil fuel systems (Business-As-Usual analysis). By evaluating initial investment and ongoing operational costs, we can determine the financial feasibility and potential savings of the new technologies.

Evaluating current CO_2 emissions and calculating projected reductions for each scenario is another key component. This involves assessing baseline emissions from existing DH systems and estimating the potential reductions achieved through renewable energy sources and waste heat recovery technologies. By comparing these projections, we can quantify the environmental benefits and contribution to decarbonization goals.

Assessing the long-term economic and environmental impacts includes analysing potential cost savings, improvements in energy efficiency, and reductions in greenhouse gas emissions. Additionally, it is important to evaluate the electricity consumption and grid impact of the proposed solutions, ensuring they are sustainable and compatible with the current and future energy infrastructure.

By thoroughly analysing these aspects, the project can develop robust strategies for integrating low-grade and waste heat technologies into DH systems, ensuring the solutions are economically viable, environmentally sustainable, and technically feasible.

5. Data collection and Documentation

5.1 Forecasts of the need for energy resources by type of fuel and other heat resources

To collect and summarise data from the last few years on existing heat consumers and potential new users of the DH system, general information about heating networks, existing losses in the networks, briefly describe and provide information about heat sources (their standing and efficiency, types of fuel used, etc.). To evaluate the feasibility of connecting the nearby separate DH systems, we will assess the capacity of the available heat production sources and their utilization levels. Additionally, we will examine the throughput reserve of the heat transfer pipelines and their technical condition. Develop a schedule for the production and consumption of heat for the last few years. Provide aggregated data on the prospective use of heat due to building renovation and the heat supply network renewal.

After the formation and selection of targeted measures for the development and modernisation of the heat supply system, the need for primary energy resources in the long-term can be predicted and planned. When planning the further need for energy resources, it is recommended to consider and evaluate the following circumstances.

Projections of the demand for energy sources by fuel while striving for the abandonment of fossil fuels and the transition to the full use of renewables and waste energy for the heat supply.

When planning future heat production in DH networks, evaluating how to integrate new heat sources and maximise the use of existing sources will be necessary. The most important criterion is the reduction of CO_2 emissions or even the avoidance of these emissions. When planning changes in the production sector of the heat supply system, it is necessary to evaluate changes in the consumption side in the near and long term. In Europe, there is already experience in installing low-temperature heat supply networks. Some conclusions are already relevant for heat suppliers to reduce heat transfer losses, increase the reliability and durability of pipelines, and more efficiently integrate RES.

The fourth-generation DH system has a maximum temperature of the supplied water in the networks of 60-65ºC, which should be enough for heating and preparing hot water.

Plastic pipes are already beginning to be used to construct heat supply routes. To achieve greater efficiency of the heat supply system, it is necessary to encourage heat consumers to maintain the temperature of the return water as low as possible.

With the transition of rubble to using lower temperatures in existing buildings, technical solutions must be implemented at the building's heating point, in the building's internal heating system, and in hot domestic water treatment. The building renovation process to reduce heat consumption must be well-planned and aligned with the planned changes in district heating systems. Newly constructed buildings are subject to increasingly stringent energy efficiency requirements.

There are practical examples of small-scale attempts to implement even a fifth-generation DH system for low-temperature heating when the supply temperature reaches up to 40-45ºC and returns 20-25ºC. Decisions are combined with the so-called status of the producing consumer, when buildings "share" excess heat and cooling energy.

The theoretical evaluation of pilot projects and the realisation of small-scale projects will provide opportunities to learn and improve the transformation of urban heating systems and future optimal energy production combinations.

5.2 Technical solutions

The previous report delivered by the consortium partners, the Technical Solutions Portfolio provides a comprehensive evaluation of LGERES and their potential integration into DH networks. The study focuses on developing technologies and strategies to upgrade low-temperature energy sources, such as solar thermal, geothermal, biomass, and industrial waste heat, to the higher temperature requirements of DH systems. The report pays attention to the situation in Lithuania, Poland, and Slovakia, where DH systems are historically relevant for the energy system, particularly HT-DH networks.

DH systems are pivotal in efficiently supplying heat to urban areas, especially in colder climates. However, many of these systems, particularly in Eastern Europe, were built when fossil fuels such as coal and natural gas were abundant and inexpensive. As the energy landscape shifts towards sustainability, these older systems require significant technological upgrades to incorporate renewable energy sources. This report outlines 24 innovative technological solutions designed to facilitate the integration of LGERES into DH networks, aiming to reduce dependency on fossil fuels and lower GHG emissions.

6. Energy efficiency management

For better efficiency of the infrastructure of the heat supplier and the use of personnel to achieve a better financial result, it makes sense to study the possibilities for the development of new services provided by the heat supplier and improvement of the quality of these services. Among the possible development of services are noted for example:

- Flexibility of supply and demand for the electricity system – balancing services.
- Generating electricity for your own and market needs.
- Centralised cooling supply.
- Integration of finished heat storage solutions for more efficient operation of production sources and increased working hours resources.
- Planning, installation, and operation of integrating renewable energy sources—solar power plants, solar collectors, and heat pumps—into DH systems.
- Maintaining building heating substations, providing quality heat and hot water supply services, and ensuring mandatory requirements for building internal systems.
- Energy efficiency services and their potential in the heating and cooling sector (e.g. ESCO services in heat and coolness).

When examining the possibilities of improving the services provided at present and their development, it is appropriate to consider the potential for using the company's personnel and infrastructure, accumulated experience, financial standing, opportunities for employee motivation, and the interest of shareholders in developing services. The experience of the Nordic countries shows that heat suppliers are increasingly expanding their activities to other adjacent areas, where they can effectively use their existing advantages compared with other market participants.

7. Financial Analysis

An analysis of the economic situation of the company is essential for understanding its financial health and capacity to undertake new projects. This involves examining the Profit and Loss (P&L) Statement and the Balance Sheet.

Estimating the initial investment size is a critical step in assessing the economic viability of the project. This involves conducting a cost breakdown analysis by main cost items, such as equipment, installation, and infrastructure upgrades, to model the total investment required. Additionally, estimating operational and maintenance costs is crucial for understanding the ongoing financial requirements. This includes analysing indicative operational expenses, such as labour, materials, and energy costs, to ensure the project remains financially sustainable over time. Expected energy rates and revenue potential are also key factors in this analysis. By using tariff trends and demand patterns, we can forecast future revenue streams. This involves examining historical data on energy prices and consumption patterns to predict future rates and revenue potential. Understanding these trends helps in developing a robust financial model that can withstand market fluctuations and ensure long-term profitability.

Collaborating with local partners to determine funding strategies is essential for securing the necessary financial resources. Identifying potential funding sources, such as grants, loans, and private investments, is a critical step in this process. Evaluating management solutions for DH sites involves assessing the capabilities of local partners and stakeholders to manage and operate the systems effectively. This includes reviewing their technical expertise, financial stability, and operational experience to ensure the project's success.

Assessing the legal and operational requirements for accessing funding sources in each target country is crucial for ensuring compliance and eligibility. This involves understanding the specific regulations, eligibility criteria, and documentation required by funding agencies. Developing and analysing scenarios to evaluate the impact of variables on the project's viability is also important. This includes considering factors such as funding availability, policy changes, and market conditions. By modelling different scenarios, we can identify potential risks and develop strategies to mitigate them, ensuring the project's financial feasibility and long-term success.

By conducting a comprehensive financial analysis that includes these elements, the project can develop a strategy for integrating low-grade and waste heat technologies into DH systems. This approach ensures that the solutions are not only economically viable but also sustainable and resilient in the face of changing market conditions. The financial analysis will provide a clear picture of the initial investment required, the ongoing operational costs, and the potential revenue streams, allowing for informed decision-making. It will also highlight the importance of collaboration with local partners and the need to secure diverse funding sources to support the project's implementation. By understanding the regulatory landscape and developing flexible scenarios, the project can adapt to various challenges and opportunities, ensuring its long-term success and contribution to the decarbonization goals of the target countries.

Conclusion

The DH case study could consist of two parts. For example, the first is the **Development part** (explanatory note, explanatory statement, etc.), which could contain a detailed inventory of the situation, analysis, calculations and other supporting material, as well as reflect the company's aspirations to increase the efficiency of the system, use more waste and environmental heat, lower the parameters of heat supply, expand the market and develop new activities, improve quality, etc. some of the measures specified in this paragraph do not even require investments, but only reorganisations, efforts or the like.

The second part—**the Investment part**—could be a list of solutions requiring investments. These are summary tables that indicate what specific investments should be made, the technological description, the main parameters, the year of implementation, sources of financing, ways of acquisition, etc.

Summary table (Comparative table of investment efficiency)

No	Indicator name		Before investment	One year after investments
1	Available capacity for energy production (MW)	Available capacity and RES used.		
		Available Low-grade renewable energy generation		
2	The total annual amount of energy production (GWh/year)	Using fossil fuel		
		Using biofuel		
		From grade renewable energy		
3	Annual CO_2 emissions (Tones)			
4	Length of heat networks (km)			
5	DH is working on the parameters	Temperatures (T)		
		Pressures (bar)		
6	Heat losses in DH network (%)			
7	Number of heating/cooling users			
8	Total space heating area (m^2)			
9	Investments (mill. EUR) Heat production	In this number, biofuel boilers		
		Low-grade renewable energy generation		
10	Investments (mill. EUR)	Heat supply system		

Digitising the sector. Based on the sector's analysis in the country and in other EU countries, it is appropriate to formulate a strategy for digitising DH and the steps for implementing digitisation, which would help to focus on the process's final objectives, opportunities and continuity needs.

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