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IEA DHC

INTERNATIONAL ENERGY AGENCY
TECHNOLOGY COLLABORATION PROGRAMME ON
DISTRICT HEATING AND COOLING



SUMMARY FOR NON-TECHNICAL AUDIENCES

PROJECT RESULTS OVERVIEW 2023 – 2026 ANNEX XIV

About this Overview

This collection brings together briefs and summary reports from the nine international research projects completed under IEA DHC Annex XIV (2023–2026). The projects explore technical, financial and business approaches to developing district heating and cooling—from integrating new heat sources and meeting peak demand to improving feasibility assessment, pricing and market development.

How to use this collection

The collection has two parts:

- **Project briefs:** Nine very brief introductions, providing a quick overview of every project.
- **Summary reports:** More detailed summaries for the first seven projects, bringing together their main findings and conclusions.

Both parts follow the project order listed below. The final two projects were shorter in scope, so no separate summary reports were produced; they are represented by their briefs only.

Projects in this collection

1. InteGradeDH — Large-scale integration of low-grade sources into district heating networks through geothermal seasonal storage and heat pumps.
2. FAST DHC — Feasibility Assessment Tool for District Heating and Cooling.
3. Financial frameworks' impact on district heating.
4. RE-PEAK — How to cover peak heat loads in district heating networks with renewables?
5. FlexVal — Flexibility and the district heating value chain: advanced analysis and compatible pricing.
6. HY2HEAT — Using electrolysis waste heat in district heating networks.
7. Can a sustainable district heating business model be decisive for future competitiveness?
8. GHG Emissions and Resource Exergy Savings from District Heating in Europe and China, 2022.
9. DE-ployment — District Energy Market Development Guidelines.

The briefs and summary reports retain their individual layouts and any original page numbering. Start with the briefs for an overview of the research, then turn to the available summary reports for further detail on the projects that interest you.

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www.iea-dhc.org/the-research/annexes/2023-2026-annex-xiv.

IEA DHC Annex XIV

InteGradeDH – Large-scale integration of low-grade sources into DH networks through geothermal seasonal storage and heat pumps

KEY MESSAGES

1. Unlocking low-grade waste heat for DH decarbonization

Low-grade waste heat (WH) from industrial processes and urban infrastructure represents an important but still underused resource for decarbonizing district heating (DH). Its use is often constrained by two mismatches: many WH streams are below the temperature required by existing DH networks and are largely available in summer, when heat demand is low. InteGradeDH investigated how heat pumps (HPs) and borehole thermal energy storage (BTES) can recover, upgrade, store, and use such heat more effectively in DH systems.

2. Providing a structured framework for combining waste heat, heat pumps, and seasonal storage

InteGradeDH developed a planning-oriented assessment framework for integrating WH into DH networks through HPs and seasonal BTES. The project examined different temperature levels for both WH and DH, as well as different HP-based configurations, operating schemes and performance indicators, supported by a Python-based techno-economic model. BTES was explored with a focus on medium-deep (1 km) systems. Beyond technical and economic performance, the project also addressed implementation aspects such as risk exposure, ownership arrangements, business models, and tariff structures for hybrid WH recovery systems with storage and HPs.

3. Case studies show technical feasibility, but economic viability remains strongly case-dependent

The considered case studies of Göttingen and Bolzano showed that, within the assessed configurations, HPs and BTES can significantly expand the use of otherwise difficult-to-integrate WH. In Göttingen, data center WH at around 30 °C was assessed for a university campus with high DH temperature requirements, showing that temperature matching and drilling cost are decisive for feasibility. In Bolzano, already exploited high-temperature WH from a waste-to-energy plant and low-temperature WH from a dairy facility were evaluated for summer storage, assuming an expansion of the existing urban DH system. The results showed that long-term stable operation is achievable. Economic viability was found to be challenging for the considered cases, but feasibility thresholds were identified by varying source and network temperatures, drilling costs, electricity prices, financing conditions, and suitable contractual arrangements, offering insight to extend the analysis to other boundary conditions.

More details on the project are available on www.iea-dhc.org.

IEA DHC Annex XIV

FAST DHC – Feasibility Assessment Tool for DHC

KEY MESSAGES

1. Addressing the DHC debate: centralised 4GDH vs TSNs

Thermal source networks (TSNs) have been recently introduced as a subclass of 4th generation district heating (4GDH) systems. TSNs integrate consumer-side heat pumps (HPs), transforming district heating and cooling (DHC) networks into a collective heat source and sink for connected buildings. The differences between conventional 4GDH and TSN configurations have led to a fundamental debate within the international DHC community over the role, applicability and advantages of TSNs.

2. Providing an evidence-based comparison tool for pre-feasibility assessments of low-temperature DHC projects

With the aim of supporting early-stage decision making, the FAST DHC tool provides a transparent, consistent and practical framework for evaluating DHC solutions under diverse urban climatic and infrastructure conditions. It enables a rapid yet robust assessment of three distinct system configurations: 4GDH, TSN and individual HP-based systems. Unlike simulation tools that require detailed hourly data, it uses component-based techno-economic modelling on a seasonal resolution and country-specific defaults derived from validated datasets to inform calculations.

3. Validation with diverse case studies highlights the capabilities of the FAST DHC tool

Validation across four diverse feasibility case studies, including 4GDH and TSNs, demonstrated the tool's high applicability, particularly in urban settings, where it was able to successfully reproduce levelised costs estimates within an acceptable 20% deviation of the original case study values. These findings confirmed that the FAST DHC methodology is generally suitable for low-temperature DHC evaluations in city contexts. However, the case study analyses also indicated scope for future work, notably refining HP sizing at building level, testing with alternative network and storage sizing calculations, as well as further validating the tool with case studies involving larger cooling demands and sparse, rural environments.

More details on the project are available on www.iea-dhc.org.

FINDH PROJECT SUMMARY

Key Message	Details
Urgent investment need	Europe alone requires **€144–300 billion by 2030** and **€541–2,000 billion by 2050** to scale district heating and meet climate goals. This is a substantial opportunity for investors, but the current deployment is **not on track**, hindered by a **financial viability gap**. All things equal, the markets alone will not ensure deployment of district heating at the scale and speed projected towards 2050.
Financial viability gap	Investors may demand **>10% returns** for new district heating projects (avg. 11% in our sample), but unsubsidised DH projects may yield **single-digit returns** (in our modelling projects yielded 4-9% internal rate of return). Higher hurdle rates roughly **halve DH deployment** (e.g., 28% market share at 4% vs. 16% market share at 12%). Very high (50%) subsidies may barely bridge the gap – unlikely to be affordable for indebted states, indicating importance of private sector participation.
Standardisation is universal - bundling vs. customisation	**Standardised frameworks** (on e.g., risk registers, municipal guarantees) are no regrets. Bundling projects helps attract large investors, while **customised solutions** are needed for heterogeneous projects.
Policy and regulatory certainty	**Stable, long-term policies** (e.g. through the heat planning requirement in EU Energy Efficiency Directive) and **derisking tools** (loan guarantees, anchor customers) are critical. A **level playing field** (e.g., taxing externalities) must be created between DH and alternatives like gas boilers and heat pumps.
Sustainable finance and customer acceptance	**Sustainable finance** can drive decarbonisation but simplification is helpful for adoption among DH operators. **Customer acceptance** is key to cash flow – awareness, affordability, and mandated connections (if competitive) can boost adoption.

IEA DHC Annex XIV
RE-PEAK – How to cover peak heat loads in district heating (DH) networks with renewables?
KEY MESSAGES

1. Peak heat load has multiple and ambiguous definitions.

Peak heat load depends on the current and specific situation. Literature's multiple approaches to define it with texts, equations and graphs underline the ambiguity. The survey reveals durations from 50 to 1,250 hours per year (median: 200, mean: 350).

2. Peak heat loads are primarily fossil-based.

Peak heat load units must have low investment costs, as they are operated for only a few hours per year. High operation costs are accepted. Today, most peak heat load in DH networks units are fossil-based - a finding which is verified by the survey.

3. DH operators' transition strategies are oriented towards proven technologies.

Half of the surveyed DH networks have a net-zero strategy: DH operators select existing and proven technologies. Green gas boilers are among many chosen solutions, but are not a dominating solution; i.e. hydrogen and carbon capture are not broadly in the focus. In contrast to DH operators` practice-based responses, other DH experts significantly more often highlight the role of demand-side management.

4. DH operators combine peak heat load technologies around thermal energy storage.

A high share of survey respondents would combine different technologies for peak heat load. Exclusively in combinations, thermal energy storage is the most-mentioned option. Techno-economics depend on the network-specific duration of peak loads: biomass boilers or heat pumps are efficient for e.g. 1,000 hours per year, while for a very short duration (e.g. 50 hours per year) green electric, gas, or oil boilers are most efficient.

More details on the project are available on www.iea-dhc.org.

IEA DHC Annex XIV FlexVal – Flexibility and District Heating Value Chain

KEY MESSAGES

1. Flexibility is becoming a core feature of future district heating systems

As variable renewable electricity, electrification of heat supply, and low-carbon heat sources increase, district heating systems need to become more flexible. The FlexVal project shows that flexibility is not limited to a single technology or solution, but emerges from the coordinated use of thermal energy storage, demand response, heat pumps, electric boilers, CHP, low-temperature operation, and smart system control.

2. District heating flexibility must be assessed from a systemic and local perspective

The value of flexibility depends strongly on the surrounding energy system, electricity market conditions, taxation, regulation, and the existing district heating infrastructure. Long-term energy system modelling and Nordic operational modelling show that flexibility can improve cost efficiency and system robustness, but the benefits vary significantly by local context and operational year. This highlights the need for case-specific analysis rather than generic solutions.

3. Buildings are a key enabler of low-temperature and flexible district heating

The demand side plays a central role in unlocking district heating flexibility. Improved building-level control, digital diagnostics, lower return temperatures, and solutions such as advanced domestic hot water substations can support low-temperature operation without necessarily requiring extensive retrofits. However, technical potential alone is not enough: tariffs, ownership models, and incentives must be aligned so that building owners, tenants, and district heating operators all benefit.

4. Flexibility should be integrated already in planning, design, and pricing

The project shows that flexibility is most valuable when considered early in system planning, network design, and business model development. Smart control and peak-shaving assumptions can reduce overdimensioning and total system costs, while pricing mechanisms can steer both operators and customers towards more efficient operation. Future-proof district heating therefore requires integrated planning across the value chain, from buildings and networks to heat supply and energy markets.

More details on the project are available at [on the project website at iea-dhc.org](iea-dhc.org).

IEA DHC Annex XIV

HY2HEAT – electrolysis waste heat utilization

KEY MESSAGES

1. The hydrogen economy framework is evolving, but waste heat is barely considered.

Electrolysis capacities are expanding country by country, each following its own roadmap for hydrogen infrastructure. While 2030 targets are mostly well-defined, 2050 plans remain uncertain in many regions, leading to long-term ambiguity.

2. Heat pump integration for waste heat upgrading requires careful design, as configuration impacts performance.

Simulations show that preheating water before heat pumps boosts efficiency and cuts energy use. Higher waste heat temperatures further enhance performance by reducing thermal lift and electricity demand. Dynamic modelling confirms stable year-round heat supply, with feasibility dependent on electrolyser temperature, system design, and district heating network characteristics.

3. Large electrolysers with high full-load hours can offer flexibility and lower hydrogen production costs.

Using waste heat as a base load in district heating can be cost-effective, especially with low electricity prices. Economic feasibility depends on electrolyser size, hydrogen strategy, and alternative heat sources. Long-term supply contracts enhance financial viability, efficiency, and emission reduction.

4. The synergetic benefits are evident, but challenges remain to be addressed.

Waste heat utilization offers long-term economic and environmental benefits. However, challenges such as high investment costs, infrastructure adaptations, and low waste heat temperatures remain, requiring collaboration among stakeholders and clearer market structures for successful integration.

More details on the project are available on www.iea-dhc.org.

IEA DHC Annex XIV
SOCIAL SUSTAINABILITY- In the Context of DH Business Models
KEY MESSAGES

1. The hidden value of social sustainability

District Heating (DH) is a technology that can have both a strong economic value (often based on economy of scale) and an environmental value (depending on the fuels resorted to). The third dimension of sustainability (the social dimension) is less explored. By conducting value chain analyses of DH in different countries and an in-depth analysis of a case study, the research team identifies that social values beyond the expected social values linked to employee satisfaction and wellbeing exist and can strengthen the value proposition of the DH business model. However, the practice of capitalizing on the possible values is nascent or not explored to date.

2. Social value generation needs to be prioritized top down

With the aim of understanding the way that DH companies can generate and offer customer values, several key performance indicators for assessing social sustainability in DH activities were identified. It was identified that DH companies could benefit from actively working with social value generation. To do so is often a governance decision. The idea of fostering and strengthening social values needs to be incorporated into value chains (making them transparent), customer interaction (empowering the customer), educational efforts (engaging with the young and society at large), the design of buildings (inclusive and aesthetic), dedicated sustainability investment thresholds and sector coupling and other. Hence, to harvest social sustainability values management needs to be involved and support.

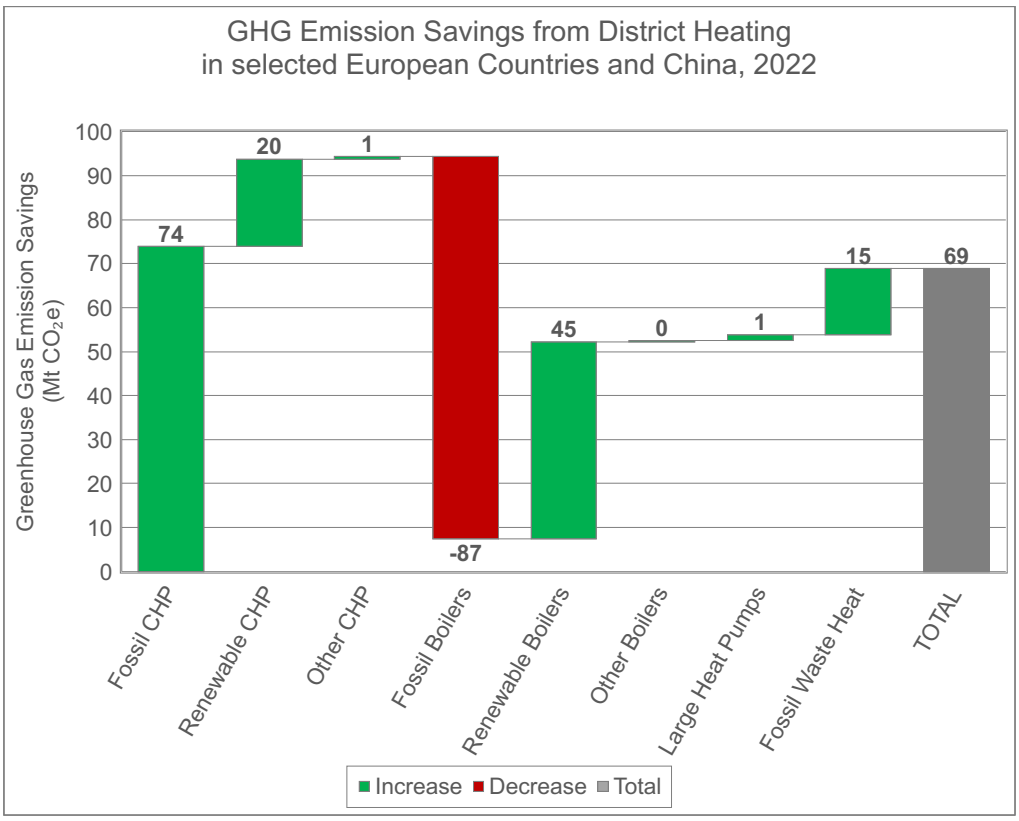
3. Being embedded in the local community strengthens competitiveness

Once the decision has been made, to harvest social sustainability values, a suggested next step would be to review the current value chain to understand where there is room to include factors that can generate social values. Dialogue with the surrounding ecosystem can be initiated to identify the interest and room for co-creation and co-investments across stakeholders. Identification and follow up on desirable social key indicators and revisit the business model logic to understand how the ongoing activities need to shift to pursue social values. There is no need to start large scale, instead a stepwise approach can be sufficient to anchor the DH company to the society making it an integral part of the local community. Being embedded and anchored to many stakeholders will strengthen the value delivered by DH companies and thereby their competitiveness.

More details on the project are available on www.iea-dhc.org

District Heating: The Proven Path to Fast, Efficient Decarbonization

District heating already delivers large-scale, proven emissions cuts and efficiency gains.



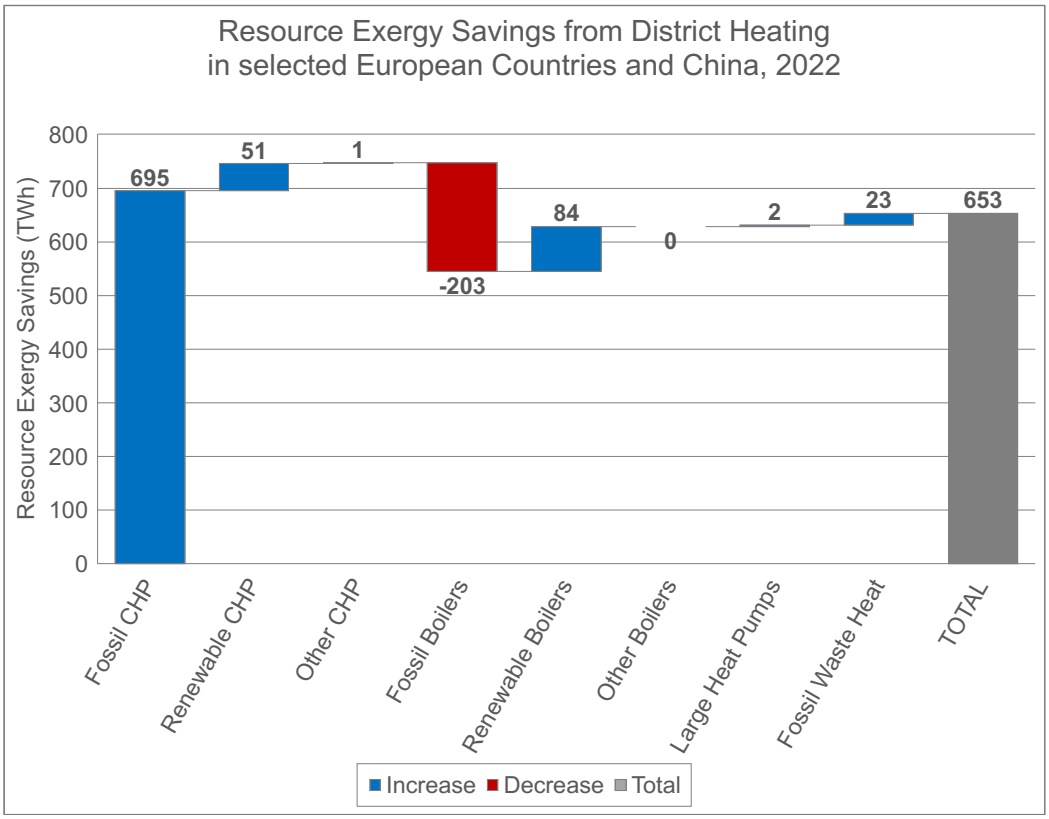
- **69 million tonnes CO_2 equivalents cut in 2022** — equal to removing 27 million cars from the road.
- **653 TWh of resource exergy preserved** — comparable to avoiding the operation of 52 large natural gas power plants or 73 000 modern on shore wind power generators.
- **CHP was the backbone in 2022:** cogeneration maximized fuel efficiency compared with separate generation.

High-Impact Transition Pathways

- **Replace fossil boilers** first for fastest emissions cuts.
- **Maintain efficient fossil CHP** during clean-grid transition.
- **Boost renewable and waste-heat** supply with stable incentives and network expansion.

Resource Exergy — A Next-Level Metric Enabling True Efficiency

It captures both quantity and quality — the real useful work energy can deliver.



Priority Actions for Decision Makers

- **Phase out fossil boilers**—replace with cost-stable district heating from CHP, renewables, and waste-heat sources.
- **Maintain fossil CHP** until low-carbon capacity and cleaner grids are ready.
- **Accelerate geothermal, solar-thermal, and large heat-pump deployment** in district heating networks.
- **Adopt resource exergy metrics** in national and EU frameworks to connect climate, security, and productivity targets.

Modern district heating, guided by resource exergy metrics, forms a cornerstone of rapid, resilient decarbonization. For detailed country-level results, data and methods, consult the full report on “Savings from District Heating in Europe and China, 2022”.

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DE-ployment

Helping cities and governments turn district energy ambitions into reality.

District Energy (DE), including district heating and district cooling, is a proven solution for decarbonizing cities, improving energy efficiency, and strengthening energy resilience. But in spite of its technical maturity, many regions continue to face barriers to deployment, including fragmented policies, limited institutional capacity, financing challenges, and lack of practical guidance.

DE-ployment was developed under the IEA Technology Collaboration Programme on District Heating and Cooling (IEA DHC) to help governments, municipalities, utilities, developers, and other stakeholders navigate these challenges. Rather than focusing solely on technology, the project provides practical resources to support every stage of DE market and project development, from assessing market readiness to implementing bankable projects.

The DE-ployment ecosystem combines a practical implementation guide with a suite of complementary digital tools designed to support informed decision-making, knowledge sharing, and continuous learning.

TOOLKIT

Explore the DE-ployment Toolkit

01 · READ

Deployment Guide & Toolkit

Enabling district energy markets, an eight-step project process, business and implementation models, and practical checklists (IEA DHC, 2026).

https://iea-dhc-guidelines-wiki.readthedocs.io/en/latest/about/index.html

02 · ASSESS

DE-cision Assessment Tool

Check market readiness with a 42-question questionnaire, map stakeholders by power and interest, and compare district and building-level options with a life-cycle cost analysis.

https://ngci.encs.concordia.ca/beta-dhc-tool/

03 · LEARN

Case Study Database

Fourteen integrated case studies across seven market types and nineteen thematic best practices, on a filterable map of cities.

https://iea-dhc-guidelines-wiki.readthedocs.io/en/latest/toolkit/case-studies/index.html

04 · EXPLORE

Knowledge Wiki

Access an evolving library of technical guidance, financing resources, policy examples, and practical references, updated as the market evolves.

https://iea-dhc-guidelines-wiki.readthedocs.io/en/latest/index.html

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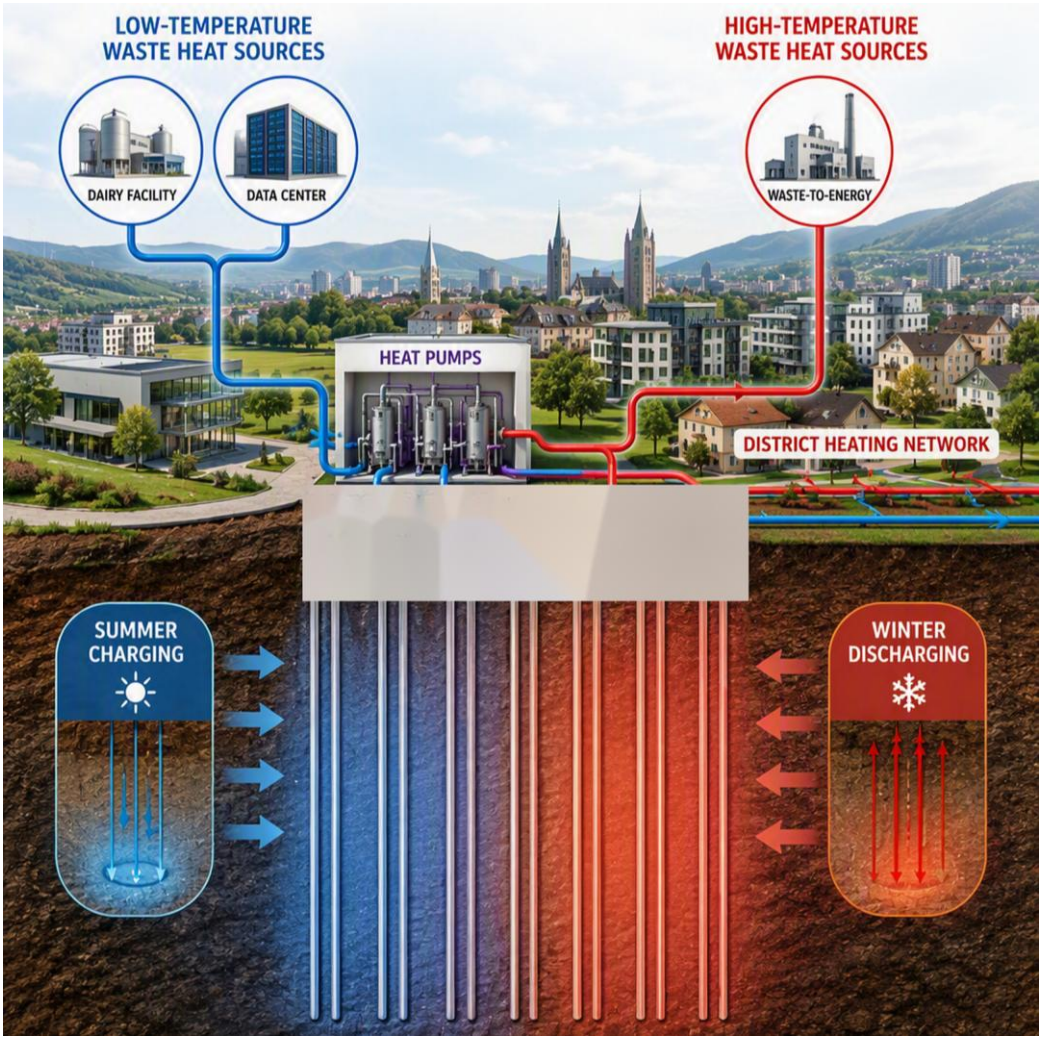
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DISTRICT HEATING AND COOLING



SUMMARY FOR NON-TECHNICAL AUDIENCES

INTEGRADEDH - LARGE-SCALE INTEGRATION OF LOW-GRADE SOURCES INTO DH NETWORKS THROUGH GEOTHERMAL STORAGE AND HP

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BACKGROUND AND RATIONALE

Decarbonizing the heating sector is a central part of the broader energy transition, and district heating can support this transition by integrating renewable and recovered heat sources in areas with concentrated heat demand. In this context, waste heat from industrial processes and urban infrastructure represents a particularly relevant resource. However, much of this heat remains underused because it is often available at temperatures below those required by existing district-heating networks, or at times of the year when heat demand is low. The InteGradeDH project addressed this challenge by examining how heat pumps and seasonal underground heat storage (in particular medium-deep borehole thermal energy storage) can help make better use of low-grade waste heat in district-heating systems.

The report assesses how low-grade waste heat can be integrated more effectively into district-heating systems through the combined use of heat pumps, seasonal thermal storage, and suitable system configurations. It focuses on technically and economically feasible integration pathways and considers not only technical performance, but also organizational and business-related conditions relevant to implementation. Two case studies, Göttingen and Bolzano, were used to connect the methodological work to real local contexts and to derive broader lessons for replication.

SCOPE OF THE PROJECT

The project examined how continuous waste-heat sources can be combined with heat pumps and borehole-based seasonal storage to overcome two common barriers to integration: the mismatch between source temperature and network requirements, and the mismatch between continuous heat availability and strongly seasonal heat demand. It considered both high-temperature waste heat, which may be integrated more directly, and low-temperature waste heat, which typically requires stronger support from heat pumps and storage.

The project also looked beyond engineering alone. In addition to the technical and techno-economic assessment, the final report addresses business models, risk exposure, and pricing implications. This is important because implementation depends not only on whether a concept works thermally, but also on whether its cost structure, ownership arrangements, and contractual setting make it practical in real district-heating systems.

FINDINGS FROM THE GÖTTINGEN CASE STUDY

The Göttingen case study focused on the north campus of Göttingen University, where waste heat from a modular data center was examined as a possible source for district-heating supply and for seasonal underground storage. The selected campus area has an annual heat demand

of about 40 GWh_{th}, and the data-center source provides low-temperature waste heat at around 30 °C.

Two storage options were assessed. The first was shallow borehole thermal energy storage. The second was medium-deep borehole thermal energy storage. The shallow storage results showed a clear trade-off. Direct waste-heat recovery without seasonal storage performed better economically under the current Göttingen conditions, while adding storage could increase the amount of heat supplied and improve carbon-emission reduction. In other words, shallow storage improved heat utilization, but not enough to outweigh its additional cost under the tested conditions.

The medium-deep option led to a more restrictive conclusion. The report shows that such a concept may be technically feasible but is difficult to justify economically in Göttingen under current conditions. The main reason is the combination of relatively low source temperature, high district-heating supply temperature, and high drilling cost. The broader lesson from Göttingen is that early temperature matching is critical. If the source is relatively cool and the heating network operates at high temperatures, heat-pump-based seasonal storage becomes much harder to justify economically, even where it can be made to work technically.

FINDINGS FROM THE BOLZANO CASE STUDY

The Bolzano case study examined an existing city-level district-heating system that already integrates waste heat from a waste-to-energy plant, includes a large hot-water storage tank, and is likely to significantly expand in the next few years. This made Bolzano a useful case for studying how additional waste-heat integration and seasonal underground storage could support further decarbonization and diversification of heat supply in an established urban network. The project focused on two waste-heat summer-storage pathways: high-temperature waste heat from the municipal waste-to-energy plant and low-temperature waste heat from a dairy facility.

For the high-temperature pathway, the results were technically strong. The selected system remained thermally stable over the long-term simulation and could cover a large share of the residual winter district-heating demand. However, this technical performance came with very high investment cost, and the economic indicators remained unattractive under the adopted assumptions.

For the low-temperature pathway, the results also showed technically stable operation, but with a much smaller annual heat contribution. Similarly, the economics remained unfavorable. The report identifies drilling-related capital cost, electricity price, and financing conditions as the main factors governing viability. It also shows that lower district-heating temperatures improve thermodynamic performance, but do not by themselves alone reverse the economic

conclusion. The main lesson from Bolzano is that technically stable operation is possible for both pathways, but economic viability depends strongly on local cost and financing conditions.

CROSS-CUTTING FINDINGS AND IMPLEMENTATION IMPLICATIONS

Taken together, the case studies show that heat pumps and borehole-based seasonal storage can expand the practical use of waste heat in district-heating systems by addressing two fundamental barriers: the temperature mismatch between waste-heat sources and network requirements, and the temporal mismatch between relatively continuous heat availability and strong seasonal heat demand. At the same time, the report makes clear that technical feasibility alone is not a sufficient basis for implementation.

Several broader lessons emerge from the project. First, the value of a waste-heat source depends not only on the source itself, but also on the district-heating network that is expected to receive the heat. Source temperature, network temperature, heat-pump lift, and the role of storage all matter together. Second, seasonal storage should be understood as a system-level measure rather than as a stand-alone asset. Its usefulness depends on whether it increases the annual share of usable heat in a way that justifies the additional infrastructure. Third, medium-deep borehole concepts require early screening of drilling cost and geological uncertainty, because these factors dominate the economic outcome.

The report also emphasizes that implementation depends on business and organizational arrangements. Hybrid systems that combine waste heat, heat pumps, and borehole storage involve multiple assets and often multiple actors. This creates additional needs for coordination, monitoring, contracting, and risk allocation. The project therefore supports business and tariff structures that distinguish clearly between fixed-cost recovery and variable operating costs, and that clarify the responsibilities associated with waste-heat delivery, system operation, and long-term performance. In particular, the report identifies a two-part tariff as a relevant pricing approach for systems with high fixed investment and electricity-dependent operation.

IMPLICATIONS FOR FUTURE APPLICATION

The report does not present a universal business case for integrating waste heat through heat pumps and seasonal underground storage. Instead, it provides a structured basis for identifying where such solutions are more likely to be technically sound, economically plausible, and organizationally implementable. The most promising applications are those in which waste heat is reliable, the temperature gap between the source and the network is not

too large, district-heating temperatures can be reduced or are already relatively favorable, and drilling and financing risks can be kept under control.

The replication guidance in the report points toward a staged approach. Future projects should first define the system boundary and characterize the source and demand conditions. They should then assess the role of network temperature, storage need, and heat-pump integration before moving to detailed techno-economic evaluation, sensitivity analysis, and implementation design. In this way, the report supports not a single predefined solution, but a practical assessment logic for identifying viable concepts in other district-heating contexts.

OVERALL CONCLUSION

InteGradeDH shows that heat pumps and seasonal underground storage can significantly widen the practical use of low-grade and otherwise mismatched waste-heat sources in district-heating systems. The project also shows, however, that successful deployment requires a set of favorable local conditions, still within realistic ranges, but possibly difficult to occur simultaneously. Network temperatures, source characteristics, geology, drilling cost, electricity price, financing conditions, and implementation structure all shape the final outcome. For this reason, the specific feasibility ranges identified in the case studies should not be transferred directly without local reassessment.

The main contribution of the project is therefore not to claim that the proposed concept works or does not work everywhere, but to provide a structured basis for deciding where further local assessment is justified. In that sense, the report contributes both to technical understanding and to practical decision-making on future integration of waste heat and seasonal storage into district-heating systems.

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SUMMARY FOR NON-TECHNICAL AUDIENCES

FAST DHC - FEASIBILITY ASSESSMENT TOOL FOR DISTRICT HEATING AND COOLING

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1 BACKGROUND INFORMATION

The FAST DHC (Feasibility Assessment Tool for District Heating and Cooling) project was carried out under the framework of the International Energy Agency Technology Collaboration Programme on District Heating and Cooling (IEA DHC). FAST DHC was an international research collaboration between London South Bank University (LSBU), the Austrian Institute of Technology (AIT), Aalborg University (AAU), and Danfoss Climate Solutions (DCS). The project ran from February 2024 to July 2025 and consisted of 5 work packages led by the partner institutions. Figure 1 illustrates the project structure, its work packages (WPs) and their interdependencies, as well as the main tasks within each WP.

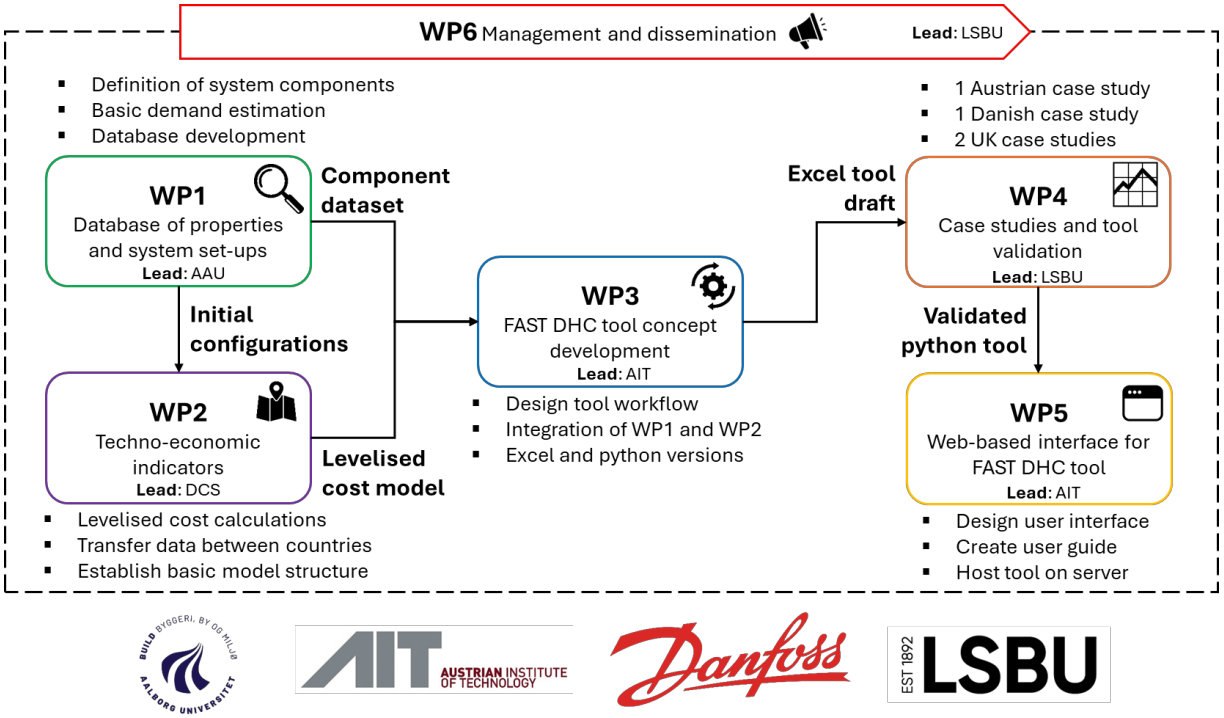


Figure 1: The structure of the FAST DHC project, highlighting its WPs and partners.

2 INTRODUCTION

The transformation of district heating (DH) systems has been conceptualised as the transition from the 1st to the 4th generation DH networks (4GDH). Recently, hybrid solutions of DH and individual solutions – called thermal source networks (TSNs) – have been introduced as a subclass in 4GDH [1]. Due to their ability to also provide cooling, they are often classified under the wider term of district heating and cooling (DHC).

In TSNs, the novelty is the integration of consumer-side heat pumps (HPs), which in effect transforms the purpose of a distribution network (DN), from supplying heat or cold at directly useful temperatures, to serving as a collective heat source and sink for the connected individual HPs. As these HPs supply buildings with a temperature according to the service requirements, the DN operating temperatures are flexible.

The differences between conventional 4GDH and TSN configurations, particularly the transition from large-scale central H&C generators to building-level HPs, have led to a fundamental debate within the international DHC community over the role and applicability of TSNs, particularly as the previously used term “5th generation” might lead to the perception that TSNs are a progression from the 4GDH, which is not necessarily the case [2]. This was demonstrated in [3], where for a single-source system without cooling, 4GDH was shown to be economically superior to a TSN configuration. On the other hand, TSNs could be a viable alternative in mild climates with heating and cooling demands of similar magnitudes, particularly where traditional DH networks are not present [4]. Furthermore, it is important to consider that DHC is not necessarily the most economical solution, as the high investment costs associated with DNs might not be justified in locations with low heating and cooling demand densities, where standalone HPs might be the cost-effective solution.

The ongoing debate over the merits and challenges of traditional 4GDH systems and TSNs was the main motivation for the FAST DHC project. There is uncertainty over the role and applicability of TSNs, and in which cases they can outperform a 4GDH network or individual H&C systems, in terms of system efficiency, costs and environmental footprint. Typically, the selection of a certain DHC typology demands a case-by-case detailed assessment to identify the best system design, and there is no “one-size-fits-all” solution. This is a data-intensive process that typically involves the use of commercial tools, which require information that might not be available in early planning stages (e.g. hourly demand data). In some cases, existing feasibility tools fail to consider all system properties (e.g. cooling or individual H&C solutions), thus being unable to provide a fair comparison between 4GDH and TSN systems.

Conversely, the FAST DHC project is aimed at supporting early-stage decision making with a freely available web-based tool for the techno-economic performance evaluation of 4GDH and TSNs, and their comparison to individual H&C solutions. The tool can give users an indication

as to which H&C system represents the best potential investment under the assumed boundary conditions, being particularly useful for end-users with limited resources or expertise to perform more detailed analyses. This includes municipalities and consultants conducting first-phase assessments, where hourly data is not yet available. Therefore, the novelty of FAST DHC lies in the way that it can provide a pre-feasibility comparison with very little input from users, enabling them to focus their next evaluation steps towards the most promising solutions, thus saving time and money.

3 TOOL METHODOLOGY

3.1 TOOL OVERVIEW

The FAST DHC tool is a techno-economic decision support tool consisting of a structured Graphical User Interface (GUI) backed by Python scripts and lookup datasets. It operates on a modular architecture across four sequential input-output modules, as shown in Figure 2.

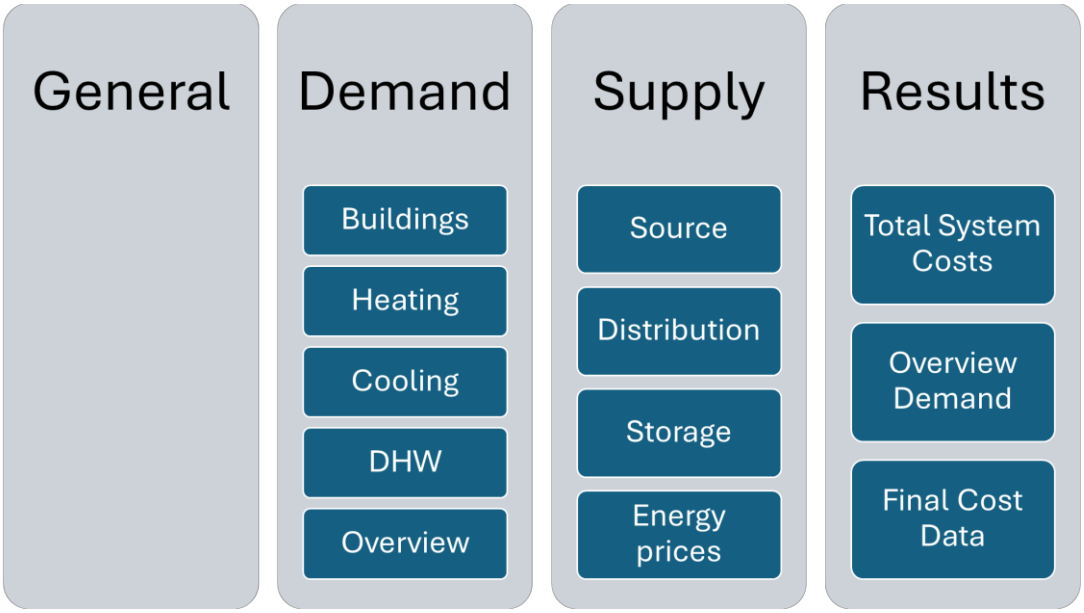


Figure 2: Overview of the user modules (i.e. tabs) in the FAST DHC web tool.

The tool relies on a seasonal resolution (winter, spring, summer, autumn/fall) rather than hourly profiles, balancing practicality with technical accuracy suitable for early-stage studies. The functionalities, inputs and outputs of each of the tabs from Figure 2 are described below:

General Information: Project context definition (e.g. country, full load hours, discount factor);

Demands: Definition of thermal demand profiles across three building types: single-family homes (SFH), apartment buildings (APP), and non-residential buildings (NRB), as well as heating system parameters (underfloor or radiator based);

Supply Technologies: Configuration of generation technologies (e.g. HPs, boilers, waste heat), distribution parameters (e.g. heat losses) and storage components (diurnal or seasonal).

Tool Outputs and Results: Visualisation of calculated metrics, including total annualised and levelised costs with breakdown of component-specific costs.

3.2 SYSTEM CONFIGURATIONS

The FAST DHC tool can evaluate the techno-economic performance of three principal H&C configurations, namely conventional centralised 4GDH, TSNs and individual solutions. Their characteristics and modelling approaches are described in Table 1. The results module can be used to visualise calculated outputs and enables side-by-side comparison.

Table 1: Description of system configurations/typologies in the FAST DHC tool.

Configuration	Space Heating Supply	Cooling Supply	Hot Water Supply	Network Temps
4th Generation District Heating (4GDH)	Central, via network	Individual HPs	Central, via network	65°C/30°C
Thermal Source Network (TSN)	Decentralised networked HPs	Networked or individual HPs	Decentralised networked HPs	15°C/5°C
Individual H&C systems	Individual HPs	Individual HPs	Individual HPs	N/A

3.3 DEMAND CALCULATIONS

Thermal demands are estimated based on default values for average floor area (m^2) for different types of buildings, their specific thermal loads (kW/m^2), and full load hours per season. These values can be edited and are used to calculate space heating (SH), domestic hot water (DHW) and space cooling (SC) loads, as follows:

Space Heating: Peak thermal load uses a simultaneity factor to account for the fact that not all connected buildings require their full heat load simultaneously. This factor decreases as the number of connections increases, converging to about 0.65 in large mixed-use areas.

Domestic Hot Water: DHW demand is assumed to have no significant seasonal variation. Peak DHW load is calculated using a probabilistic flow rate formula defined in European guidelines [5], which considers the number of households and aggregated/maximum flow

rates, ensuring realistic sizing that accounts for simultaneity effects. DHW storage to alleviate instantaneous heating capacity can be included as per user selection.

Space Cooling: Calculations are based on typical full-load hours and average cooling loads per building type and age for each country. As space cooling is provided at the building level, simultaneity factors are not applied.

3.4 COMPONENT SIZING

3.4.1 HEAT GENERATION TECHNOLOGIES

Heat source capacities are derived from the seasonal demand profiles. Users specify the share of energy covered by base load generators (e.g. heat pumps or waste heat) versus peak load generators (electric, biomass or gas boilers). The sizing principles for different heat generation technologies are provided in Table 2.

Table 2: Sizing logic for heat generation technologies in the FAST DHC tool.

Component	Sizing Principle	Key Inputs/Assumptions
Central heat pump	Sized based on maximum seasonal demand, and a safety factor of 1.5.	Seasonal COP values calculated based on source and distribution temperatures.
Back-up air-source heat pump (central)	Automatically allocated to cover unmet demand if the user-defined source capacity is insufficient.	Sized using the same safety factor (1.5) and ambient air as the heat source.
Central boiler	Sized based on the uncovered peak load based on user selection.	Efficiencies vary for electric (99%), gas (90%) and biomass (85%) boilers.
Decentral or individual heat pumps	Sized per building based on peak SH, SC and DHW loads.	Accounts for DHW storage effects and COPs based on network/air temperatures.

3.4.2 DISTRIBUTION NETWORK

Network length calculation is critical for infrastructure cost (CAPEX) in DHC systems. FAST DHC uses an empirical model based on building density indicators, specifically the Plot Ratio (ratio of total heated floor area to total land area). The total network trench length is estimated using the effective width method, linking the land area to the specific pipe length per hectare,

which is calculated using a logistic fit derived from Danish GIS data for DH networks, ensuring that the calculation reflects realistic saturation in dense urban areas versus sparse regions.

Network CAPEX is derived by combining the calculated length with cost curves which depend on the maximum thermal network load. Network operational expenditure (OPEX) is scaled according to the total annual thermal energy delivered.

3.4.3 THERMAL STORAGE

The tool supports two types of thermal storage:

Seasonal Storage: Used to store excess heat from cooling (rejected from non-residential buildings) for winter heating use. For 4GDH, conventional hot water tanks are modelled. For TSNs, Borehole Thermal Energy Storage (BTES) is considered, with capacity based on typical assumptions for geothermal systems scaled by volume (depth and area).

Diurnal Storage: Short-term buffer storage used to optimise electricity costs for the central heat pump by shifting consumption to hours with lower day-ahead electricity prices (peak shifting). This flexibility is based on precomputed cost savings derived from historical Austrian electricity price data and optimisation tools (IESopt [6]).

3.5 ECONOMIC MODEL AND DATABASE OF COMPONENTS

The FAST DHC tool utilises the levelised cost concept to provide a long-term, comparable metric (EUR/MWh) for district and individual H&C solutions, factoring in future reinvestments of components with different technical lifetimes. This involves gathering information from a database of 13 technological components typical to both DHC and individual H&C technologies. This database includes information on lifetime, capacity/size as well as CAPEX and OPEX for 13 different technologies, obtained mainly from the technology catalogues from the Danish Energy Agency [7]. Additionally, the tool also provides indicative data on heat recovery costs for 14 heat sources based on a research project commissioned by the UK Government [8]. Where applicable, costs are scaled using power functions derived from empirical catalogue data to account for various unit sizes.

For levelised cost calculations, CAPEX is converted into annual values using the annuity method based on a discount rate (default 5%) and component lifetime. Costs are normalised across countries using Purchasing Power Parities (PPPs) and adjusted for inflation to ensure comparable national price levels. OPEX includes energy as well as operation and maintenance (O&M) costs. These are calculated based on system performance (e.g. COP or efficiency) and country-specific pricing. Electricity tariffs are differentiated as follows:

Household (HH) tariffs are applied to decentralised (building-level) heat pumps.

Non-household (NHH) tariffs are applied to central heat pumps. The tool allows for detailed tiered tariff structures (bands) and includes distribution charges that vary by consumption level.

4 CASE STUDIES AND VALIDATION

A critical part of the FAST DHC project involved testing the tool with case studies related to the different system configurations described in Table 1. Four case studies that consist of feasibility assessments carried out with other software tools, such as IESopt [6] and energyPRO [9], were replicated with FAST DHC for validation purposes, and these are described in Table 3.

Table 3: Description of case studies replicated with the FAST DHC tool.

Case Study	Typology	Location	Generation Capacity and Main Heat Source	Key Features
1	4GDH	Bristol, UK	750 kW heat pump, supermarket waste heat	Small, urban, only heating
2	4GDH	London, UK	26 MW heat pump, wastewater heat	Large, urban, only heating
3	TSN	Vienna, AT	1 MW of heat pumps, ground-source	Small, urban, heating & cooling
4	TSN	Midtjylland, DK	429 kW of heat pumps, geothermal collectors	Small, rural, only heating

A comparison of case study results for key parameters is provided in Table 4. Overall, demand estimations were closely aligned across all case studies, which indicate the methodology used for that purpose was reasonable. There is just one validation point for cooling demands (case study 3), and the tool should be further tested in different countries and contexts to validate its cooling demand estimations. However, FAST DHC has a highly flexible approach to demand calculations, as all relevant inputs are editable by the user.

In terms of component sizing, heat pump capacities are in good agreement for 3 out of 4 case studies, with a significant discrepancy being observed for case study 3, involving a TSN. This issue is due to the non-optimised allocation method for calculating HP capacities at a building level in the FAST DHC tool, which calculates separate DHW and SH capacities and defines the maximum value as the final heat pump capacity at the building level. The methodology used for estimating network length proved to be reasonably accurate for the first 3 case studies, but a significant deviation was observed for case study 4. As the latter was the only case study for a rural environment, our conclusion is that the methodology used for estimating

network length is less accurate in rural settings. Large variations were also observed in thermal storage sizing. However, as accurate thermal storage sizing would require detailed assessments on an hourly basis, the discrepancy in results was deemed reasonable.

Table 4: Comparison of percentual differences in case study and FAST DHC results.

Item	Case Study 1 (4GDH)	Case Study 2 (4GDH)	Case Study 3 (TSN)	Case Study 4 (TSN)
Heating demand	-3%	N/A	-1%	+3%
Cooling demand	N/A	N/A	-1%	N/A
Total heat pump capacity	-15%	-15%	+155%	+3%
Network length	0%	-9%	+13%	-47%
Thermal storage size	-9%	+52%	-68%	N/A
Annualised CAPEX	-14%	+5%	-6%	+50%
Annual OPEX	+31%	-1%	-39%	+33%
Annualised costs	+15%	+1%	-30%	+40%
Levelised costs of energy	+19%	+1%	-10%	+36%

The analysis of estimated annualised costs shows good agreement (<15%) for the 4GDH case studies (1, 2), whereas TSN case studies (3, 4) had a higher disparity in results (<40%). CAPEX estimates had a close match for the urban case studies (1, 2 and 3), while case study 4, located in a rural setting, was largely impacted by the difference in length and costs for the distribution network. OPEX values also varied significantly across most case studies. The TSN case studies obtained a significant variation in electricity costs, which was linked to the lower granularity of price data in FAST DHC and different efficiency (COP) assumptions. Additionally, high discrepancies were observed for O&M estimates for all case studies, which is expected as these were mostly estimated using fixed rule-of-thumb values (e.g. 1% of total CAPEX).

Finally, a comparison of levelised cost estimations indicates that the FAST DHC tool was able to reproduce results from urban case studies within a ±20% difference. The rural case study 4 had a larger deviation in levelised costs (+36%) and further work is needed to test the tool against other rural DH projects. This discrepancy is illustrated in Figure 3, which compares the results for case studies 2 (urban) and 4 (rural). Other limitations that might need to be addressed in future versions include HP sizing at building level, network length and storage calculations, as well as testing with other case studies involving larger cooling demands.

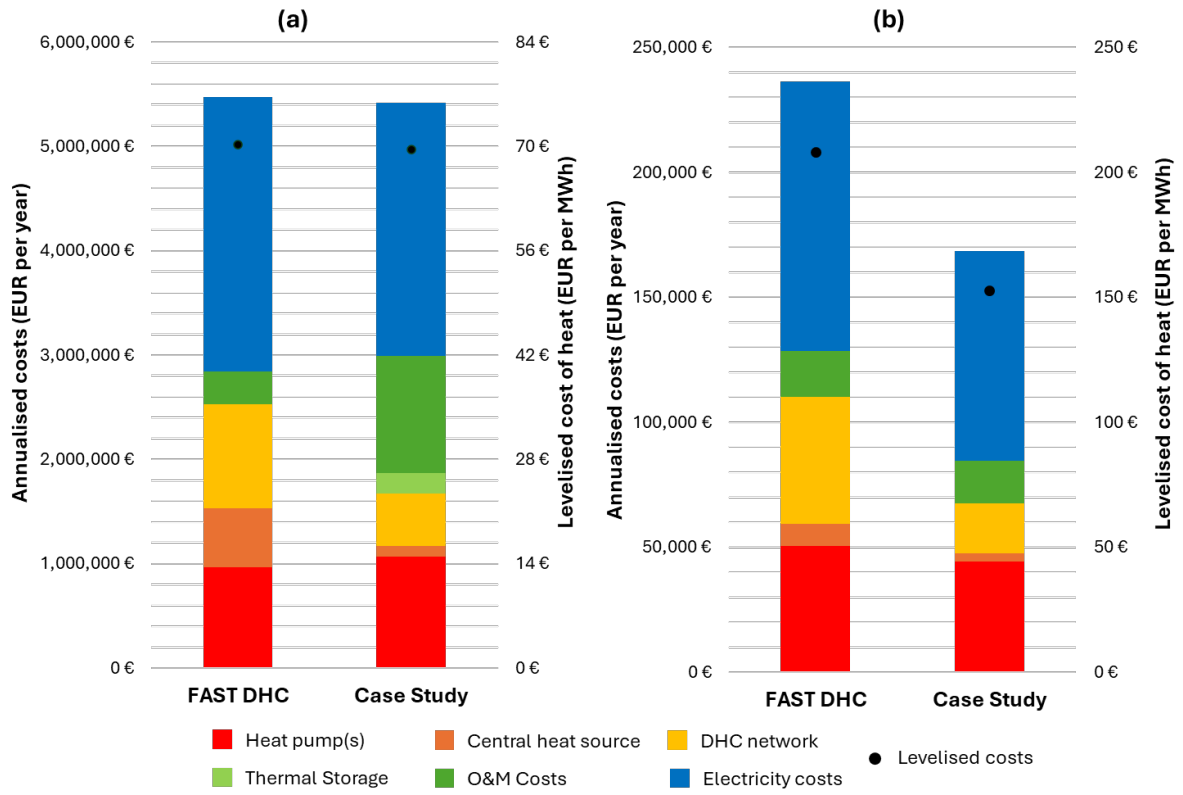


Figure 3: Comparison of estimated annualised costs per component and levelised costs for Case Studies 2 (a) and 4 (b).

5 TYPOLOGY COMPARISON

With the purpose of illustrating the functionalities of the FAST DHC tool, case study data were also used to evaluate how annualised and levelised cost estimates compare across different system typologies (4GDH, TSN and individual) for the same boundary conditions. This exercise was aimed at indicating to users how the FAST DHC tool should be applied, and also at evaluating how different parameters can be determinant when comparing the economic competitiveness of low-temperature DHC networks and individual H&C solutions.

Case study 1 was replicated for all system typologies available in the FAST DHC tool, and the results of this comparison are shown in Figure 4**Error! Reference source not found.**. As it can be observed, the tool predicts similar levelised costs for a conventional 4GDH network (€150 per MWh) and individual solutions (€148 per MWh), whereas a TSN would lead to higher levelised costs (€170 per MWh) under case study 1 conditions. The price parity between 4GDH and individual systems can be explained by the assumption that individual technologies would operate bivalently, i.e. building-level air-source heat pumps are assumed capable of providing both heating and cooling. This assumption is not considered for residential buildings connected to TSNs, as these are unlikely to have the required infrastructure for central cooling provision, which explains the higher cost estimates achieved for TSNs.

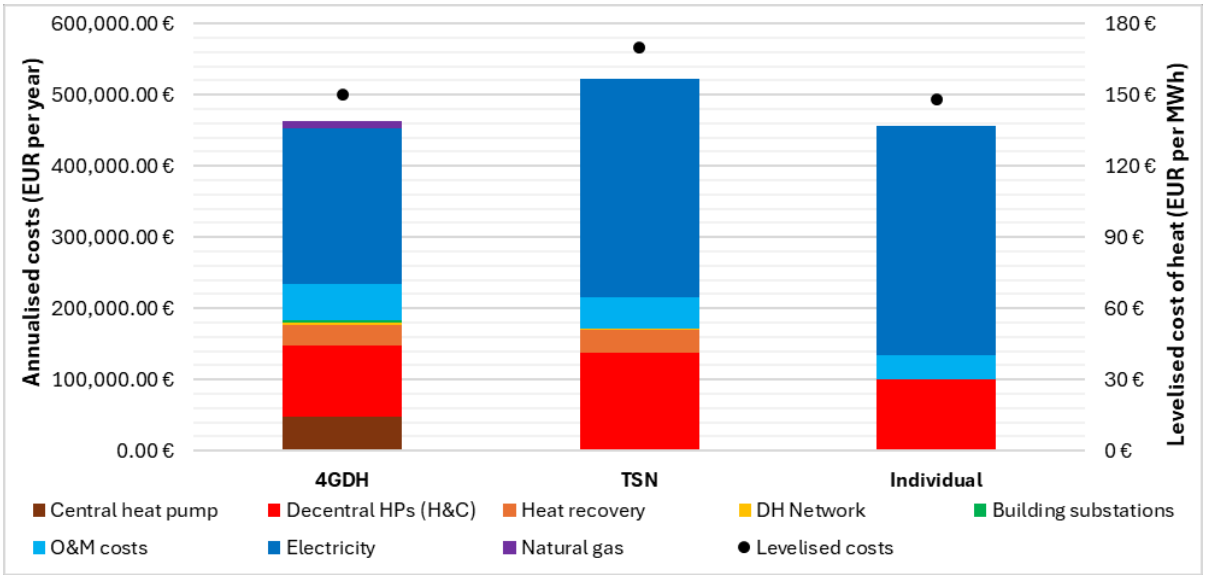


Figure 4: Annualised and levelised costs for different typologies in case study 1.

Sensitivity analyses were also carried out to test how different assumptions may impact results. If separate individual systems were required for heating and cooling, the levelised costs for the individual set-up would increase significantly to €167 per MWh. On the other hand, if TSNs could deliver both H&C, their levelised costs would reduce to €146 per MWh, making them the cheapest option amongst the three analysed typologies. Another key assumption that is determinant to the comparison is the temperature of the main heat source. If the heat source for case study 1 was changed from supermarkets to data centres, the levelised costs of the 4GDH configuration would reduce by 15% to €128 per MWh, whereas TSNs would not be impacted considerably. These results are illustrated in Figure 5.

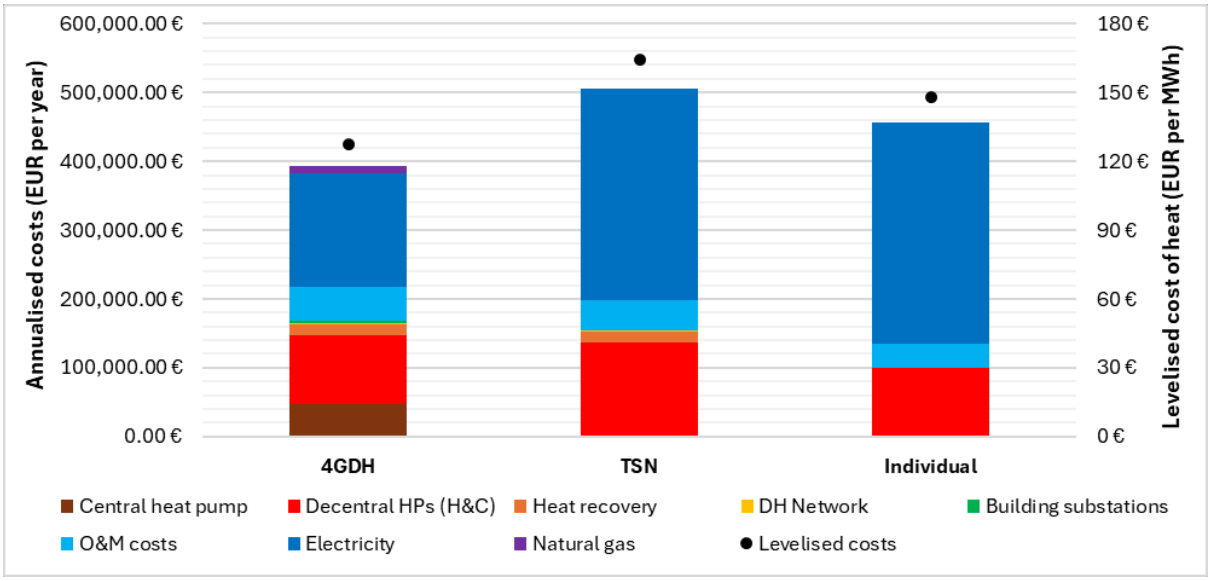


Figure 5: Typology comparison where the primary heat source is changed from a supermarket to a data centre.

6 CONCLUSIONS

The FAST DHC project developed an easy-to-use, pre-feasibility modelling tool intended to evaluate the annual and levelised costs of low-temperature DHC systems: specifically conventional 4GDH and TSNs, as well as their individual heat pump-based counterfactual. This effort was motivated by the need for a simple comparison tool for early-stage decision-making, especially given the complex debate within the DHC community regarding the technical advantages and applications of centralised 4GDH versus the emerging TSN concept.

The FAST DHC tool provides a transparent, consistent, and practical framework for evaluating these DHC solutions under diverse urban climatic and infrastructure conditions. It enables rapid early-stage assessment of the three distinct configurations, allowing users to define scenarios and configure technologies using default cost data derived from validated datasets. This modular interface supports scenario comparison without demanding detailed hourly data or specialised simulation expertise.

Four case studies were replicated to validate and test the tool's functionalities, demonstrating its effectiveness, particularly for urban applications and 4GDH systems, where it reproduced annualised cost calculations with an acceptable accuracy. Overall, levelised cost estimates for urban case studies were within ±20%. However, some challenges and limitations were observed, particularly relating to TSN modelling. The rural TSN case study obtained the largest difference in levelised costs (+36%), and further work is required to test the tool against other rural DHC projects. Other limitations that should be addressed in a future version of FAST DHC include more refined heat pump sizing at building level, testing with alternative network and storage sizing calculations, as well as case studies involving larger cooling demands. Lastly, expanding the FAST DHC tool to other countries of interest, in Europe and elsewhere, would further strengthen the position of the tool as the "go-to" pre-feasibility indicator for other DHC markets with considerable growth potential.

Overall, the FAST DHC project was able to deliver a simple yet robust and reliable tool for the comparison of centralised 4GDH, TSN and individual H&C systems, being particularly effective for cities. The FAST DHC tool supports informed decision-making by making the trade-offs between infrastructure cost, energy use and system design transparent and reproducible. In doing so, FAST DHC can bridge the gap between strategic planning and technical feasibility analysis, thus supporting cities in understanding the best solution for decarbonising their thermal energy supply.

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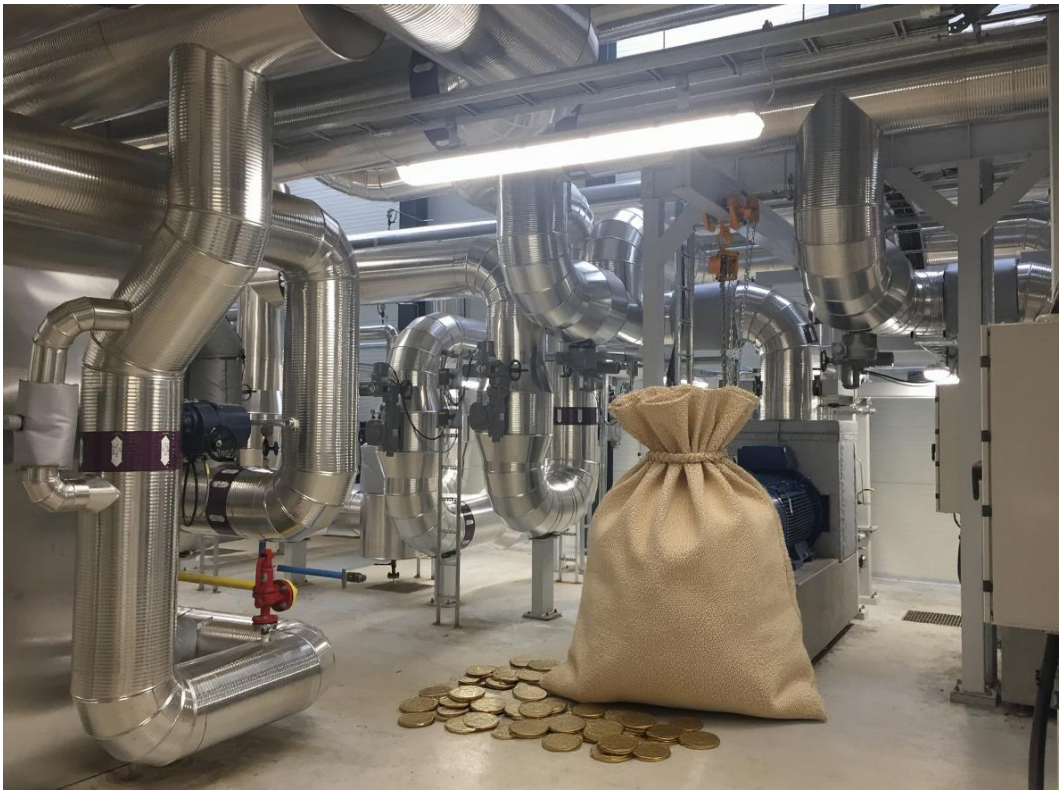
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INTERNATIONAL ENERGY AGENCY
TECHNOLOGY COLLABORATION PROGRAMME ON
DISTRICT HEATING AND COOLING



SUMMARY FOR NON-TECHNICAL AUDIENCES

FINDH – FINANCIAL FRAMEWORKS' IMPACT ON DISTRICT HEATING

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THE FINDH PROJECT IN A NUTSHELL

Europe needs €144–300 billion by 2030 to scale district heating (DH) and meet climate goals, but current deployment is "not on track", according to IEA. This report reveals why: a financial viability gap is a barrier to investments. Scaling DH requires policymakers to derisk or take the lead, investors to adjust thresholds, and operators to innovate.

The FinDH Project (IEA DHC Annex XIV Project 03 - Financial frameworks' impact on district heating) provides a foundational study for understanding finance's role in DH deployment. We do so through interviews with 38 experts in DH and finance, literature studies, energy system modelling of financial impacts on DH deployment in a case city, and GIS analysis of the wider European implications. This improved understanding of DH in financial terms, i.e. as an asset/asset class, bridges the investor and DH sector communities.

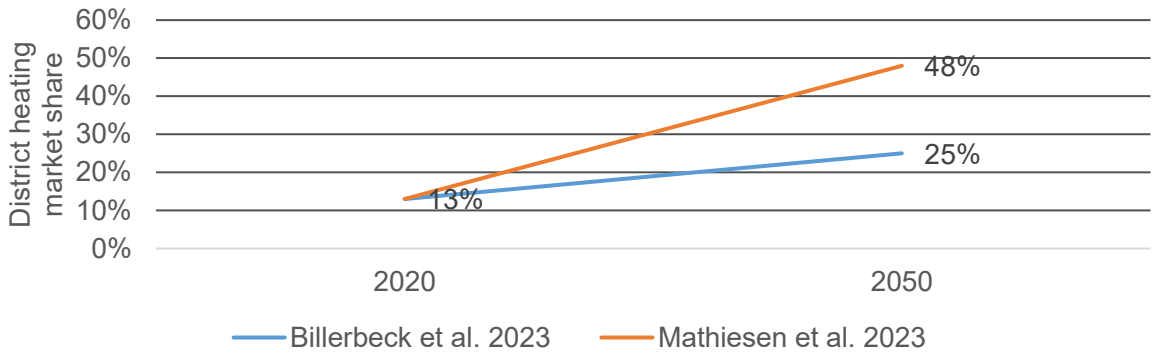
The focus in this study is how to understand DH as an asset – or asset class. We find that DH is an attractive – but somewhat overlooked – sub-class of (sustainable) infrastructure:

- High upfront costs and investment volumes: Requires long-term capital (e.g., pension funds, municipal bonds)
- Two classes - Greenfield and brownfield: New projects are riskier, while established systems can offer stable, inflation-linked returns
- Complex: Variation in technologies, regulation and availability of energy sources.

Investors will benefit from both looking at the "forest" (standardised) and the "trees" (customised) in DH financing: standardized frameworks help assess DH risk-return profiles at volume, while a customised approach is useful for heterogeneous DH projects.

NEED FOR SPEED – NEED FOR MONEY

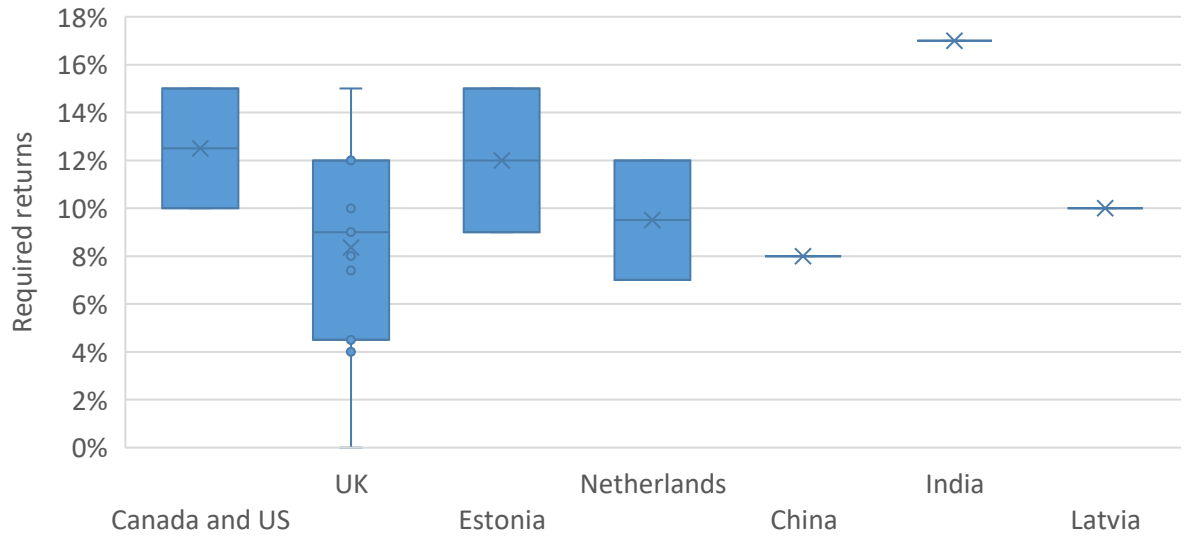
Two European studies indicate an increase in deployment speed from approx. 1%-point/decade to 1-2%-points/year in Europe towards 2050, to achieve potential DH shares.



Matching the large-scale and fast-paced deployment, substantial funds are estimated to be needed for DH in Europe: by 2030, €144-300 billion and by 2050 €541-2 000 billion. While these numbers – like other future market estimates – should be taken with caution, they illustrate the need for better understanding of the financial aspects of DH.

FINANCIAL VIABILITY GAP FOR DISTRICT HEATING

A financial viability gap is blocking DH expansion: Depending on the lifecycle-stage, the related risk and the type of capital (e.g, equity vs. debt), investors may require more than 10% returns (our study averaged 11%), but unsubsidised DH projects we analysed yield single-digit returns. This mismatch limits deployment, even where DH is socially and environmentally beneficial.



While there is wide variation in these numbers, and some cases show single digit returns requirements, one thing is clear: higher returns requirements mean lower DH deployment. In the example below, our modelling of a new (greenfield) DH system shows that DH market share drops as the hurdle rate for generation assets increase. The results are conservative, as the hurdle rate is only applied to generation assets. Inclusion of network assets would mean even stronger impact of increasing hurdle rates (less DH deployment). Hurdle rate is the minimum required return of an investment and is used as a decision threshold. It can be the same as the weighted average cost of capital – i.e. the cost of capital for financing a project.

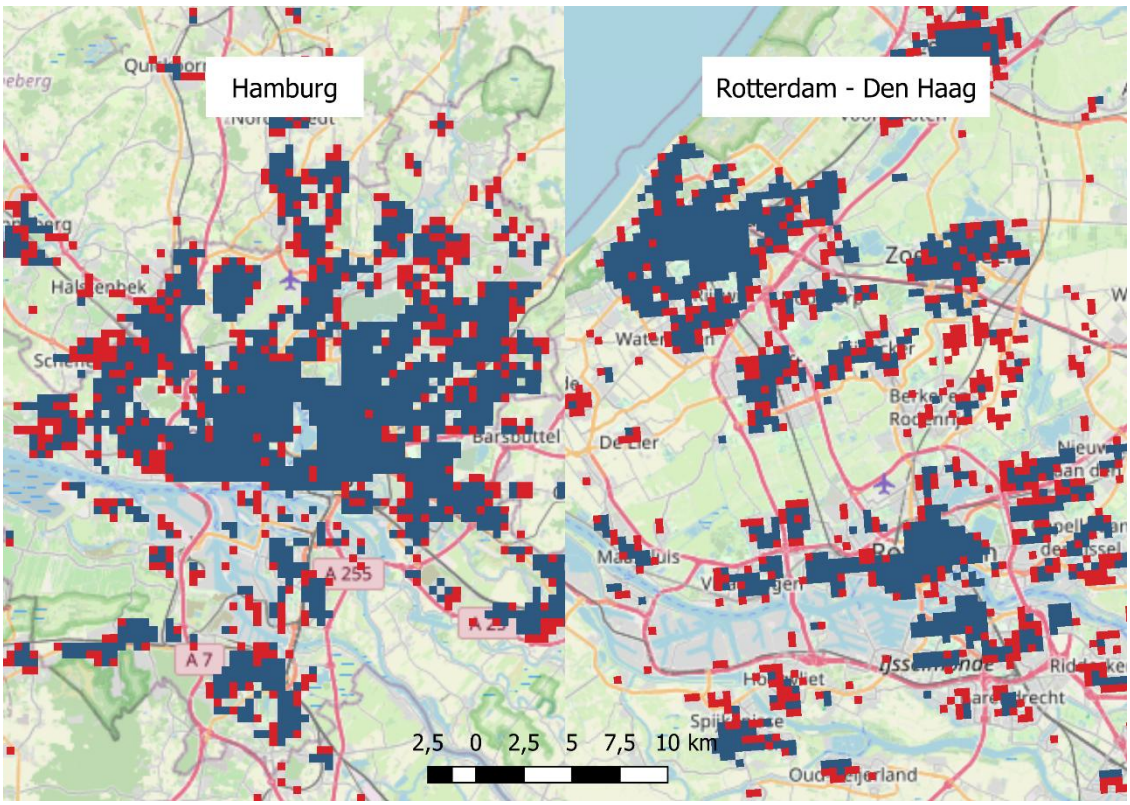
Hurdle rate	DH share – 2050
2%	31
4%	27
8%	18
12%	15
20%	9

Hurdle rates are make-or-break for DH deployment:

- At a 4% hurdle rate, DH could cover 28% of heat demand by 2050
- At 12%, coverage drops to 16% - almost halving potential deployment
- Subsidies fall short: Even at 50% support, DH IRR barely meets investors' ~11% required return (figure - blue line). Lower required returns (e.g. derisked) are critical to scale DH.

Hurdle rate	Investment subsidy in % for DH production assets			
	0%	10%	20%	50%
2%	4	5	5	9
4%	6	6	7	10
8%	8	9	9	15
12%	9	10	11	17
20%	9	10	12	25

Extrapolating the city case to a European scale, and assuming a greenfield "start from scratch" (i.e. no existing DH), the difference between 4% (red) and 12% hurdle rate (blue) corresponds to a drop from 53% to 47% DH market share. These results are moderate, but as noted above, inclusion of network assets in the hurdle rate-thresholds would mean less DH deployment, as hurdle rates increase.



RECOMMENDATIONS

While our study is concerned with the financial aspects of DH, we start the recommendations around macro-finance (i.e. the relation between asset financing and the wider economy). Macro-financial regimes here define the different financial conditions under which states operate and intervene in the financing of assets. These may range from pure market-based (where historical development has not provided examples of widespread deployment of DH), over various levels of derisking and support, to the mostly publicly driven deployment and financing of DH (where wider deployment of DH has been seen historically). All things equal, expecting wide deployment of DH based on financial incentives is unlikely to be successful.

TWO TRENDS: STANDARDISE AND BUNDLE – OR CUSTOMISE IT

While there are very competent financial stakeholders globally, some investors remain unfamiliar with DH as an asset, e.g. in transitioning markets like the UK, with unproven concepts such as sector coupling and waste heat recovery, or in distinguishing between riskier greenfield projects and safer brownfield projects. Standardizing regulatory frameworks – including municipal guarantees and project proposal methods – can clarify DH's financial potential, alongside tools like risk registers and metrics (e.g., sustainability scorecards). Bundling DH projects across geographies can attract large investors, though the diversity of DH systems often limits this to large utilities with scalable models. While standardization aids bundling, customised solutions may still be needed, benefiting from specialized investors or public funding channels like Denmark's KommuneKredit. Authorities may also mandate bundling of e.g. neighbourhoods to prevent cherry-picking, balancing returns and fostering stable investments aligned with societal needs and local acceptance.

CLOSING THE FINANCIAL VIABILITY GAP – OR BYPASSING IT

Against the backdrop of high risk, especially during the early stages of the project life cycle, the rate of return may fail to meet investors' expectations, creating a financing gap. To address this, measures include blended finance, loan guarantees and revenue guarantees to reduce risks and/or to boost returns. Additional strategies include publicly funding feasibility studies, and regulatory tools such as mandated customer connections. Securing anchor customers can stabilize cash flow, while leveraging existing assets can improve project viability. If derisking is insufficient, concessional finance may relax return requirements but still necessitate regulatory oversight. If public support is provided, it should follow the principle of transformative impact, to channel scarce financial resources where they achieve the highest impact.

ALWAYS RELEVANT: POLICY AND REGULATORY CERTAINTY

Derisking and stable investment conditions are intertwined and regulatory and policy clarity is crucial. Stable policies must prioritize widespread deployment of DH to avoid reliance on market forces or election cycles, e.g. through robust heating plans under the EU's Energy Efficiency Directive. Also, aligning regulations to avoid mixed signals (in e.g., balancing profitability, affordability and security of supply – and in EU directives), and carefully implementing price regulation. A level playing field should be created between technologies, such as DH and heat pumps, e.g. by taxing externalities.

SUSTAINABLE FINANCE AS A DRIVER, NOT A BARRIER

Meeting sustainability thresholds for incremental decarbonization can be challenging, even when efforts are substantial. Finance can achieve high impact by funding low-carbon assets replacing less sustainable technologies. Regulatory improvements should recognize decarbonization progress across all portfolios and simplify compliance for small DH companies with limited staff. If regulatory frameworks provide proper incentives for involved stakeholders, financial resources can be re-channelled from unsustainable to sustainable assets via financial markets, where financial institutions organize the process. Against the background of high public debt and deficits, mobilising private capital is pivotal.

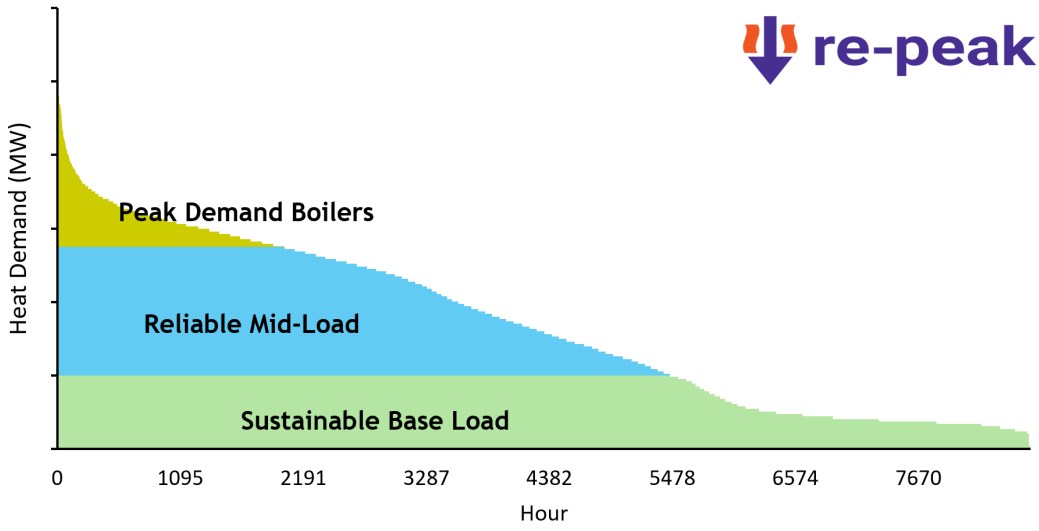
CUSTOMERS = CASHFLOW, SO ACCEPTANCE IS KEY

DH tends to benefit from economies of scale as a growing customer base reduces costs and boosts cash flow. However, end-user acceptance is critical and can be hindered by distrust, resistance to home modifications, and scepticism from intermediaries like housebuilders – or simply lacking competitiveness. Strengthening the customer base requires raising awareness about DH's benefits, competent regulation and customer protection, while incentivizing the construction sector through education and regulations. Historically, these measures and DH's cost savings have driven moderate adoption, while higher uptake may require zoning and mandated connections – if prices remain competitive. Balancing customer and societal benefits, such as affordability, with financial returns is key, as lower required returns – and thereby heat prices – can expand DH adoption, justified by its long-term, stable investment profile.

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SUMMARY FOR NON-TECHNICAL AUDIENCES

RE-PEAK – HOW TO COVER PEAK HEAT LOADS IN DHC NETWORKS WITH RENEWABLES?



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Sorted district heating demand curve, own illustration by Tallin University of Technology

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ABOUT THE INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) is an intergovernmental organisation that serves as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-1974, the IEA was initially established to coordinate measures in times of oil supply emergencies.

As energy markets have changed, so has the IEA. Its mandate has broadened to incorporate the “Three E’s” of balanced energy policy making: energy security, economic development and environmental protection. Current work focuses on climate change policies, market reform, energy technology collaboration and outreach to the rest of the world, especially major consumers and producers of energy like China, India, Russia and the OPEC countries.

With a staff of nearly 200 who are mainly energy experts and statisticians from its 28 member countries, the IEA conducts a broad program of energy research, data compilation, publications and public dissemination of the latest energy policy analysis and recommendations on good practices.

ABOUT IEA DHC

The Technology Collaboration Programme on District Heating and Cooling was founded in 1983. It organizes and funds international research which deals with the design, performance, operation and deployment of district heating and cooling systems. The initiative is dedicated to helping to make district heating and cooling and combined heat and power effective tools for energy conservation and the reduction of environmental impacts caused by supplying heating and cooling.

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INTRODUCTION

District heating (DH) networks remain heavily dependent on fossil fuels, despite the growing momentum of renewable energy sources. At present, numerous DH networks have incorporated renewable or low-CO_2 alternatives, including geothermal and solar thermal energy, biomass, heat pumps, waste heat, and waste incineration for heat generation. These heat supply systems, often characterized by fixed-cost intensity, typically require a specific number of full-load hours to be economically viable, primarily fulfilling the base load demand. However, a predominant challenge in most DH networks lies in addressing the peak heat load for achieving complete CO_2-neutrality. Currently, peak heat load plants predominantly operate using fossil gas or oil boilers. Therefore, RE-PEAK investigates how peak heat loads in DH systems can be met through non-fossil energy sources.

PROJECT BACKGROUND AND OVERVIEW

The project was funded by IEA-DHC within the IEA-DHC Annex XIV call for proposals. The project duration was November 2023 to April 2025. The project partners are summarized in the following table.

Table 1: Project partners and main authors and contributors.

ENERGIE INSTITUT an der Johannes Kepler Universität Linz	**Energieinstitut an der Johannes Kepler Universität Linz (lead partner)** Simon Moser, Magdalena Pflügl, Robert Müllehner, Melanie Knöbl, Gabriela Jauschnik
TAL TECH	**Tallinn University of Technology** Anna Volkova, Hesham Ali, Aleksandr Hlebnikov, Janita Andrijevskaja
Euroheat & Power | DHC+	**Euroheat & Power** Evan Bernardi, Victoria Lienard, Chiara Cecchin, Laura Junasová

METHODS

The project addressed three central topics: First, a definition and taxonomy for peak heat demand was developed; second, scenario analysis and a techno-economic assessment were conducted. Furthermore, a comprehensive survey of district heating operators and experts was conducted.

To offer an overview of the current understanding of the term peak heat load, both a scoping review and systematic literature research were conducted. Both approaches overlap but differ in detail: The systematic literature review follows a predefined protocol to comprehensively and reproducibly identify relevant sources. In contrast, the traditional literature review is less standardized. The results of both approaches are analysed, and the characteristics of the term are extracted, which are divided into criteria and influencing factors. On this basis, the taxonomy is developed, which hierarchically structures the identified criteria and influencing factors and enables a systematic classification of peak heat demand. This taxonomy forms the basis for further research and is interactively accessible in the Kumu tool. The resulting subsection covers the various definitions of peak heat demand, classification criteria, types of peak heat demand, as well as influencing factors and technologies for peak load reduction, which are considered a separate category within the taxonomy.

To assess how different generation units and technologies can handle peak heat loads in different district heating networks, the networks were categorized by size and operating temperature (i.e. the four categories are large-scale, high-temperature; large-scale, low-temperature; small-scale, high-temperature; small-scale, low-temperature. These categories allow for a targeted analysis of suitable generation units and technologies for each network type. For each category, heating load profiles were created based on monitoring data, taking into account building load, flow temperature, and heat losses. In three scenarios (10%, 20%, and 40% of total capacity), different technologies (gas boilers, electric boilers, heat pumps, and biomass boilers) were evaluated for their suitability for peak load management. The technical analysis included an assessment of energy efficiency, primary energy savings, and CO_2 emission reduction compared to gas boilers. These factors helped identify the best-performing technologies for each network.

The most promising technologies for CO_2-neutral peak heat demand coverage were economically compared. The Levelized Cost of Heat (LCoH) method was chosen because it allows for direct comparability. The LCoH method calculates heat generation costs taking into account the low full-load hours during peak heat demand. Five technologies were examined: gas boilers, electric boilers, biomass boilers, heat pumps, and seasonal thermal storage. Literature values were used for seasonal thermal storage. Fuel costs came primarily from EU sources; Austrian values were used where data were missing. Two grid sizes were considered: a 10 MW peak load unit for small networks and a 100 MW one for larger networks. The peak

load duration was estimated at 50 to 1,000 hours per year, oriented on the survey conducted as part of the project.

The survey was conducted based on an existing questionnaire from a preliminary Austrian study and adapted for the current research. Experts from Estonia and Austria as well as the project team supported the optimization of the questionnaire. The target group consisted of international DH operators and DH experts, whose experiences provided insights into peak load coverage. The survey, which was conducted online in 2024, included closed and open-ended questions. The survey was promoted over four months through direct contact, newsletters, social media, and mailing lists, including the project partners contacts and Euroheat & Power dissemination; moreover, IEA-DHC secretariat and experts supported the dissemination. 163 responses were collected, of which 153 were valid after data cleanng – 70 from DH operators and 83 from DH experts. The results were analyzed separately for DH operators and DH experts, comparing similarities and differences regarding peak load definitions, their causes, and supply methods.

DEFINITION AND TAXONOMY OF PEAK HEAT LOAD

The research on peak loads in district heating networks analyses the current challenges and hurdles for a low-CO_2 heat supply. The literature review provides a sound understanding of the definitions, characteristics, and complexities of peak loads, also in comparison to heat, electricity, and buildings. By examining various definitions and approaches, a solid foundation for future research and strategy development is established. The development of a taxonomy for peak loads, based on defined criteria and influencing factors, provides a systematic framework for further analysis and innovation in demand management. This taxonomy promotes communication between stakeholders and lays the foundation for creative solutions and strategic developments. However, the multitude of criteria, such as network size and consumption pattern, makes standardization difficult, and the dynamic nature of peak loads requires continuous adaptation.

Various approaches to defining peak loads, including textual, graphical, and mathematical, were presented. Despite the detailed investigation and development of the taxonomy, the topic requires further research. A future focus will be on the impacts of climate change on peak loads, particularly due to extreme outdoor temperatures, as well as the necessary adaptations for efficient and sustainable district heating networks. The influence of changing consumption patterns, such as the increased use of electric heat pumps or the integration of local and central heat storage, is also unclear. Furthermore, the integration of alternative renewable energies, such as green hydrogen or renewable electricity, plays a key role in the future balancing of supply and demand in climate-friendly district heating systems.

TECHNO-ECONOMIC OPTIONS FOR CO2-NEUTRAL PEAK HEAT LOAD SUPPLY

In this study, three renewable technologies—electric boilers, heat pumps, and biomass boilers—were evaluated for their ability to cover peak loads in twelve DH network scenarios, compared to traditional gas boilers. Efficient peak load generation is critical due to the limited operational hours and significant environmental impact, including high emissions, which challenge CO_2-neutrality goals.

The analysis considered primary energy consumption, CO_2 emissions, and the levelized cost of heat (LCoH) for each technology. In large-scale DH networks, heat pumps consistently showed the lowest primary energy consumption, outperforming electric and biomass boilers. Biomass boilers, however, showed the lowest CO_2 emissions in many scenarios, followed by heat pumps. Despite the energy efficiency of heat pumps, factors such as higher capital costs and operational limitations, especially in low-capacity or low-temperature networks, must be considered. Additionally, demand-side management or thermal energy storage could offer alternative solutions to address peak load challenges. The analysis also highlights the importance of the electricity mix in determining the environmental benefits of heat pumps and electric boilers, with cleaner grids improving their performance. Finally, while biomass is considered a renewable option, its emissions depend on sourcing, transport, and combustion processes.

The following overview identifies the key cost drivers and potential for cost reductions based on the results of the technical feasibility study. Biomass (wood chips and wood pellets) has high investment and fixed costs, but low fuel costs. They are less suitable for short peak heat loads because the LCoH (Levelized Cost of Heat) only decreases with higher full load hours. Similarly, heat pumps have high initial costs and still high costs for electricity, making them expensive for shorter peak heat load use. Electric boilers, on the other hand, have low investment costs, but higher electricity costs. They are well suited for short peak heat loads. Gas boilers powered by green hydrogen have higher investment costs than electric boilers but are cheaper than biomass plants. Fuel costs are highest when green hydrogen is used.

PEAK HEAT LOAD SURVEY

The sample of 70 DH networks covers a broad range of networks, from 600 MWh/year to 6,000 GWh/year. 67 networks state to supply 90 % or more of the heat for space heating and hot water. The average ratio of summer to winter demand is around 10%. The survey confirms that peak loads are mainly covered by fossil fuels, even in networks with a significant share supplied by low-CO_2 units. Half of the respondents have a strategy for net-zero heat supply, and heaving a strategy is not correlated with the network size.

Peak heat loads appear in two variants, where one is short-term peaks e.g. in the morning and in the evening, the other are longer-term peaks e.g. during cold spells. Some define peak heat loads as exceeding a certain threshold, other refer to the actual peaks in a period. These situation-dependent responses leave the definition of peak heat loads being ambiguous. In the survey, excluding outliers, the range of peak heat loads has an annual duration from 50 to 1,250 hours. The median peak heat load duration is around 200 hours annually, with a mean of 350 hours (n = 52).

The chosen or expected low-CO_2 options are heterogeneous. Thermal energy storage is the most often chosen option but electric, green gas, biomass and green oil boiler technologies as well as heat pumps follow closely. Even more relevant, DH operators predominantly choose a combination of units. High investment costs are the most significant barrier for the transition.

While, in their expectations and future choices, DH operators rely on proven technologies existing today, DH experts repeatedly refer to the potentially more cost-effective options associated with demand-side management. In general, hydrogen and carbon capture technologies are hardly mentioned.

CONCLUSION

Research on peak heat loads in district heating networks analyses current challenges and barriers to a low-CO_2 heat supply. A literature review provides a comprehensive understanding of the definitions and complexities of peak heat loads. A developed taxonomy enables systematic analysis, but the diversity of criteria makes standardization difficult.

Approximately half of district heating providers have plans to decarbonize their networks, mostly based on existing and proven technologies. New technologies such as hydrogen or carbon capture are rarely considered. Technologies are evaluated based on criteria such as rapid start-up capacity and cost. Thermal energy storage (meaning: short-term buffers) and demand response are preferred solutions for peak heat loads, almost exclusively in combination with other energy sources. Combining different systems is considered advantageous in order to efficiently address “lower” and “upper” peak heat loads.

As part of the project, a SWOT-like matrix was created to serve as a decision-making aid and summarizes the analysis of technologies for covering peak loads. It considers both technical and economic factors and survey results. Key technologies include green gas and hydrogen boilers and CHPs, biomass boilers and CHPs, e-fuels or biofuel boilers and CHPs, renewable electric boilers and heat pumps, and thermal energy storage.

Other technologies not included in the matrix are relevant in specific cases. For example, grid preheating reduces short-term peaks but is not suitable for longer cold periods. Demand response is cost-effective but offers less control.

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SUMMARY FOR NON-TECHNICAL AUDIENCES

FLEXIBILITY AND DISTRICT HEATING VALUE CHAIN

ADVANCED ANALYSIS & COMPATIBLE PRICING

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1 INTRODUCTION

The global heating sector is still based mainly on fossil fuels, and mitigating the natural gas dependency within the European heating sector has become a priority. district heating (DH) with its broad selection of low-carbon heat supply options, and building-specific heat pumps are the main solutions for the heating sector along the pathway towards clean and resilient energy systems. DH systems can also help in providing flexibility for the decarbonizing power system with increasing shares of variable renewable energy (VRE). This creates a fertile environment for electrification, but also requires flexibility from the systems. In fact, a flexible implementation of DH can boost its economic performance.

The project *Flexibility and district heating value chain – advanced analysis & compatible pricing (FlexVal)*, set out to investigate the impacts of measures that increase flexibility of DH systems such as thermal energy storages (TES), demand response (DR), flexible heat supply by heat pumps (HPs), excess heat (EH) recovery or combined heat and power (CHP). Also, DH network control strategies and topology design point of views are considered. The project in general emphasises a bottom-up perspective, and the impact of improving the demand side, i.e. building heat distribution, part of planning of low-carbon DH. This is an improvement to the traditional top-down approach where the feasibility of planning decarbonisation of DH is only considered from the heat supply perspective (Figure 1**)**.

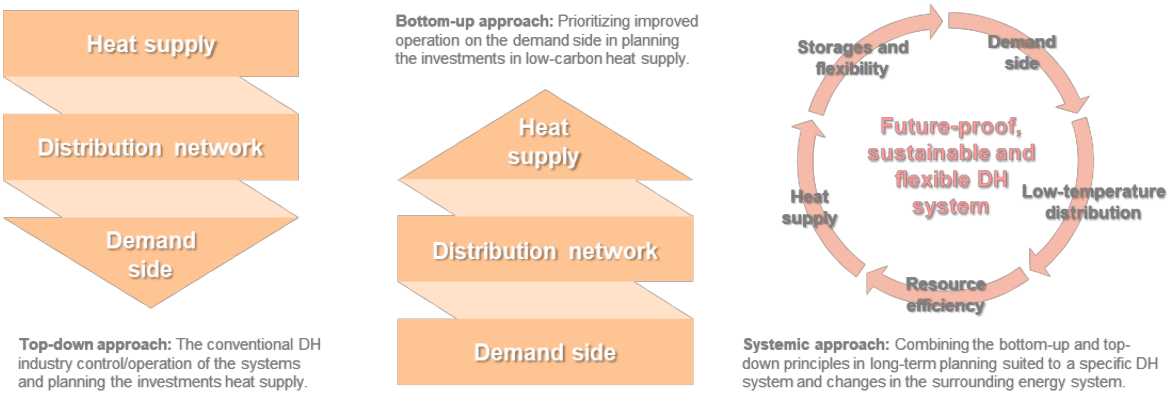


Figure 1: Summarising the top-down, bottom-up and systemic approaches describing the scope of work within the FlexVal project.

The research was carried out by four organisations, VTT Technical Research Centre of Finland in a lead role and looking into operational flexibility of DH within the Nordic energy system 2030, IVL Swedish Environmental Research Institute focusing on potential of district heating flexibility options in a long-term perspective, DTU Technical University of Denmark and the Civil Engineering Department studying future-proof design and operation of demand side components and the Flemish Institute for Technological Research VITO working on Flexibility from network design including operational aspects

2 LONG-TERM PERSPECTIVE ON THE HEAT ENERGY MIX INCLUDING FLEXIBILITY

The TIMES modelling framework [1] can be used to optimize energy systems over a mid to long-term horizon. The model is driven by exogenously defined demands for energy services and is based on a perfect-foresight, linear programming, bottom-up approach, where the objective function is the minimization of the total system cost. The energy system in question is represented by different processes that are connected by flows of commodities.

In this study, TIMES Gotland model is used to investigate the development of local district heating systems, considering the impact of the surrounding energy system. The objective function is cost minimisation. To represent the energy supply and demands in more detail in the model, the island is divided into six regions; HEM (Hemse), KLN (Klintehamn), LGN (Ljugarn), ROM (Roma), SLT (Slite) and VIS (Visby). Each region, in turn, is further divided into two or three areas (sub-regions), representing DH area (A1), next-to-DH area (A2) and rural (heat-sparse) area (A3). The model time horizon covers the period between 2020 (the base year) and 2050. Residential, commercial and industrial energy demand is considered as well as transportation demand, and fertilizer demand of the agricultural sector. A more detailed description of the model structure and input assumptions is provided in the full final report.

Investigated scenarios are Gotland 1) with (OS) or 2) without (NOS) additional offshore wind. Sensitivity cases for a both scenarios consider a capacity fee (DH_tariff), introduction of low-temperature DH (LTDH) and low-temperature DH with a bonus for improved cooling (LTDH_Tariff_Bonus).

The first very visible result is the impact of the surrounding energy system on the development of the DH systems. The overall outlook on heat supply in the OS and NOS scenarios vary greatly as visualised in Figure 2.

Other notable difference between scenarios and cases is the impact of capacity fee and introduction of low-temperature distribution. In both scenarios, the introduction of capacity fee reduces the demand for DH considerably. Low-temperature distribution clearly strengthens the future potential of DH, and also creates an incentive for electrification of the heat supply especially by HPs.

Concerning the TES, they are predominantly used significantly more in the future than during the reference year 2020. An increase of ~400-700% in discharged heat is observed in all scenarios and cases where DH still has a meaningful share in total heat supply, i.e. excluding the OS scenarios and cases with both the capacity fee and the low-temperature tariff bonus. The expected increase is pronounced especially during 2040 and 2055.

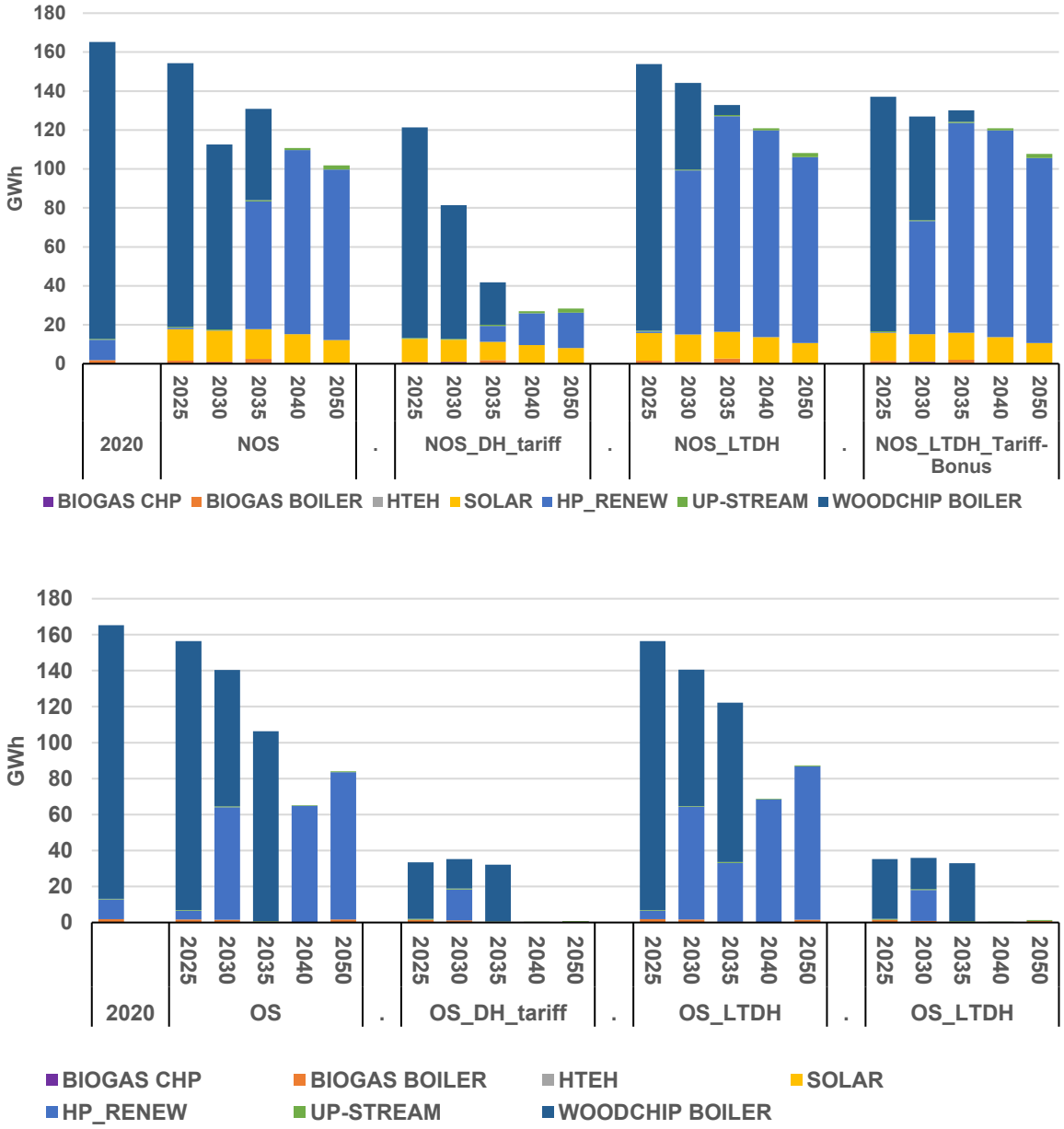
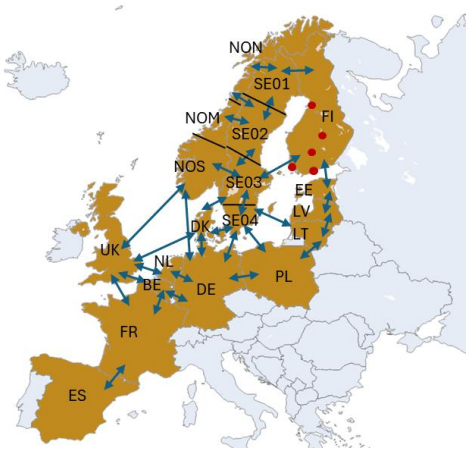


Figure 2: DH production in the NOS (top) and OS (bottom) scenarios. Abbreviations: High-temperature excess heat (HTEH), Sea water (RENEW), Heat pump (HP)

While the study presents a very specific case located in an island and that is potentially experiencing a remarkable change in local electricity production capacity, the results still highlight the importance of looking into the future developments within the surrounding energy system when evaluating decarbonization pathways for DH systems. Also, the impact of steering mechanisms is very visible providing food-for-thought on concreate measures for the DH operators.

3 OPERATIONAL FLEXIBILITY IN NORDIC DISTRICT HEATING SYSTEMS 2030

Here, the focus is on the potential of DH flexibility measures including demand response (DR), thermal energy storages (TES) and flexible heat supply, and assessing their systemic impacts on 1) Northern Europe energy system (right) and 2) specific DH system levels. The work is based on utilising the Backbone energy system modelling framework. The modelling approach considers the impact of different weather years as one of the sensitivity factors addressed. The overall aim is to provide a realistic representation of the changes the current operational environment.



As a starting point, insights from the industry were collected by targeted interviews. The discussions concluded that flexibility is becoming an essential feature of district heating systems, but no single solution stands out universally, as the most suitable measures depend on the local system and national context. While TES and DR are seen as promising and, in many cases, already implemented technologies, their wider deployment is still limited by challenges related to economic viability, scaling, regulation, and practical adaptation. The discussion also highlighted the growing importance of data, digital tools, and smart controls for improving system operation and enabling flexibility, although data access and integration remain obstacles. In addition, national market structures, taxation, and pricing models strongly influence what kinds of flexibility investments are feasible, and customer engagement is crucial, since the value and benefits of flexibility need to be clearly communicated.

Energy system level modelling (Northern Europe Backbone [2] model) showed that flexibility within DH systems supports the efficient operation of the wider energy system [3], but the benefits of additional TES and DR-based flexibility in the studied scale are modest and, more importantly, do not consider district heating operators' perspective as the modelled area is treated as if operated by a single stakeholder. This represents a need for a system-specific analysis. The overall finding on changes in DH supply presented in Figure 3 is that additional flexibility shifts biomass consumption from HOBs to CHP units and use EBs and HPs increases. The results also show the significant impact of the chosen weather year, emphasising the value of extensive model-based evaluation in e.g. feasibility assessments.

The system specific modelling task is carried out for a case system of Kuopio [4], a medium-sized city in Finland with ~125 000 inhabitants and an extensive city-wide DH system (1 TWh).

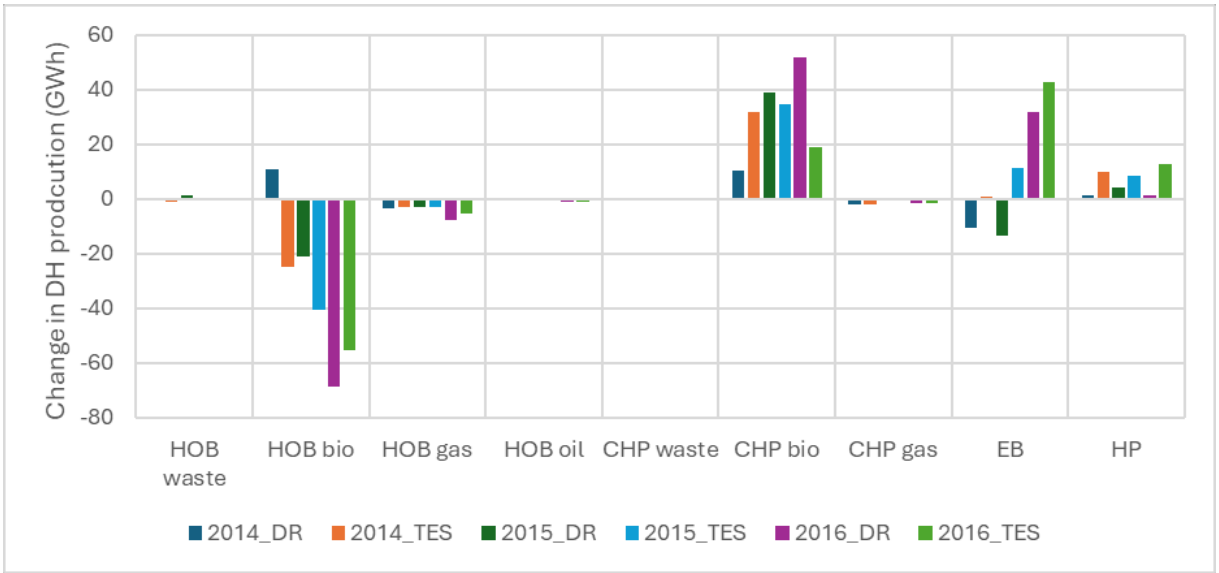


Figure 3: Changes in DH production (DR and TES vs. the reference scenario).

The scenarios were that there is 1) no TES or DR in the system (noTES), 2) TES is included (TES), 3) DR is included and 4) both DR and TES are included. Three climate and respective historical electricity price years (2022, 2023, 2024) were considered. The results show benefits of additional flexibility, but also (as in the energy system level investigation) that the operational environment can have a huge impact on the e.g. operational costs as depicted in Figure 4.

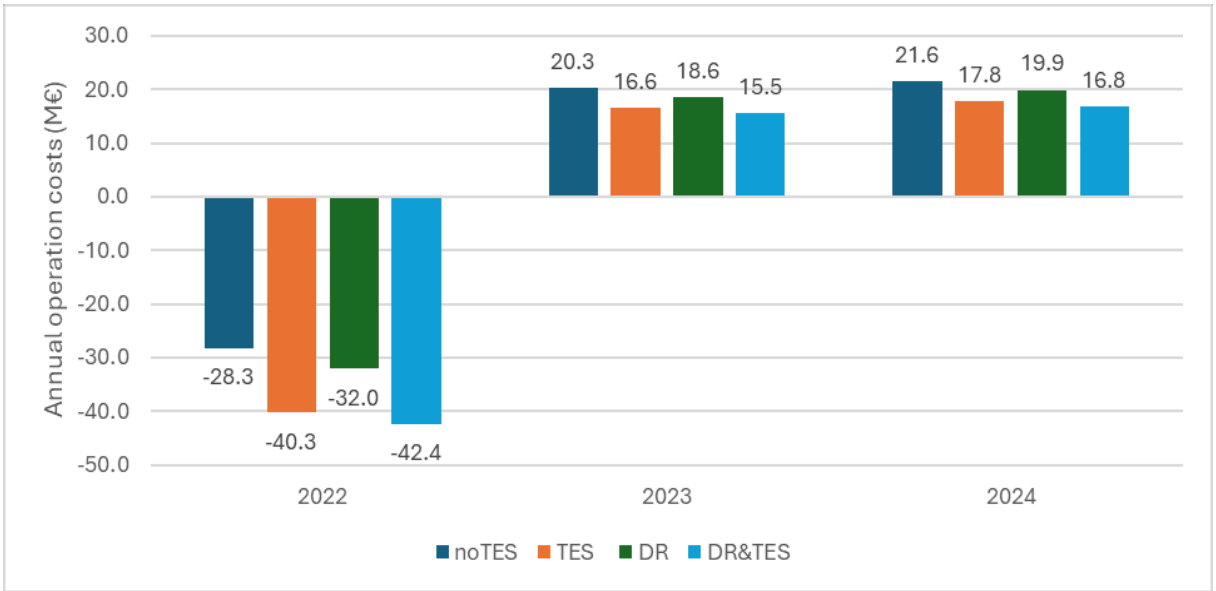


Figure 4: Total operational costs in each scenario and operational year.

As a conclusion, flexibility measures clearly improve the cost efficiency of DH systems, but the impact can be outweighed by changes in operational environment. However, ensuring a versatile heat supply portfolio (emphasising EBs, HPs and flexible CHP units) and improving flexibility by additional TES and DR capacity increases the robustness of the system.

4 FUTURE-PROOF DESIGN AND OPERATION OF BUILDINGS CONNECTED TO DISTRICT HEATING

This section aims to present the results of improving design, control and operation of space heating (SH) and domestic hot water (DHW) systems in buildings connected to DH networks. The objective was to document how low temperatures are already possible for the existing building stock and reflect on how this work relates to business models. The focus is on residential multi-apartment buildings with little or no renovation, and that have radiators as the heat distribution solution.

Viborg (Denmark) DH system and the local utility acts as a case example, and the location of the measurement activities and experimental work. Viborg has targeted low-temperature distribution as it is seen as a bottleneck for decarbonization by HP, EB and biogas boiler-based future heat supply when phasing out natural gas as the current, main heat supply option. Viborg has also introduced motivation tariffs (discount/penalty for the energy price) rewarding consumers that have efficient cooling and can cope with low supply temperatures.

One of the main results of the work is a methodology [5] for using heat cost allocator and energy meter data to improve the low-temperature operation within a building heating system. Based on this methodology, Figure 5 shows the evolution and impacts of gradually improved supply temperature curve-based control for single multi-apartment building while maintaining (more than) adequate comfort in terms of indoor temperature.

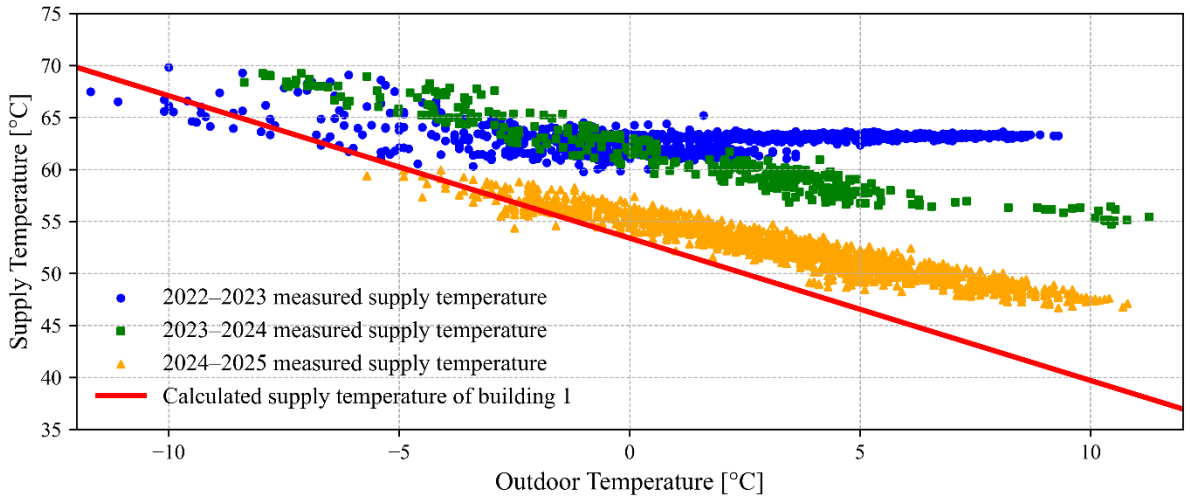


Figure 5: Calculated minimum supply temperature curve based on data from the 2021-2022 heating season compared with measured substation supply temperatures over heating seasons [6]

In addition to heat distribution systems in buildings, domestic hot water (DHW) supply remains one of the issues that can require or result in high DH temperature levels. A cascading DHW substation utilising aftercooling concept and a substation with a booster HP to offset circulation heat losses were studied. The analysis and field measurements, focusing on buildings equipped with radiator heating systems, confirmed substantial reductions in return temperature in the range of 3.0–5.8 °C and 5.4–6.7 °C for the aftercooling design under 3GDH and 4GDH conditions, respectively. For the DHW substation equipped with a booster heat pump, an average return temperature of approximately 27.9 °C was documented. While technically attractive, the additional investment costs and electricity consumption mean that this configuration should primarily target large buildings that currently act as bottlenecks for reducing network temperatures.

The economic assessment indicate that benefits of lowering operating temperatures depend on the market context. For space heating systems, motivation tariffs can effectively reward good performance and support sustained low-temperature operation. Nonetheless, the analysis also highlights clear challenges. Incentives (or penalties) are often distributed equally among tenants regardless of individual behaviour, and the link between user operation of radiators and elevated return temperatures is not always transparent to end-users. Also, building owners in rented properties may have limited interest in investing in system optimization if the bonuses are distributed to the tenants. These aspects can be clearly revealed through the current level of digitalization but require further discussion and regulatory adaptation due to their significant technical and economic impact.

The cost analysis of the DHW substation show (Figure 6) that traditional user-owned models often do not provide sufficient incentives for investment, whereas company-owned models allow district heating operators to capture system-level benefits more effectively, making the deployment of advanced DHW substations more economically viable – particularly in those critical buildings where temperature reductions create the greatest value.

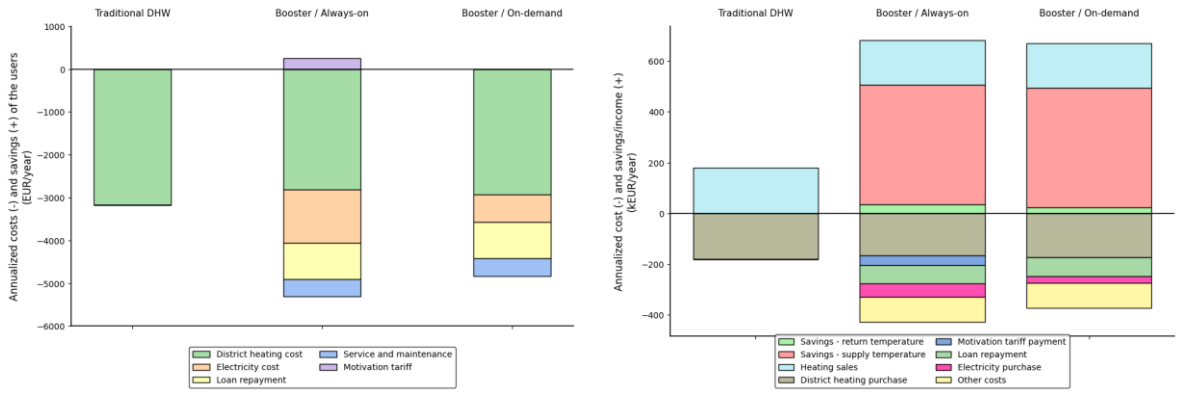


Figure 6: Comparison between annualized costs and savings/income for end-users' ownership (left) and company ownership (right) business models for booster HP substations.

5 FLEXIBILITY FROM NETWORK DESIGN INCLUDING OPERATIONAL ASPECTS

An important although often overlooked contribution to flexibility of systems is the way a network is designed. Operational aspects are crucial for the day-to-day efficiency and interactions, but the impact is also influenced by the optimality of the design. Traditional methods rely heavily on established guidelines and are primarily driven towards so-called peak based conditions: a network must guarantee energy supply under worst case conditions and is dimensioned accordingly, often including extra redundancy. This redundancy can be exploited to provide flexibility. However, this comes with a hidden surplus capital investments and operational losses, and ultimately an impact on feasibility. It is the aim of this chapter to investigate how an optimal design of networks can be influenced, when a priori smart control strategies are considered, i.e. designing the network specifically for the modus operandi.

VITO has been developing the frameworks of STORM and PathOpt for the past years. STORM represents a district energy controller [7], optimising the operation of the buildings, districts and the network by peak shaving, interaction with the electricity market and network balancing, and PathOpt, a topology design toolbox for optimisation of network topologies [8] considering specific geographic conditions. In this work [9], [10], both frameworks' principles are combined.

A fictive case in the Belgian city of Menen was created to investigate the impact of peak shaving on the optimal design of a network. Even though large-scale uptake of DH in Belgium is rare, potential is there. In the case of Menen, this holds true as a historic city centre with typical entangled street pattern and high building density has a water treatment facility representing a heat source. Area and the selected case study zone, is shown in Figure 7.

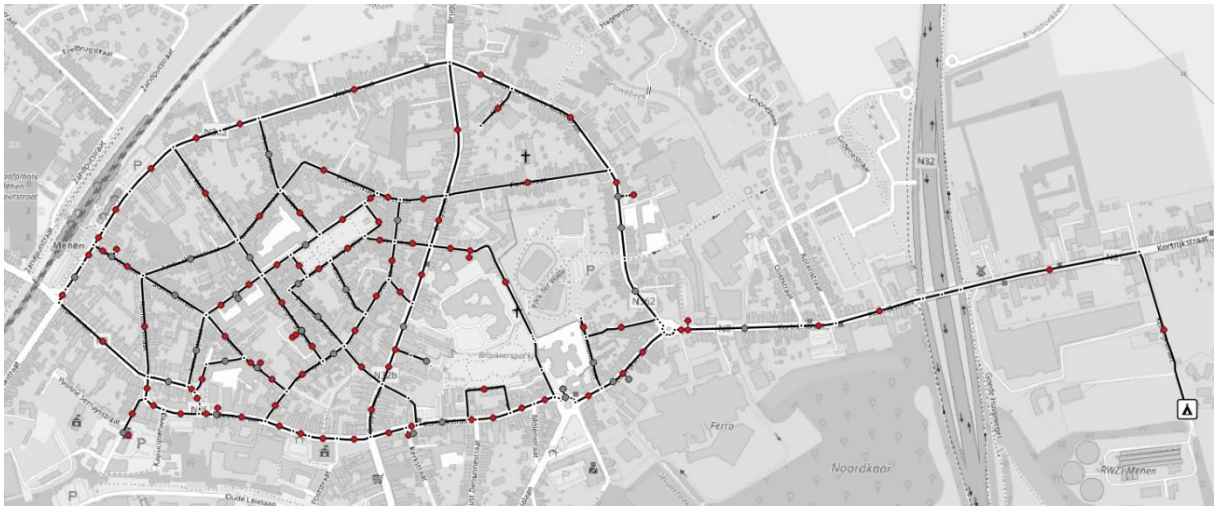


Figure 7: Case study project zone. Menen, a historical city centre near a wastewater treatment facility eastward of the city.

A total of three scenarios were studied: scenario with original demands and the corresponding network topology and sizing, scenario 1 with all consumers with a targeted 20 % peak demand reduction and finally, a scenario 2 with 5 largest consumers with a 30 % peak demand reduction. In all cases, the network topology, pipe sizing, production capacity and total cost of ownership were optimised over a long lifetime.

Figure 8 represents the network topology for scenario 2 with the 5 largest consumers identified. This optimised topology can be compared to Figure 7 and its potential pipeline routes.

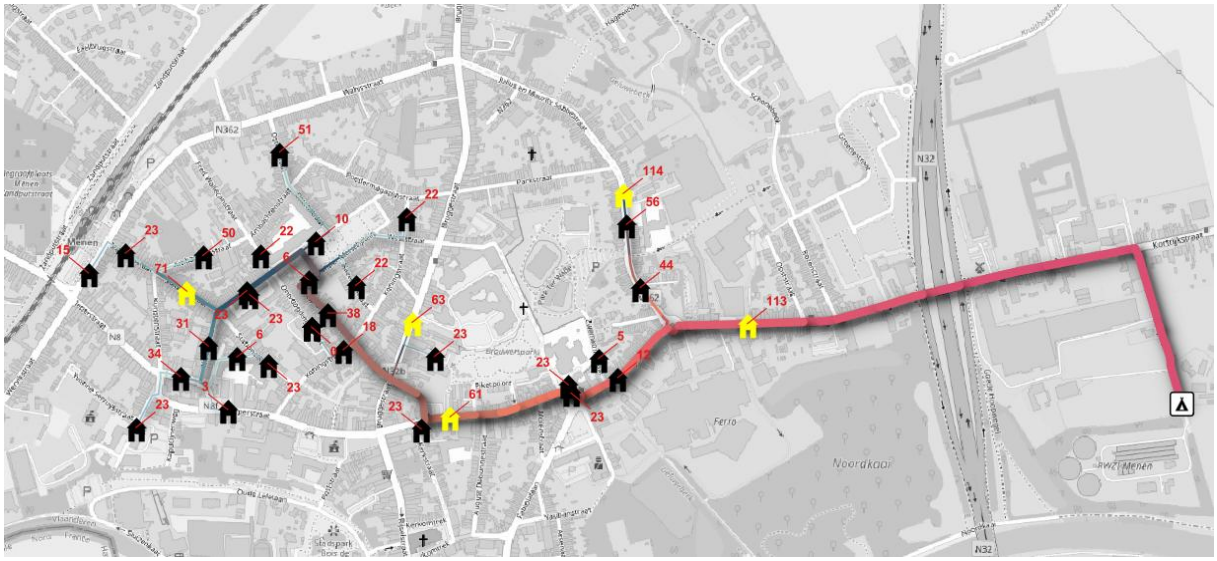


Figure 8: Optimal network topology for a scenario where the 5 largest consumers are intelligently controlled and have their peak power reduced by 30%.

The total cost of ownership (TCO) for scenarios with demand reduction were 10% and 4.6% lower than without the demand reduction. The impact on capital investments for the network was negligible.

The study showed the relevance of the network design phase for the operation of the system in order to avoid compensating for rigid designs later through operation. The main results showed that including operational flexibility assumptions in the design phase can reduce overdimensioning. When peak demand is lowered through control, required pipe diameters and peak production capacity decrease, and the total system costs can be reduced. However, the results also revealed a trade-off: although total cost of ownership and capital expenditure may decrease, the resulting cost per delivered megawatt-hour can increase, especially in low-density networks where heat losses become more dominant. Thus, designs optimised for flexibility are not automatically optimal in terms of unit heat cost.

Another key finding was that targeted flexibility (on smaller number of large consumers) is often more effective than uniform control (across all connected buildings). Overall, it can be said that flexibility from network design is real and significant, but highly context-specific.

6 JOINT ANALYSIS AND OVERALL CONCLUSIONS

Study on **long-term perspective on flexibility** showed that flexibility measures significantly influenced the long-term, cost-optimal development of district heating systems. Their effectiveness depended heavily on the broader energy system. Pricing mechanisms for DH also strongly shaped system operation and the results.

As a summary, flexibility-oriented investments and tariff reforms had been crucial for decarbonised, cost-efficient district heating, but their design needed to be tailored to local conditions currently and what is expected of the future making long-term perspective a relevant task.

Work on **Operational flexibility in Nordic DH systems** assessed district heating as a source of flexibility from both energy system and operator perspectives. District heating played a role in balancing fluctuating electricity production from renewables, although in the scale studied (capacities for TES and DR) the overall impact on an energy system level was small.

Modelling in Northern Europe showed that extra demand response or storage improved system performance and lowered costs, but benefits of additional capacity diminished e.g. in Finland, where thermal storage capacity already exists. At the operator level, demand response and storage provided savings and improved system robustness.

As a conclusion, operational flexibility has become central to DH systems given the continuing growth of wind (and solar) power and has the potential to grow in importance.

Future-proof buildings connected to DH had the focus on the building level, arguing that buildings are a vital but often overlooked source of flexibility (directly and indirectly) and efficiency in DH. Many obstacles to low-temperature DH originate from operational inefficiencies and misaligned incentives rather than technical limitations.

Analysis of large apartment buildings pointed out faults such as poorly functioning radiators and inadequate control strategies that often result in higher supply temperatures. Digital tools and metering data can address these issues without major retrofits, highlighting the strong role of digitalisation for low-cost improvements. Advanced domestic hot water substation concepts using aftercooling and booster heat pumps can offer technical solutions for retrofitting.

Economic analyses found motivation tariffs encouraged better operation but were generally insufficient as incentives for major building level investments. Alternative business models, such as utility- or company-owned substations, can enable operators to gain benefits quicker or more likely.

In summary, future-proof district heating depends on building-level measures. Digital diagnostics, improved control, and innovative substations enabled low-temperature operation

and flexibility, but broad adoption requires incentives and ownership structures that are aligned with system-level benefits.

By employing the STORM energy controller and PathOpt optimisation tool, the study on **Flexibility from network design including operational aspects** showed that peak-based design resulted in oversized pipes and higher costs. Including smart strategies like peak-shaving reduced total cost of ownership.

Case studies revealed that while optimised design did not alter network routing much, it improved cost efficiency. However, lowering peaks could increase unit energy costs, highlighting the need for tailored optimisation rather "rule-based" solutions.

As conclusions, combining advanced control with design optimisation is especially valuable for new or expanding district heating systems. Building flexibility into infrastructure early avoids rigid designs and improved long-term performance.

As an overall conclusion for the entire project, four main learnings can be drawn:

1. Building-level actions are in key role
2. Flexibility is a systemic feature of DH coupled with the energy system
3. Solutions are strongly context-specific
4. Anticipating future development is crucial

Buildings play a central role in unlocking flexibility and efficiency across district heating systems. Lower return temperatures, improved controllability, and demand response at the building level are targeted. Improved control through digitalisalisation and technical solutions such as advanced substations, are available but extensive retrofits are not always needed.

Flexibility in district heating is based on operating a system and its assets in an optimal manner. The strong increase of variable renewable energy sources (wind, solar) and the electrification of DH heat supply have resulted in a situation where storages and flexibility are becoming very attractive. This also has implications for pricing (incentives for increasing e.g. building-level flexibility), and network design and its operation, i.e. towards low temperature levels.

The effectiveness of the measures depends strongly on local context, including electricity market conditions, taxation, regulatory frameworks, and the maturity of the district heating sector. There is also a mismatch between modelled system-level benefits and operator-level incentives. As a result, policy design, regulation, and taxation are important factors in determining whether flexibility solutions are adopted at scale.

The benefits of flexibility are maximised when it is considered early in design, rather than retrofitted later. Networks designed with operational flexibility in mind avoid over-dimensioning, and buildings prepared for low-temperature operation enable long-term efficiency gains at low additional cost. However, future-proof district heating requires both strategies.

ABBREVIATIONS

Abbreviation	Meaning
4GDH	Fourth Generation District Heating
AMB	Ambient air (heat source)
ASHP	Air Source Heat Pump
CHP	Combined Heat and Power
COP	Coefficient Of Performance
CO_2	Carbon dioxide
CTES	Cavern Thermal Energy Storage
DH	District Heating
DHC	District Heating and Cooling
DHN	District Heating Network
DHW	Domestic Hot Water
DR	Demand Response
EB	Electric Boiler
EED	Energy Efficiency Directive
EH	Excess Heat
ENTSO-E	European Network of Transmission System Operators for Electricity
EPBD	Energy Performance of Buildings Directive
FGC	Flue Gas Condenser
HCA	Heat Cost Allocator
HDh	Heating Degree hours
HEX	Heat Exchanger
HOB	Heat-Only Boiler
HP	Heat Pump
ICE	Internal Combustion Engine
IRR	Internal Rate of Return
LTDH	Low-Temperature District Heating
LFO	Light Fuel Oil

O&M	Operation and Maintenance
OPEX	Operational Expenditure
OS	Offshore wind scenario
PLR	Part-Load Ratio
PTES	Pit Thermal Energy Storage
Ref.	Reference scenario
SH	Space Heating
sTES	Seasonal Thermal Energy Storage
TES	Thermal Energy Storage
TTES	Tank Thermal Energy Storage
TCO	Total Cost of Ownership
TRV	Thermostatic Radiator Valve
VOM	Variable Operation and Maintenance
VRE	Variable Renewable Energy

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SUMMARY FOR NON-TECHNICAL AUDIENCES

HY2HEAT – USING ELECTROLYSIS WASTE HEAT IN DISTRICT HEATING NETWORKS

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2 Future Electrolysis capacities and waste heat utilisation in district heating 5
3 Technical integration concepts 6
4 Techno-economic assessment 7
5 Stakeholder perspective and recommendations 7
6 Conclusion 8

1 INTRODUCTION

The HY2HEAT project explores the potential of integrating electrolysis waste heat into district heating networks (DHNs) to enhance energy efficiency and support decarbonization. Electrolysis, a key hydrogen production process, generates substantial waste heat, which is often dissipated instead of being harnessed. This study assesses the technical feasibility, economic benefits, and policy considerations of utilizing electrolysis waste heat in DHNs.

Hydrogen is widely recognized as a crucial component of the future energy system, particularly as economies transition towards carbon neutrality. The production of green hydrogen via electrolysis plays a key role in decarbonizing various sectors, including industry, transport, and heating. However, electrolysis is an energy-intensive process that generates large amounts of heat, much of which remains unexploited. Capturing and utilizing this waste heat could provide an additional renewable energy source for district heating (DH).

DHNs offer a particularly promising opportunity for integrating electrolysis waste heat. DHNs are a well-established solution for urban heating, efficiently supplying heat to residential, commercial, and industrial consumers. By integrating electrolysis waste heat into these systems, excess thermal energy can be repurposed, thereby reducing the reliance on fossil fuel-based heating sources and improving the efficiency of the hydrogen production process. This integration would also support the development of a more sustainable and cost-effective energy system. An overview of the concept is shown in Figure 1.

The HY2HEAT project investigates the feasibility of such an approach by analysing the technical configurations required for effective waste heat recovery, the economic benefits of heat integration, and the regulatory and policy frameworks that could support implementation. A central aim of the project is to identify how electrolysis waste heat can complement existing DH sources while minimizing the need for additional infrastructure investments. Through a combination of modelling, case studies, and stakeholder engagement, the study evaluates practical solutions for waste heat utilization. By addressing these aspects, the study aims to

contribute to the broader goal of energy system decarbonization and increased energy efficiency. Understanding the role of electrolysis waste heat in DH will optimize hydrogen production while supporting the transition to a more sustainable energy landscape.

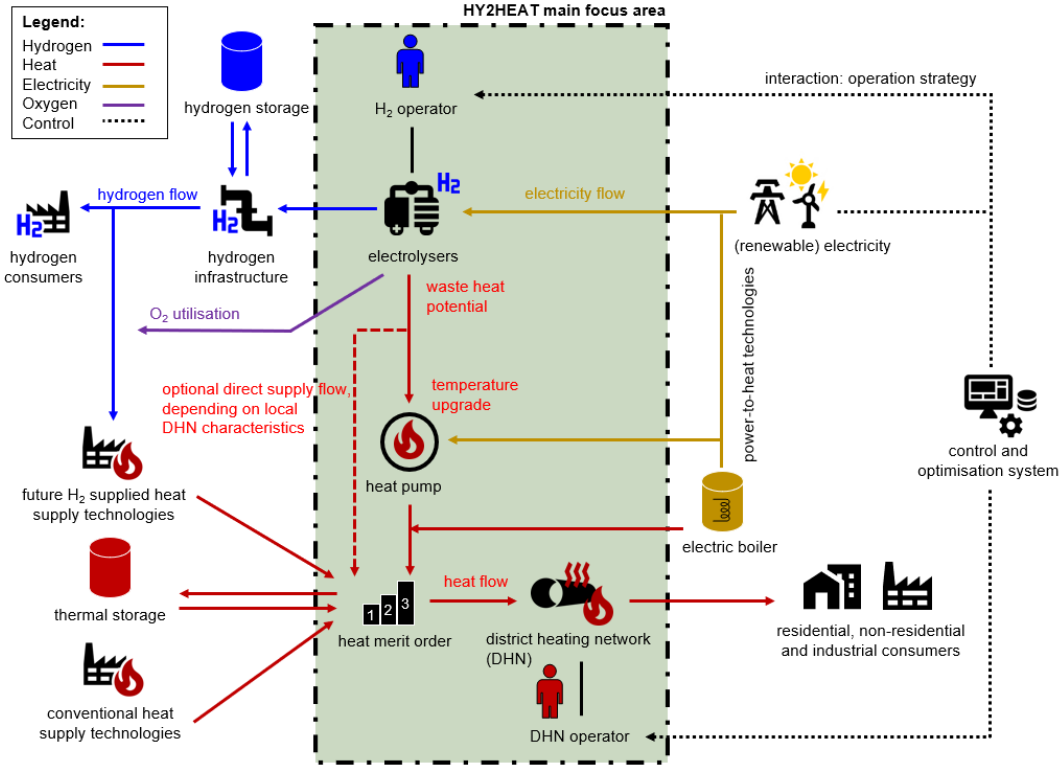


Figure 1: Graphical overview of HY2HEAT concept, its system boundaries, involved stakeholders, and potential components

2 FUTURE ELECTROLYSIS CAPACITIES AND WASTE HEAT UTILISATION IN DISTRICT HEATING

Electrolysis capacity is projected to expand substantially in the coming decades, driven by increasing hydrogen demand and decarbonization targets. European countries have outlined ambitious plans and roadmaps for hydrogen production, with the European Green Deal envisioning over 500 GW of electrolysis capacity by 2050. Aligning this expansion with DHNs requires strategic planning to ensure efficient waste heat utilization.

The potential for integrating electrolysis waste heat into DHNs depends on several factors, including waste heat temperature, operational stability, and spatial proximity to DH infrastructure. Alkaline Electrolysis (AEL) and Proton Exchange Membrane Electrolysis (PEM-EL) generate waste heat at temperatures of 50–80°C, making them suitable for modern low-temperature DHNs but requiring additional heat pumps for conventional DHNs with supply temperatures of up to 130°C. Fluctuations in electricity prices and the intermittent nature of renewable energy sources impact the stability of electrolysis operations, affecting the consistency of waste heat supply. Implementing thermal storage solutions and optimizing

hydrogen production schedules can improve integration with DH demand. Infrastructure investments and policy support are crucial in ensuring that waste heat recovery aligns with future electrolysis capacity growth.

Electrolysis capacity expansion and waste heat integration into DHNs vary based on national priorities, regulatory frameworks, and infrastructure. Some regions with well-developed DH and supportive policies can integrate waste heat more easily, while others prioritize hydrogen exports or industrial applications, making integration more complex. Factors such as grid stability, energy market regulations, and investment incentives further influence feasibility. Aligning expansion strategies with local conditions is essential for efficient implementation.

Strategic coordination between hydrogen production and DH sectors will maximize the benefits of electrolysis waste heat utilization. Infrastructure planning, financial mechanisms, and regulatory adjustments are essential to ensure that the growing electrolysis capacity contributes to a more sustainable and efficient energy system.

3 TECHNICAL INTEGRATION CONCEPTS

Integrating electrolysis waste heat into DHNs requires efficient technical solutions that ensure compatibility with existing infrastructure. Heat exchangers facilitate the direct transfer of heat from electrolysers to DHNs, minimizing energy losses. However, because waste heat temperatures are typically too low for direct use, heat upgrading is essential. Heat pumps play a crucial role by raising the waste heat temperature to a usable level, enabling its effective integration into DH.

Preheating strategies further enhance system performance. By using waste heat to elevate DHN return temperatures before final upgrading in the heat pump’s condenser, the system's coefficient of performance (COP) improves by up to 110%, and the required heat pump capacity decreases by up to 50%. However, this method is only viable when waste heat is at least 10°C above the DHN return temperature. By reducing additional energy input, preheating makes electrolysis waste heat integration more cost-effective.

Thermal energy storage solutions help balance fluctuations between waste heat availability and DH demand. Hydrogen production varies based on electricity market conditions and renewable energy availability, leading to inconsistent heat supply. Thermal energy storages mitigate these fluctuations, optimizing heat delivery. The feasibility of storage depends on hydrogen production schedules and the type of electrolyser used.

Strategic co-location of electrolysers near DHNs is crucial to minimize heat transport losses. Infrastructure investments in heat recovery technologies should be carefully planned to align with DH expansion. By optimizing system configurations, electrolysis waste heat can serve as a stable and sustainable component of DH, reducing reliance on fossil fuels.

4 TECHNO-ECONOMIC ASSESSMENT

The economic feasibility of integrating electrolysis waste heat into DHNs depends on multiple factors, including operational efficiency, infrastructure costs, and market conditions. A techno-economic assessment evaluates the financial viability of heat recovery from electrolysis and its potential impact on the levelized cost of heat (LCOH).

Reducing the LCOH is a major benefit of waste heat recovery. By utilizing waste heat from electrolysis, DH operators can reduce primary energy consumption, lowering heating costs by up to 23% based on the evaluated case studies. This reduction makes DH systems more competitive and supports the transition to low-carbon energy sources. Hydrogen producers also benefit from waste heat integration, as reduced cooling costs and potential sales of waste heat leads to operational cost savings.

Despite these benefits, integrating electrolysis waste heat may require significant infrastructure investment. The installation of heat exchangers, heat pumps, and, if necessary, thermal storage solutions involve upfront capital expenditures that must be balanced against long-term savings. The economic feasibility depends on the scale of integration, the efficiency of heat recovery technologies, and the stability of waste heat supply.

Market mechanisms and policy incentives play a critical role in ensuring financial viability. Regulatory support, in the form of subsidies, tax incentives, or heat purchase agreements, can encourage investment in waste heat recovery. Transparent pricing structures for waste heat transactions between hydrogen producers and DH operators are necessary to establish a fair and predictable economic framework.

Long-term cost reductions and operational savings can justify initial investments, making waste heat recovery an attractive option for both the hydrogen and DH sectors. Strategic planning, technological advancements, and regulatory support will be essential in maximizing the economic benefits of electrolysis waste heat utilization.

5 STAKEHOLDER PERSPECTIVE AND RECOMMENDATIONS

The perspectives of key stakeholders, including DH operators, hydrogen producers, and policymakers, highlight various factors that either drive or hinder the integration of electrolyser waste heat into DHNs. The results from a survey with 70 responses underscore the recognition of potential benefits and motivations for this integration, such as sustainability improvements, decarbonization goals, contributions to a circular economy and in some cases economic advantages. However, several challenges have been identified. These include the need for additional infrastructure and high investment costs, proximity constraints between

electrolysers and DHNs, limited awareness of the concept, and regulatory barriers. Existing policies usually do not sufficiently incentivize waste heat utilization, creating uncertainty for investors and slowing the adoption of integration technologies. There is a need for clearer regulatory frameworks that formally recognize electrolysis waste heat as both a valuable energy source and a coproduct of hydrogen production.

Market structures and pricing mechanisms must be established to facilitate fair and transparent transactions between hydrogen producers and DH operators. Without structured pricing, the economic benefits of waste heat recovery remain unclear, limiting participation from both sectors. Infrastructure investment remains another significant challenge, as modifying existing DHNs and hydrogen production facilities to accommodate waste heat recovery requires substantial financial resources. Public-private partnerships and financial incentives are critical to overcoming these barriers.

Enhanced collaboration between stakeholders is necessary to align technological capabilities, operational strategies, and policy frameworks. Coordinated efforts will help optimize waste heat integration and maximize the benefits for both the hydrogen and DH sectors. Highlighting successful good practice examples can also serve as a motivational driver. Stronger regulatory support and targeted funding mechanisms will ensure that waste heat recovery becomes a core component of the energy transition.

6 CONCLUSION

Integrating electrolysis waste heat into DHNs presents an opportunity to enhance energy efficiency, reduce carbon emissions, and improve the economic viability of both hydrogen production and DH systems. The growing deployment of electrolysers will provide an increasing source of waste heat that, if effectively captured and utilized, can support the decarbonization of heating sectors.

Optimized heat recovery strategies, such as preheating DH return and using heat pumps for temperature upgrading, will maximize system performance. Thermal energy storage solutions can help balance fluctuations in heat supply and demand, improving reliability. Infrastructure investments, regulatory alignment, and financial incentives will be essential to facilitating the large-scale adoption of electrolysis waste heat recovery.

Coordinated planning between hydrogen producers, DH operators, and policymakers is necessary to unlock the full potential of this integration. By implementing supportive policies, establishing transparent market mechanisms, and encouraging technological innovation, electrolysis waste heat can become a key contributor to a more sustainable and efficient energy system.

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SUMMARY FOR NON-TECHNICAL AUDIENCES

SOCIAL SUSTAINABILITY IN THE CONTEXT OF DH BUSINESS MODELS

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1 Project Objective and Methods for Data Collection

A background to District Heating is provided first (1.1). Next, the methods for data collection are presented (1.2).

1.1 District Heating

District Heating (DH) is a technology that provides buildings that are connected to a distribution network with space heating and, often, domestic hot water. The heat is either generated in a production unit (it can be a combined heat and power plant or a plant for heat generation only) or obtained from an industrial process, or the urban infrastructure, and the heat carrier is water. Sustainability is discussed in the context of ensuring that current needs are met without compromising the needs of future generations. It considers economic, environmental and social sustainability. Depending on the heat supply, the impact on the environment of DH varies and it can be environmentally sustainable. The conventional DH configuration is based on economy of scale where the central heat supply is optimized so that the cost of producing one more unit of heat is minimized. DH operations can therefore be economically sustainable. However, when addressing social sustainability less is known about the way that DH generates or erodes social sustainability values. In this project, an attempt to understand social sustainability and if it can impact the competitiveness of DH business models is made.

1.2 Methods for Data Collection

Social sustainability impact on business model competitiveness is an unexplored field of research. Information has therefore been collected by a number of complementary methods. First, an analysis of DH value chains in two mature DH markets (Sweden and Denmark) and in two maturing DH markets (Belgium and Canada) was made. A value chain encompasses value adding activities. A distinction is made between primary and supporting value activities. Primary value activities are needed to make and provide the product to customers (inbound logistics, operations, outbound logistics, marketing and sales and services) whereas supporting value activities (firm infrastructure, human resource management, technology development and procurement) are needed to make the cycle from production to sales work.

Next, literature was screened followed by the design of an interview guide to collect data on social sustainability in the context of DH of a case study. The case was chosen based on three criteria. First, the case needed to be situated in a DH market that was not yet mature. Second, the DH system should still be in the planning phase, allowing the research team to engage early and contribute to discussions around alternative and desirable business model features. Third, the DH project had to demonstrate strong potential for both economic and environmental sustainability: such a system would enable the research team to focus on exploring the

dimension of social sustainability, rather than concentrating on the already well-addressed economic and environmental aspects. According to the descriptions provided by the City of Burnaby in Canada, their foreseen network qualified on all items. Canada is a maturing DH market, the system is foreseen to be commissioned in 2026-27 and it is foreseen to make use of the waste heat from the waste to energy plant in the Metro Vancouver area (operating 24/7 since 1988) at a competitive price. In total, 28 interviews were conducted with stakeholders linked to the DH project of Burnaby. Based on the results oft he value chain analyses, literature screening and interviews, a social layer for DH was derived using the tool of business model canvas. The canvas has an economic, an environmental and one social layer.

2 Results

Results are presented in conjunction to different activities undertaken in the project. Results from value chain analyses are presented first (2.1). Next, results from literature screening are summarized (2.2). Thereafter interview results are provided (2.3) followed by the results from analyzing the competitiveness of DH business models when resorting to social values (2.4).

2.1 Value Chain - Results

Analyses of economic, environmental and social sustainability values were made for DH value chains in Sweden, Denmark, Belgium and Canada. In Canada the analysis was linked to the case study whereas it was made on a generic, national value chain in the other three countries. Comparing the different parts of the value chain of the case to the generic features identified for the Swedish, Danish and Belgian DH markets it is identifiable that the value chain of the case study is more advanced on waste heat dialogues. It also appears as if a foreseen ownership of substations can support the control of the system as well as the ability to offer various win-win arrangements and services. In table 1, similarities and differences of the value chain of the case and of the generic DH value chains in Sweden, Denmark and Belgium are summarized.

Table 1: Similarities and differences of value chain characteristics based on review of the Burnaby case. Similarities and differences are compared to the value chains in SE, DK and BE

Inbound Logistics	**Operations**	**Outbound Logistics**	**Marketing & Sales**	**Post Sales Activities**
The fuel supply is waste heat supply	Like value chains in SE, DK and BE	Control of substation facilitates energy services	Waste heat recovery dialogue exists, co-creation & collaboration will come	Different service offerings are foreseen
Forthcoming: low temperature waste heat from sewage		Forthcoming: manage Legionella in cooling		

2.2 Literature Screening - Results

The first result from the literature screening was that there is limited knowledge on how sustainable business models generate value and even less so on how socially sustainable values materialize. It is also concluded that there does not seem to be any previous study on the topic of socially sustainable business model in DH.

In the literature there are numerous studies on how companies can work with their employees to ensure a rewarding, social workplace. It can be things like work safety, gender equality, ethnicity, age, the opportunity for training on the job etc. Such factors are the social factors that are part of the concept of Environmental, Social and Governance factors (ESG). We concluded that such factors are managed by legislation (worker safety for example) whereas other aspects are voluntary (employee satisfaction, the reputation of the company etc.). In this study, we wanted to understand what social values can be realized that can enhance the competitiveness of the DH business case. We concluded that the social aspects of the ESG framework are already known and decided to focus the attention of this study beyond the social values that can be generated by the social dimension of the ESG framework.

The second result from the literature screening was that 24 social key performance indicators (SKPIs), beyond ESG factors, could be identified as relevant to the supply of heating and/ or cooling. Revisiting the value chain analyses with the SKPI factors a third result was that social values can be generated across DH value chains.

2.3 Interview - Results

28 interviews were performed with stakeholders linked to the Burnaby DH project. At an overall level, the results show that factors that should have the largest potential to generate social sustainability values in the Burnaby DH project context are (i) to create local jobs, (ii) ensure transparent communication across the value chain, (iii) invest in buildings to signal sustainability value, (iv) keep the DH price at the same level or lower as other heating alternatives, (v) engage in partnerships with the local community (local heat supply recover, joint co-creation of commercial values), (vi) offer both heating and cooling and (vii) consider sector coupling between DH and electricity.

2.4 Social Sustainability Impact on the Competitiveness of DH - Results

To understand if the social dimension of sustainability can change the business models of DH companies the results from the value chain analyses and the interviews performed were used to identify what a potential, social layer of a DH business model can look like (the methodology of a triple layered business model canvas was applied). The layer is summarized in figure 1.

When it comes to **employees** the ESG factors were taken for granted (conditions of work, diversity, gender balance, fair remuneration, development etc.). In the context of social values and **governance** we identified that several choices could be made at governance level, that could have a social impact. Such are for example, lower investment criteria for sustainable investments (longer pay back accepted, lower rates of return accepted), the will to co-create and co-invest with customers (sharing investment costs), undertake philanthropic activity (in support of the local community), educate the young and the wider society (in energy efficiency/ energy use), build new knowledge through research & development engagements (knowledge that benefits the company and the wider society), efforts for empowering customers/ heat providers (investing in digitalization for example) and have a policy of transparent dialogue across the value chain. Based on the interview material it appears as if only a few of the possible choices to foster social values are identified in the context of the Burnaby DH case.

Concerning **societal culture** DH companies can foster a culture of circularity where waste and the negative impacts on the environment are minimized. Beyond environmental impact there is also a possibility to foster a sharing economy by co-creating business opportunities (such as recovering local heat sources) in the local community. In the context of Burnaby, the main fuel is waste heat from waste combustion. The waste comes from several municipalities in the metro Vancouver area and the reuse of it is therefore a first step towards joint use of local heat assets. Apart from the waste heat from the waste combustion plant there is a practice to recover waste heat from municipal sewage water in the metro Vancouver area, since the successful use of waste heat from sewage water to the Olympic Village. Hence, at municipal level there seems to be a first steppingstone for a culture of sharing. However, public-private collaborations are not yet in place (for making use of locally available heat sources).

When it comes **to the scale of outreach** DH activity is per definition geographically delimited to the region where the DH assets are. In the context of Burnaby there are several DH companies that are operating in parallel. Hence, there could be a potential to spread the idea of a sharing culture across these entities. In terms of stakeholders a sharing community would benefit some stakeholders directly (those involved in the sharing activities) and the wider community indirectly (ensuring the most cost efficient heat sources are used increasing affordability of heat and hot water supply, the use of local and environmentally sustainable fuels leading to reduced levels of air pollution and possibly a culture of sharing knowledge to the young/ wider community etc.). The scale could be further expanded by resorting to inclusive, aesthetic and signaling buildings.

Addressing the **end user** we found that social values that the end user benefits from are a carefree, resilient heat and hot water supply of high indoor comfort. Another possible benefit is to have access to recreational spaces at building level (saving space), be engaged in one's heat and hot water supply (empowered through digital tools allowing the customer to follow his/her consumption patterns, joint collaboration with the energy company to become a

prosumer), affordable heating and enjoy the feeling of being included and part of a resource efficient and sustainable heating solution. Viewing the aspect of local communities there is a possibility to engage with local heat supply owners to establish win-win solutions. As mentioned above, this engagement is underexplored both in mature DH markets and in the context of Burnaby. Other ways than heat supply to engage with the local community are to make governance decisions leading to an impact for many stakeholders in society, either directly or indirectly (research & development, education of the young, philanthropic activities etc.).

Focusing on **social values** DH can generate social values to multiple stakeholders. Examples are:

- Employees: by providing positive working conditions
- Customers: providing a carefree, resilient heat and hot water supply that is environmentally sustainable making use of local assets (generating a pride in the customer), an affordable heat and hot water supply and the possibility to engage in one's consumption of heat
- Wider society: job creation, improved air quality, affordable heating and hot water, recreational spaces, inclusion, knowledge/ education and other

Lastly, the **social impacts** of DH can be both positive and negative. If the fuel supply is not environmentally sustainable many of the positive social values are lost (improved air quality, making use of resources otherwise lost and the co-creation element with local community stakeholders). If government choices are made that isolate the DH activity from other stakeholders, the positive social impacts are further reduced (by minding its own business, the DH companies in mature DH markets reduce their potential to generate social value or to mitigate negative impact related for instance to unfair access to energy).

<table>
<tr>
<td>Local communities

Local collaboration on heat supply

<u>Governance choices</u>

Educational actions
Philantropic activity
Sustainable investment thresholds
R&D activities</td>
<td>Governance

<u>Governance choices</u>
Educational actions
Philanthropic activity
Sustainable investment thresholds
R&D activities
Co-create & co-invest
Customer empowerment

Employees

Working conditions</td>
<td>Social values

<u>Employees</u>
Positive working conditions

<u>Customers</u>
Carefree
Resilient
Affordable
Empowerment

<u>Wider society</u>
Jobs
Improved air quality
Recreational spaces
Inclusion
Knowledge transfer</td>
<td>Societal culture

Circularity and shared economy

Scale of outreach

Geographical area of the DH system

Across stakeholders

(employees, customers, wider society)</td>
<td>End User

Carefree

Resilient

Affordable

Empowerment</td>
</tr>
<tr>
<td colspan="5">Social impact drivers (positive or negative will depend on configuration of driver)

Fuel (fossil/ renewable)

Sourcing of fuel (remote/ local)

Governance decisions (promoting social sustainability or not)</td>
</tr>
</table>

Figure 1: The social layer of the DH business model (Source: result from study)

To make changes to business models that are in operation and functional is challenging, however, shifting towards social value creation has many upsides for the DH system because it anchors it to the local community.

3 Discussion

The principal objective of the project was to understand if the social dimension of sustainability can change the business models of DH companies and increase their competitiveness.

One main result of the study is the design of a potential, social layer of the DH business model. Several of the factors that can add social value are linked to choices of the companies themselves (setting sustainability thresholds, educating the young, empowering customers, engaging in co-creation activities and other). It is, however, well known that it is difficult to change the way things are done if a business model is in place that still generates profit. Indeed, pursuing social value creation is a strategic task and needs to be included in the way that companies are undertaking both operational activity and investment decisions. Doing so, it appears possible to capitalize on social values in DH.

Depending on the ecosystem in which the DH company is located, there will be different levels of incentives to pursue social values. Institutional structures like public goals and procurement standards that support social sustainability would likely support social value creation at company level. For example, establishing clear social requirements in DH procurement could be one way forward. Indeed, a supportive surrounding will also make outreach to local heat suppliers easier, which lowers the hurdle of co-creation and co-investments. However, even in the absence of institutional incentives it appears as if social values can generate new, profitable business opportunities (directly by saving money in the fuel procurement process and indirectly by anchoring the company to the local community making it difficult to be outcompeted in the mid-long term).

Circling back to the principal objective of understanding if the social dimension of sustainability can change the business models of DH companies, we conclude that, yes, that is the case.

If the DH companies decide on integrating social value creation as part of the main strategy and work actively to capitalize on them, then yes: competitiveness can increase. If not, there is a risk that social values are diluted and reduced to a tick in the box rather than generating competitiveness. Hence, taking action is important to realize the potential, social values.

Last, based on the results in the study, companies that are interested in assuming the strategic position of including social values in their business case are recommended to take the following steps:

1. Review the value chain and understand where there is room to include factors that can generate social values.

2. Turn to the surrounding ecosystem of stakeholders and engage in dialogue with them to identify where there is potential interest and room for co- creation and co-investment.

3. Make social sustainability a management matter, establish a strategy and identify relevant social key performance metrics to follow up on.

4. Revisit the business model logic and understand how the ongoing activities need to shift to pursue social values. Do any risks or opportunities occur? Can contracts be standardized?

5. Start small: identify social values that can generate both economic gain and anchor the company to society. For DH companies, engaging in local waste heat recovery would be an interesting case to pursue.

As mentioned, our project was conducted around a case study limiting the possibility to generalize the results.