Integrating renewable and waste heat and cold sources into district heating and cooling systems

Case studies analysis, replicable key success factors and potential policy implications

External study performed by

Tilia

for the Joint Research Centre

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Abstract

Based on a holistic case studies analysis of 8 efficient district heating and cooling (DHC) systems in different EU Member States (Denmark, France, Germany, Italy, Lithuania and Spain), the study investigates the design and operation of DHC systems mainly supplied by renewable energy sources and (excess) waste heat and cold sources, aiming at identifying the key success factors enabling the integration of those sources, and drivers and conditions for their replicability in other cities and communities. Finally, it suggests some potential policy guidelines to support the integration of local and low-carbon energy sources through DHC. Through the analysis of concrete operational examples, the study contributes to increasing awareness on the role and features of efficient DHC systems, which have proved to be powerful levers for deep decarbonisation, providing an evolutive backbone to balanced energy transitions.

Disclaimer

All data in this report has been researched and compiled with utmost diligence of Tilia experts. However, errors and mistakes cannot be totally excluded.

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List of Acronyms

AC	Air Conditioning
ACA	Assistance to the Contracting Authority
ATES	Aquifer Thermal Energy Storage
BAU	Business As Usual
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CHP	Cogeneration Heat and Power
COP	Coefficient of Performance
DBO	Design, Build, Operate
DC	District Cooling
DH	District Heating
DHC	District Heating and Cooling
DSO	Distribution system operator
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
EHS	Environment, Health & Safety
ERDF	European Regional Development Fund
ESCO	Energy Service Company
EU	European Union
FTE	Full Time Equivalent
GDP	Gross Domestic Product
GHG	Green House Gas
H&C	Heating and Cooling
HDD	Heating Degree Days
HOB	Heat Only Boiler
IRR	Internal Rate of Return
JRC	Joint Research Centre
KSF	Key Success Factor
LNG	Liquefied Natural Gas
MS	Member State
NPV	Net Present Value
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PEF	Primary Energy Factor
PPP	Public-Private Partnership
PtW	Power-to-Heat
PV	Photovoltaic
RDI	Research Development and Innovation
RE	Renewable Energy
RES	Renewable Energy Sources
TSO	Transmission System Operator
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital
WTE	Waste-to-energy
WWTP	Wastewater Treatment Plant

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Supervision and coordination

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Data contributors and local reviewers for the case studies analysis

We extend these special thanks to the local contacts interviewed and met for the case studies analysis:

Case studies		Name	Organisation
Taarnby (DK)	**Main contacts**	**Anders Dyrelund**	Ramboll
		Hasmik Margaryan	Taarnby Forsyning
		Birger Lauersen	Danish DH Association
Jaegerspris (DK)	**Main contacts**	**Anders Dyrelund**	Ramboll
		Hans Chr. Kjærgaard	Jægerspris Kraftvarme A.m.b.A
Paris-Saclay (FR)	**Main contact**	**Nicolas Eyraud**	EPAPS
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		Pablo Fernández Martínez	Hunosa (Grupo SEPI)
		Felipe González Coto	Hunosa (Grupo SEPI)
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		Juan Carlos Aguilera Folgueiras	FAEN (Asturian Energy Agency)
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		Kęstutis Karosas	Vilnius municipality
		Dalius Krinickas	VERT (National Regulator)
		Julija Drobinova	AB Vilniaus Silumos Tinklai
		Zenius Rinkevičius	AB Vilniaus Silumos Tinklai
		Vytautas Džiuvė	AB Vilniaus Silumos Tinklai
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		Erik Thornström	Swedish DH Association

Other contributors

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1. Executive Summary

Decarbonising heating and cooling, an EU priority

Heating and cooling (H&C) has been given a more important role in the new EU energy transition strategy established by the EU Green Deal and its associated communications. Left out of the main energy transition policies in recent decades by most of the Member States (MS), H&C in buildings and industries accounts for half of the EU's energy consumption, with 75% still generated from fossil fuels. To meet its climate and energy goals, the EU needs to sharply reduce and decarbonise its H&C demand.

District heating and cooling (DHC) is one of the main infrastructures allowing decarbonisation through smart sector integration. It enables the efficient integration of a wide range of renewable energy sources (RES) like biomass, geothermal or solar energy, and the use of various forms of (excess) waste heat and cold that otherwise would remain untapped (industries, data centres…), and is linked to energy efficiency in buildings, often providing the strongest leverage, at the local level, to achieve decarbonisation. It can also provide flexibility to the electricity grid via Power-to-Heat (PtH) solutions with electric boilers or large-scale heat pumps, especially when coupled with thermal storage, to accommodate intermittent renewable electricity production in a cost-efficient way.

Because of their numerous advantages, DHC systems appear, in many respects, as a potential backbone for integrated local energy transitions. However, public and policy awareness on those advantages and DHC uptake remain low in the EU[1]. Interestingly, the countries where this solution has been largely adopted (e.g. in Scandinavia and the Baltics) are amongst the best performers in H&C decarbonisation. Showcasing and explaining in detail the benefits of DHC through flagship projects is one of the measures identified by experts to accelerate its deployment[2].

Objective and approach

This study investigates the design and operation of **DHC systems mainly supplied by RES and waste heat and cold sources**, aiming at identifying the Key Success Factors (KSF) enabling the integration of these sources. It also discusses how these KSF could at least be partly replicated in other cities and communities.

To do so, **8 case studies** covering a wide range of contexts, technologies, energy sources, and management modes (see table below) are thoroughly analysed from a **holistic perspective**, i.e. from national policy frameworks to specific local conditions and business models. This in-depth study is to a large extent based on exchanges with DHC operators, public authorities, national DHC associations and Tilia's own experience in developing efficient DHC systems.

Country	Case Study	Installed capacity	Renewable Energy Sources	Waste Heat/Cold Sources	RES share
	Taarnby DHC	DH: 60 MW DC: 6.5 MW	Renewable electricity; Thermal storage; Biomass	Ambient energy (Wastewater)	91%
	Jægerspris DH	20.1 MW	Solar thermal; Thermal storage; Ambient energy (from the air)	CHP (gas-fuelled)	56%
	Paris-Saclay DHC	DH: 37 MW DC: 10 MW	Geothermal energy	Data centers; Laboratory	60%
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	Barcelona-Districlima DHC	DH: 79 MW DC: 113 MW	Renewable electricity; Thermal storage; Ambient energy (from the sea)	Waste-to-energy	97%
	HafenCity DH (Hamburg)	28,3 MW_{th} 1,5 MW_e	Biogas	Industrial heat; Thermal storage	90%
	Vilnius DH	1,707 MW_{th}	Biomass	In 2021: Waste-to-energy	55%
	Milan DHC	DH: 901 MW DC: 7,5 MW	Geothermal energy	Industrial heat; Waste-to-energy	68%

[1] DH systems supply only 12% of the EU heating needs (2017)
[2] In 2016, the JRC made an external study called *Efficient district heating and cooling systems in the EU* showcasing 8 flagship DHC systems (link to report)

Main Results

The case studies analysed showcase through concrete, operational examples the **key role that DHC systems can play to efficiently integrate a wide range of RES and waste heat/cold sources**, and in the effective **decarbonisation of local economies.**

Ten **KSF** have been identified, destined for **policy makers, DHC operators, municipalities, urban planners** and other key stakeholders, suggesting 5 working areas to foster decarbonisation through DHC.

A. Accelerating the integration of RES and waste energy sources in DHC through a comprehensive and coherent set of policies and support schemes

Achieving in-depth decarbonisation will require applying **climate targets across all sectors,** and the associated policy measures, in a coordinated manner at all policy levels, alongside support schemes driving investments in this direction. In H&C, further efforts are required to increase the **awareness of the multiple benefits of DHC**, and to prepare a detailed plan to **progressively phase out fossil fuels** while assuring affordability and cost-efficiency. Today, **numerous barriers** for decarbonisation through DHC remain (building codes, urban planning not integrating comprehensive energy planning, electricity tariffs not valuing demand response…), and should be addressed.

B. Building a local and participative governance: cooperation and value-sharing

DHC developments are steered at local level, usually at the municipal or district scale. **Participative approaches integrating all stakeholders** (city services, DHC operator, private actors including waste energy suppliers, end-users, citizens, national actors, etc.) **result in higher efficiency and foster local value creation** (reduction of the energy bill and CO_2 emissions, local job creation, return on investments for the DHC operator and for the municipality...).

C. Applying the energy-efficiency-first principle across sectors, to move towards more integrated energy systems

Integrated and long-term urban strategies for local decarbonisation should address H&C demand and supply simultaneously, ensuring only the needed energy is produced (energy efficiency first), through comprehensive H&C planning.

Synergies between DHC and other urban infrastructure and local activities must be

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Key Success Factors to integrate RES and waste energy sources in DHC grids

1) National policies: supportive framework for efficient DHC

- Adequate incentives for H&C decarbonisation, including DHC

2) Direct and indirect financial support to new investments

- Grants to investments and/or fiscal incentives, incl. CO_2 taxes
- Funding RDI on this topic

3) Local governance and commitment of the various stakeholders

- Local authorities as key change agents, sponsoring the projects
- Participative methods integrating end-users, energy communities

4) Energy planning as an integral part of urban planning

- Integrating H&C planning in urban development projects
- Anticipating infrastructure synergies, setting urban environmental targets

5) Energy infrastructure in buildings at the heart of the local energy system

- Building regulation and urban planning enable DHC connection
- Collective H&C where relevant, low-temperature heat emitters

6) Compatibility and competitiveness of RES and waste energy sources

- Mapping potential sources, sound techno-economic assessment of these
- Ensuring technical compatibility with the DHC grid and buildings

7) Power-to-Heat solutions valuing renewable electricity and low-temperature sources

- Heat pumps to maximise the use of low-temperature RES and waste energy sources
- Large heat pumps and electric boilers coupled with thermal storage to integrate intermittent renewable electricity

8) Sector integration

- Synergies with other networks (gas, electricity) and urban infrastructure (water, waste, transport…)

9) District cooling

- Valuing synergies with DH (higher COP, seasonality), decarbonising the growing cooling demand

10) Adaptability and continuous optimisation

- Flexible strategies (modular approach, heat cascading…)
- Permanent optimisation incentives

continuously sought and prioritised, such as waste energy from local industries, wastewater treatment plants, waste incinerators, agricultural activities, closed coal mines in coal regions in transition…

Buildings are also an integral part of DHC systems, and directly impact their deployment and performance. Key aspects of the **DHC-building nexus** include **heat emitters,** which must be compatible with DHC for a building to connect (e.g. central heating with same temperature regime), and the energy performance of buildings (e.g. higher **return temperatures** in DH result in poorer DHC performance). To integrate a higher share of RES and waste energy sources, **low-temperature technologies should be encouraged in heat emitters**, and their uptake could be promoted in the frame of the upcoming "renovation wave".

D. Making the right technology choices to progressively integrate low-carbon energy sources and district cooling

Today, it is possible to mobilise a **large spectrum of RES and waste energy sources in DHC**. However, understanding and forecasting the **key technical features** of such sources and assessing their **compatibility with the DHC network and connected buildings** is key to develop reliable, flexible and cost-efficient DHC systems.

One of the recognised advantages of DHC systems is that they are **evolutive systems**, which can integrate technologies as they develop. Mature DHC markets like Denmark or Sweden show how DHC grids evolve **towards higher flexibility** in demand and supply, introducing **smart sector integration** solutions and **district cooling**, as relevant.

In particular, **district cooling (DC) must gain higher visibility at policy level**. As cooling demand rapidly increases worldwide, resulting in significant negative climate impacts, DC can play a major role in mitigating those impacts in a cost-efficient manner (lower environmental impacts than individual solutions, higher energy efficiency, enhanced flexibility for the electricity grid, cross-sector synergies, reduced heat island effects…). **For DH operators, DC can be seen as a source of energy efficiency, a way to strengthen their offer and remain competitive against individual heat pumps, and a new source of revenue** in the context of decreasing heating consumption.

E. Creating a robust business case for modern and evolutive DHC systems

Conceiving and developing modern DHC projects following the principles above is of the utmost importance, but those principles need to be reflected in a **robust business model**, allowing to undertake the required investments. This development phase **requires a wide range of expertise** (technical, economical, organisational, operational, legal, financial…). When it does not exist in-house, new forms of public-private cooperation schemes can empower communities and DHC operators, as illustrated in some of the analysed cases.

Finally, the analysis shows the relevance of **innovative tariff structures**, reflecting as much as possible the network costs and their evolution through time, and **encouraging consumers to contribute to the overall system efficiency** (e.g. through tariffs setting return temperature targets and associated financial incentives, or seasonal tariffs). It also illustrates how participative and inclusive approaches including **energy communities** result in a more balanced share of costs and benefits across actors, and higher transparency standards. Some of these new trends are enabled by new **digital solutions** (e.g. smart meters).

2. Introduction

As the world faces a historical health and economic crisis due to the COVID-19 pandemic, the EU has put decarbonisation at the core of its recovery plan. This plan aims to achieve a resilient, inclusive, and green recovery in Europe while laying the foundations for a low-carbon future. And **heating and cooling** (H&C), left out from the main energy transition policies in recent decades by most of the Member States (MS), will be given a more important role in this new energy strategy, as highlighted in the recently published communications on EU strategy for Energy System Integration[3] and the Renovation Wave for Europe[4], supporting the EU Green Deal[5].

Indeed, H&C in buildings and industries accounts for half of the EU's energy consumption, with 75% still generated from fossil fuels[6]. To meet its climate and energy goals, the EU needs to sharply reduce its H&C demand, and replace fossil fuels with renewable and waste (excess) heat and cold sources. In residential buildings, heating, cooling and domestic hot water represent ca. 80% of the energy consumed, which is mostly supplied by old and inefficient fossil-fuelled equipment, mostly stand-alone solutions (88% of heat supply)[4]. While district heating only represents 12% of the supply, countries where this technology has been largely adopted (e.g. in Scandinavia and the Baltics) are amongst the best performers in decarbonising H&C.

District heating and cooling is one of the main infrastructure allowing decarbonisation through smart sector integration. It enables the efficient integration of renewable energy sources like biomass, geothermal energy or solar thermal, and the use of various forms of excess heat and cold, and is linked to energy efficiency in buildings, often providing the strongest leverage, at the local level, to achieve decarbonisation. It can also provide flexibility to the electricity grid via Power-to-Heat (PtH) solutions with either electric boilers or large-scale heat pumps, especially when coupled with thermal storage, to accommodate intermittent renewable electricity production in a cost-efficient way. In addition, if CHP (Cogeneration Heat and Power) plants are run to follow electricity demand, instead of heat, they can offer even more flexibility to the power system.

Because of their numerous advantages, DHC systems appear, in many respects, as a potential backbone for integrated local energy transition strategies, mainly due to the fact that they enable local authorities and other local stakeholders to combine a variety of energy efficiency and decarbonisation leverages within an overall multi-energy system, in connection with city planning. **However, public and policy awareness on those benefits remains low** at European level, and in many Member States and cities. Showcasing and explaining in detail flagship projects is highlighted by numerous experts as an essential measure to accelerate efficient DHC deployment (see, for example, the JRC report published in 2017 analysing some of the best performing DHC networks in Europe[7]).

The **purpose of this study** is to investigate how Renewable Energy Sources (RES) and waste heat and cold sources can be efficiently integrated in DHC networks. To do so, eight case studies have been identified across Europe and analysed from a holistic perspective – from national policy frameworks to specific local conditions and business models – to understand the key factors enabling decarbonisation though DHC, and explore whether some of the best practices can be replicated in other Member States and communities. The study has been carried out by Tilia under the supervision of the JRC.

The report is organised in four main sections. After presenting the methodology used for the study in **Section 3,** the eight selected case studies are deeply investigated in **Section 4**, followed by a transversal analysis in **Section 5**, including key success factors enabling the integration of RES and waste heat or cold into efficient DHC systems, and their replicability potential in other cities and communities. Finally, **Section 6** provides the conclusion of the study and some potential policy recommendations.

[3] European Energy System Integration Strategy, COM 2020(299), 8.7.2020
[4] A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives, COM 2020(662),
[5] The European Green Deal, COM 2019(640), 11.12.2019
[6] Eurostat 2018 data
[7] *Efficient district heating and cooling systems in the EU* (Link to report)

3. Methodology

A case study method has been retained for the holistic analysis of how renewable and waste heat or cold sources can be integrated into DHC networks.

This approach allows to illustrate the specific technical, economic, regulatory and operational enablers of eight efficient DHC systems in operation within different geographies and contexts in the EU. It includes strategic decisions made to reach a significant share of renewable and recovered energies in their energy mix, as well as development paths followed towards decarbonisation.

3.1 Case study selection

The first step consists in choosing the right case studies, providing sufficient insights on different models and patterns followed by some of the most efficient and innovative DHC systems in Europe in order to integrate RES and waste heat and cold sources. The selection followed 3 main stages.

a) Identification and contact of potential case studies

To identify potential case studies, the authors performed a thorough literature review, contacted national and EU DHC Associations, DHC companies and other DHC professionals within their network. They also relied on their own, first-hand operational knowledge of efficient DHC systems.

Based on this first review, a **preliminary questionnaire** was developed including the main specific criteria to take into account for the selection of case studies. In particular, a set of questions and indicators was defined to assess:

- The complementarity of the case studies in terms of geographical coverage, type of network, ownership and business model, regulatory framework, energy sources, customer structure, and additional value brought by the DHC system to the community;
- The performance of the network in terms of economic viability, price of heat for consumers, innovation, market share, competition, environmental aspects and replicability; and
- The data availability and willingness to collaborate in the study, if selected.

The answers to the preliminary questionnaires were analysed and the most relevant ones were integrated in a worksheet providing the main characteristics and key indicators of the **preselected DHC networks**.

b) Evaluation of preselected case studies

At a second stage, the preselected DHC networks were benchmarked against a set of criteria to assess its **performance** in the 8 areas below. The benchmarks and weighting of each criterion were jointly agreed between the authors and the JRC.

1. Economically viable business (necessary condition)
2. Price competitiveness against alternative solutions
    - Average price of heat (EUR/MWh)
3. Innovation
    - Number and quality of innovative features in the business model with regard to i) policy / legal framework; ii) technology (e.g. storage, linkages with other sectors and markets such as electricity); iii) environmental and social aspects
4. Stable or growing market

5. Competitive market
    - Competition for the market (DHC management)
    - Competition exists in practice between different heat production companies
    - Regulation allows new heat producers to join the network
6. Environmental performance
    - CO_2 emissions ($kgCO_2$/MWh heat, cold supplied)
    - Use of renewables and waste heat/cold (%)
7. Replicability potential
    - In terms of i) type of network; ii) policy design/legal framework; iii) business model; iv) technology; v) complexity (e.g. coordination)
8. Willingness to cooperate and actively contribute to the study.

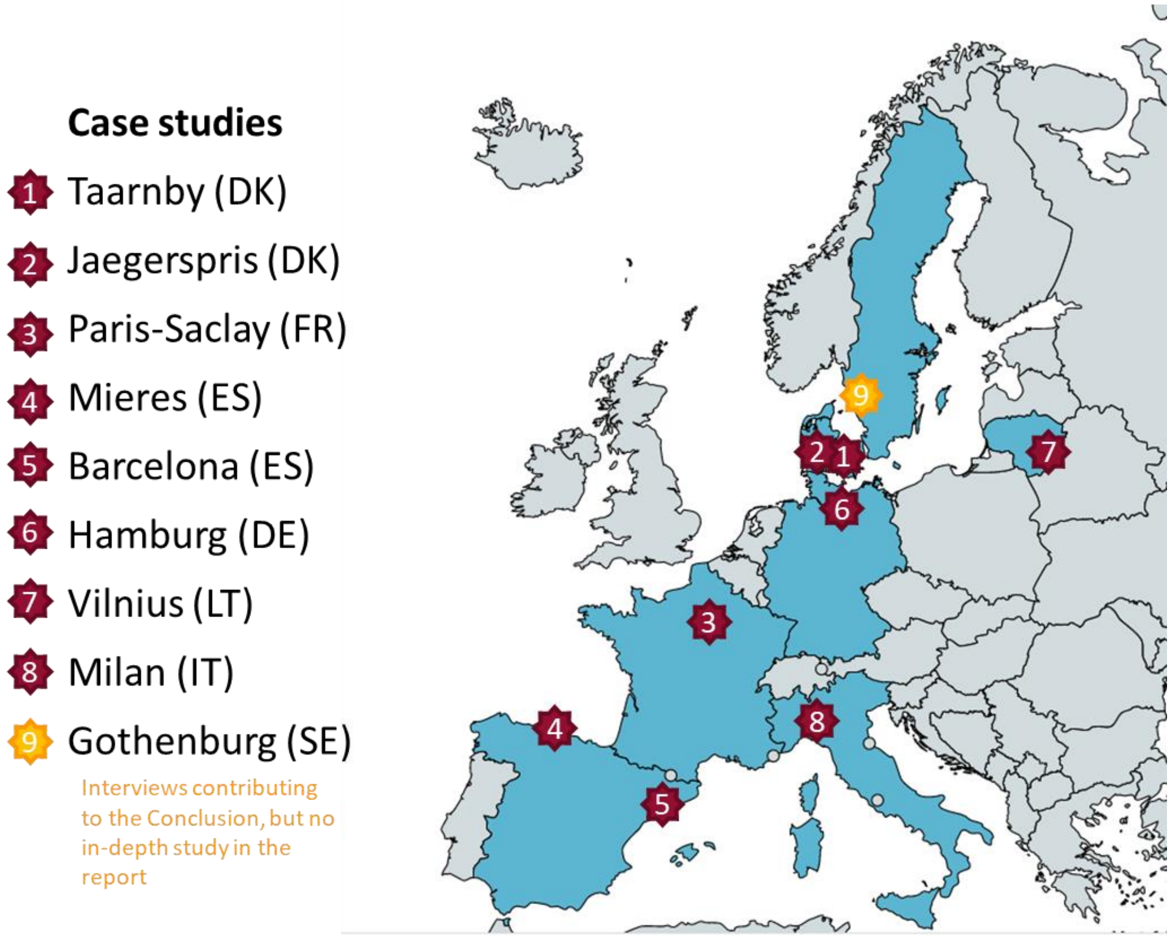
As a result, the preselected cases obtained a **performance score**, allowing to establish a comparison and ranking of the DHC systems regarding their suitability to participate in the study.

Other than performing well, the selected case studies had to be **representative** and **complementary,** showcasing diverse characteristics from a technical, urban, climate, economic and financial perspective. This was translated into 6 additional conditions to be fulfilled by the final group of case studies:

- Geographical coverage: The southern, western, central and northern EU regions should be covered in at least one case study each;
- Type of network and business model: different types of energy supplied (i.e. heating or heating and cooling), different scales and urban frameworks, different governance modes (public, Public-Private Partnership or PPP, consumer-owned);
- Regulatory framework: the group should include case studies operating in locally-regulated heat markets and at least one case study operating in a heat market with nationally centralised regulation;
- Balanced coverage of the main customer segments (residential, service, and industry);
- Diverse sources of heat/cold supply and technologies: e.g. cogeneration, renewable energy (e.g. geothermal, solar, biogas...), waste heat/cold from different sources (industries, water bodies, data centres....), heat pumps, thermal storage, etc.
- Different forms of additional value brought by the DHC system (e.g. synergies with other local initiatives and infrastructure, synergies with power system, enabling new energy management and energy efficiency services, creating value for local communities...)

c) Selection of case studies and overview of their low-carbon energy sources

The above criteria were applied to the 14 preselected networks, enabling the team to select the final group of 8 case studies (in 6 countries), complemented by interviews with a ninth case (Gothenburg[8]), overall covering a wide range of RES and waste heat and cold sources, as presented in Figure 1.



Country	Case Study	Installed capacity	Renewable Energy Sources	Waste Heat/Cold Sources	RES share
	Taarnby DHC	DH: 60 MW DC: 6.5 MW	Renewable electricity, Thermal storage, Biomass	Ambient energy (Wastewater)	91%
	Jægerspris DH	20.1 MW	Solar thermal, Thermal storage, Ambient energy (from the air)	CHP (gas-fuelled)	56%
	Paris-Saclay DHC	DH: 37 MW DC: 10 MW	Geothermal energy	Data centers, Laboratory	60%
	Mieres DH	4.1 MW	Geothermal energy from a closed colliery		98%
	Barcelona-Districlima DHC	DH: 79 MW DC: 113 MW	Renewable electricity, Thermal storage, Ambient energy (from the sea)	Waste-to-energy	97%
	HafenCity DH (Hamburg)	28,3 MW_{th} 1,5 MW_e	Biogas	Industrial heat, Thermal storage	90%
	Vilnius DH	1,707 MW_{th}	Biomass	In 2021 Waste-to-energy	55%
	Milan DHC	DH: 901 MW DC: 7,5 MW	Geothermal energy	Industrial heat, Waste-to-energy	68%

Figure 1: Map of selected case studies and summary of low-carbon energy sources used (indicated RES share includes waste heat/cold sources)

[8] Interviews with Goteborg Energi (https://www.goteborgenergi.se/english) and Swedish DH Association (Sweden's DHC profile presented in **ANNEX 7**)

3.2 Case study analysis

The case study analysis is mainly based on literature review, discussions with national and local actors identified for each case study and, for some of the cases, site visits.

The main steps followed for undertaking these analyses are described below.

1. First of all, a **detailed questionnaire** was developed and validated by the JRC, covering all the topics to be analysed. This questionnaire was shared with the contact persons of each case study to identify the most appropriate actors (stakeholders) to answer each of the ca. 100 questions, covering the following topics:

   I. National Context
   II. Local Context
   - City context
   - Heating (and cooling) market
   - Demand factors
   - Heat and cold supply factors (incl. third-party-access)

   III. Business model
   - Organization, governance and management of the DHC system
   - Economic factors
   - Profitability and financing capability
   - Cooperative approaches

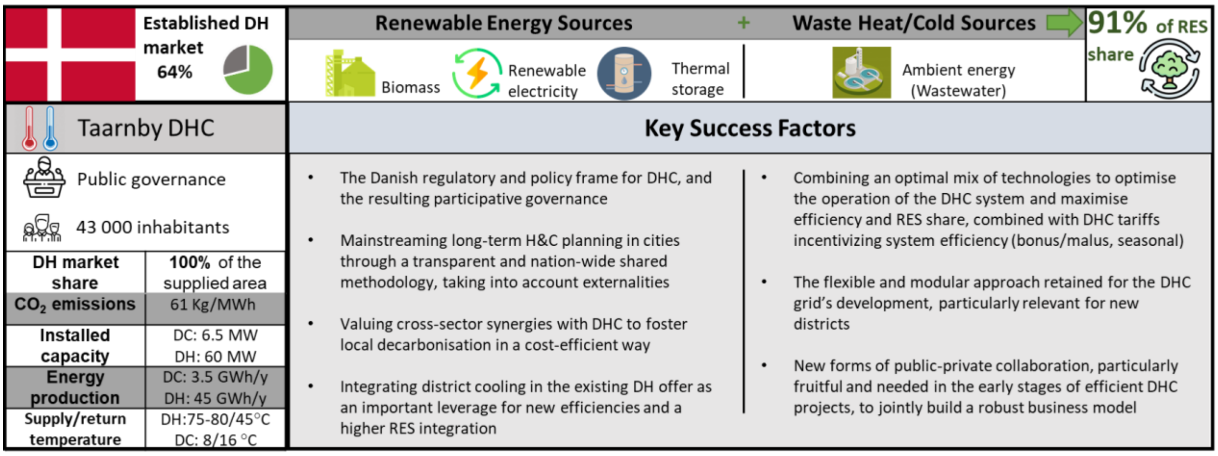
   IV. Integrating RES and Waste Heat and Cold
   V. Customer empowerment
   VI. Sector integration and Local value creation
   VII. Key Success Factors and Replicability

2. An exchange on the basis of this questionnaire enabled the authors to identify **relevant documents and information to analyse before the interviews or site visits**, and to schedule meetings with the main stakeholders participating in the case studies.
3. **Site visits** of 1 day to half of the concerned cities/municipalities took place fore the French, Spanish and German case studies. These visits included **meetings** with the DHC grid operators, in some cases with local/regional authorities, as well as visits to the DHC facilities (production plants and control rooms).
4. The case study analysis reports were shared with the **local contacts** for their **review**.
5. Finally, the analysis was reviewed and validated by the **JRC**.

4. Case studies

4.1 DENMARK: Smart sector integration through DHC in Taarnby (Greater Copenhagen)

A previous JRC report on Efficient DHC systems presented the Greater Copenhagen's integrated DHC system. Taarnby's case study showcases how this metropolitan system keeps evolving and growing, activating new decarbonisation leverages.



I National Context[9]

Denmark is committed to become climate neutral by 2050 at the latest, and has set legally binding targets to reduce Greenhouse Gas (GHG) emissions by 70% by 2030 (with respect to 1990)[10]. Those targets have been set across sectors, including 55% RES share in heating and cooling, and 90% for district heating by 2030, leading to a natural gas progressive phase out. In 2019, 50% of the electricity production derived from RES (47% wind, 3% solar).

Sector integration through DHC will continue playing a key role in achieving Danish climate targets. Indeed, Denmark has been practising sector integration since the 1970s, when CHP-based DH started its deployment, currently representing 80% of the DH supply. The last years have shown a higher integration of the electricity and heating sectors through **large heat pumps and electric boilers, enabling the use of intermittent renewable electricity in DHC systems and the provision of balancing services to the electricity grid**. The recent reduction of electricity taxes for heating and comfort cooling (excluding households consuming less than 4 MWh) recognises the benefits of further electrifying DHC systems. One of the challenges for deeper sector integration consists in valuing synergies with other sectors, such as transport and water.

District heating is the leading solution in the Danish heating market, with a share of 64% in the residential sector that keeps growing. This situation results from the application of a coherent package of policy tools and incentives since the 1970's oil crisis, aiming at achieving a cost-effective and sustainable heat supply. While these policy tools have been thoroughly explained and analysed in literature, one could highlight some of the measures provided by the Heat Supply Act[11], such as the non-for-profit principle, the support to CHP, the **local heat planning enabling DH zoning when it proves to be**

[9] Details on the national DHC context are provided in **ANNEX 1**, including key figures, actors and regulatory aspects

[10] Danish Climate Agreement for Energy and Industry (22 June 2020)

[11] The Heat Supply Act was adopted in 1979, and applies to all natural gas and district heating grids, as well as heat production plants larger than 250 kW.

the most cost-efficient solution[12], as well as the implementation of environmental taxes.

District heating laws and regulations have also shaped the DH governance and ensured a high level of transparency and consumer protection. 95% of the DH networks are owned by municipalities or consumer associations, the latter representing 35% of the total. The Danish Utility Regulator (*Forsyningstilsynet*) oversees the sector and carries out a national benchmark on a voluntary basis, to incentivize cost-effectiveness.

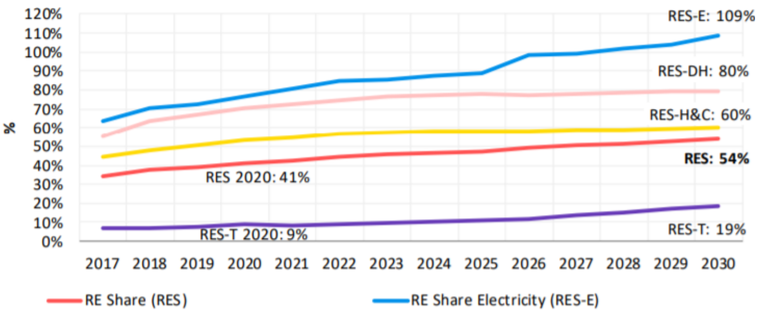


Figure 2: Renewables shares 2017-2030, with respect to 100% consumption (Danish Energy Agency)

The main **alternative to DH** is individual heating with natural gas (15.7% market share), followed by oil boilers, which keep declining. The use of heat pumps is growing, mainly in one-family houses, but the market share is still low (2.7%).

The current RES share in DH is 60.5%, while waste heat recovery represents 3% of the supply (cf. Figure 3). Biomass remains the main RES, and is the main source used when replacing fossil fuels in existing networks. Waste-to-energy is expected to continue providing base load ("MSW" in the graph below), while **the use of renewable electricity in DH is expected to significantly grow** (heat pumps and electric boilers). The main potential of waste heat recovery comes from secondary industries, such as food industries or data centres, as there are not many large industries in the country.

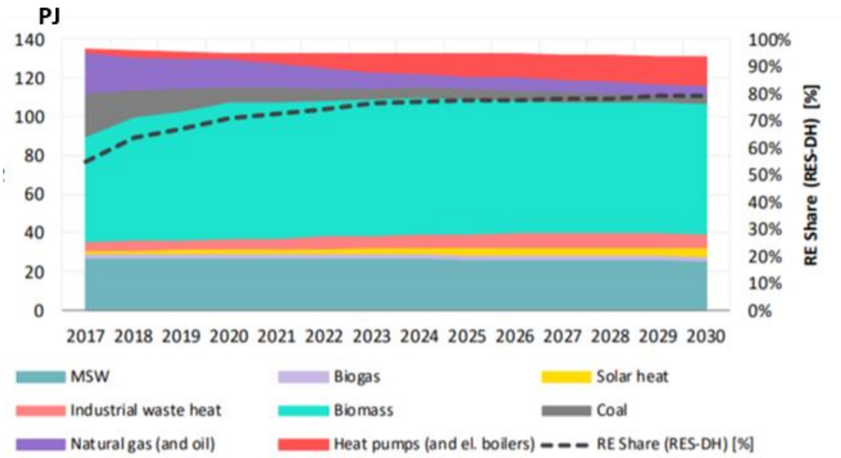


Figure 3: District heating production by type of energy and RES share (source: Danish Energy Agency)

The prospects for the deployment of district cooling are also optimistic, mainly in bigger cities. DC sales remain however insignificant when compared to DH, and are business-driven (prices are not regulated). The District Cooling Act establishes some rules and regulations aiming at protecting consumers, and requires to carry out a **combined H&C planning** when DC is combined with DH.

While the national context overall favours the development of efficient DHC systems which are cost effective for the society, **building regulations remain one of the main barriers** in Denmark, as they favour individual solutions at building level due to the **Primary**

[12] **Heat planning** is based on a common (national) methodology applied by all municipalities, based on a 20-year Cost Benefit Analysis. It allows to define the preferred collective heat supply, i.e. DH or natural gas vs. individual solutions.

Energy Factors (PEF) retained for each technology (0.85 for DH applied on heat demand, 1.9 for individual heat pumps applied on electricity consumption, and not specified but estimated at 0.1-0.2 for DC)[13]. As a result, these regulations impose buildings connected to DHC higher envelop insulation levels and/or local production of renewable energy, normally solar Photovoltaic (PV), but it could also be a small wind turbines or solar thermal.

The case studies of **Taarnby** (in Greater Copenhagen) and **Jaegerspris**, presented hereafter, are deemed reasonably representative of the national context for their type of installation, illustrating some of the current DHC trends in Denmark in cities and smaller communities, respectively.

Greenfield DH networks developed in the 1980s

While most DH companies in Denmark developed over a period longer than 40 years, some **"greenfield" DH networks** developed once the Heat Supply Act came into force in the 1980s. The Danish case studies analysed in this report showcase 2 different models of greenfield grids:

- The first one consisted of around 8 **large municipally-owned companies in the suburbs of** Greater **Copenhagen**. They were established shortly after 1980 with the aim to replace oil boilers in the most densely populated districts with DH based on efficient surplus heat from existing and new CHP plants and waste incineration facilities. Thereby **oil boilers were replaced with efficient district heat** corresponding to an efficiency of around 300% (100 units of fuel and 200 units of CHP waste heat producing 300 units of heat to the DH grid). **Taarnby** DHC system is one of these greenfield systems.
- The second group was around **80 small communities**, typically with a total heat demand between 10 and 30 GWh/y and located too **far from existing DH systems**. They were developed shortly after **1990** as a result of the energy planning encouraging to **replace oil boilers** by establishing a new DH system heated by gas-fuelled CHP engines in the range from 2 to 6 MW heat. **Jaegerspris** was the largest of all these small communities.

Those developments ran in parallel with the implementation of new gas infrastructure using Danish natural gas, the so-called **"Danish gas project"**, aiming at reducing oil-dependency and increasing security of supply. When this project was implemented by 1985, DH networks supplied by oil were obliged to **switch to gas-fuelled CHP**, and fiscal incentives encouraged to phase out oil and coal. The new greenfield DH systems in small communities also contributed to this "gas project", and benefitted from a CHP feed-in-tariff introduced to support the development of new efficient production capacity.

Reducing heat emitters' temperature in buildings

In addition, it is worth highlighting the Danish efforts on **progressively reducing heat emitters' temperature, ultimately resulting in improved energy efficiency in buildings**.

HVAC[14] engineers who designed social housing in the suburbs of Copenhagen, which had little district heating at that time, **optimized the installations** (including home radiators) **with respect to oil boilers** and found that one-string systems with **design temperatures 90/70°C** were the cheapest.

As DH developed, it pushed the temperatures down for the sake of efficiency. In 1990, the first design criteria was included in the building code: 70/40°C, which was strengthened at a second stage to **60/40 °C**, which appeared as a **good compromise between efficiency, good quality of domestic hot water and costs.**

[13] With these PEF, an equivalent heat demand of 1000 MWh would have a normative energy consumption of 850 MWh, while an alternative individual heat pump (COP 2.7) would have 704 MWh

[14] Heating, Ventilation, and Air Conditioning

As a result, today in DH networks in small communities temperatures are typically around 65 / 35 °C, while they are 10-15°C higher in larger systems like in Greater Copenhagen. The **bonus/malus component on DH tariff** (see examples in both case studies), **seeking at lowering return temperatures,** and the associated meters measuring those temperatures are proving to be **strong incentives to improve at the same time energy efficiency in DHC and in buildings.**

II Local Context

A City context: Taarnby municipality, part of Greater Copenhagen's integrated DH system

Taarnby is a 43,000 population suburb 6.5 km south from central Copenhagen, which is part of Greater Copenhagen's urban area and hosts its airport.

The municipality has its own public utility, Taarnby Forsyning[15], responsible for drinking water, wastewater, district heating and district cooling services. The aim of this company is to operate these services as efficiently as possible to the benefit of all consumers.

District heating was introduced in Taarnby in 1981, following the national energy efficiency strategy aiming to reduce oil dependency and to promote CHP in a cost-effective way, as introduced in Section I. The district cooling business unit, which does not fall under the Heat Supply Act and operates in a liberalised market, was created in 2018 in the frame of the development of the energy infrastructure of the new business district of Kastrup, and is the focus of this case study.

The Kastrup business district is a new international business area being developed close to Copenhagen's airport. The development works started in the early 2010s, with the first new building, the Blue Planet aquarium, inaugurated in 2013. In 2021 the district will host 55,000 m^2 of new buildings, including offices and hotels, as well as an existing office building. Before 2025 it is expected to grow up to 170,000 m^2 and the potential is even larger, as the business district is expected to be extended to replace a nearby old industrial area.

Figure 4: Simulation of the future eco district Scanport, which is part of the Kastrup business district and will be supplied by district heating and cooling (source: visualization Skanska 2019)

15 http://www.taarnbyforsyning.dk

The development of this new district illustrates how "smart cities also have smart backyards"[16]. The land that hosts the new business district was mostly not urbanised until the arrival of highway and a train to the airport and Sweden close to the district in 2000, and a metro station in 2007, as part of the new line connecting the airport and the city centre. This brought the opportunity to re-think this area with the local actors, and made it attractive for DC consumers like businesses and hotels, valuing the **synergies between public transport and DC**. The municipality and its public utility agreed to cover the water basins of the nearby wastewater treatment plant and established facilities to eliminate the nuisance odours in 2013 in order to welcome the new aquarium. This large consumer justified the extension of the existing DH grid, enabling a fuel switch from gas to DH of the neighbouring buildings, and setting the pillars for a **smart DHC system valuing synergies between the existing district heating grid**, **a new district cooling grid, the wastewater facilities, the electricity sector,** and interconnected to the DH system of Greater Copenhagen.

B Local heating and cooling markets

Taarnby, as all municipalities in Denmark, is responsible for implementing heat planning since the 1980s. It established and approved its first Heat Plan in 1982, identifying through a 20-year cost-benefit analysis the optimal zones for collective heating infrastructure, i.e. district heating or natural gas. As a result, **60% of the local heating market is supplied by DH**, and the remaining 40% by natural gas (see Figure 5).

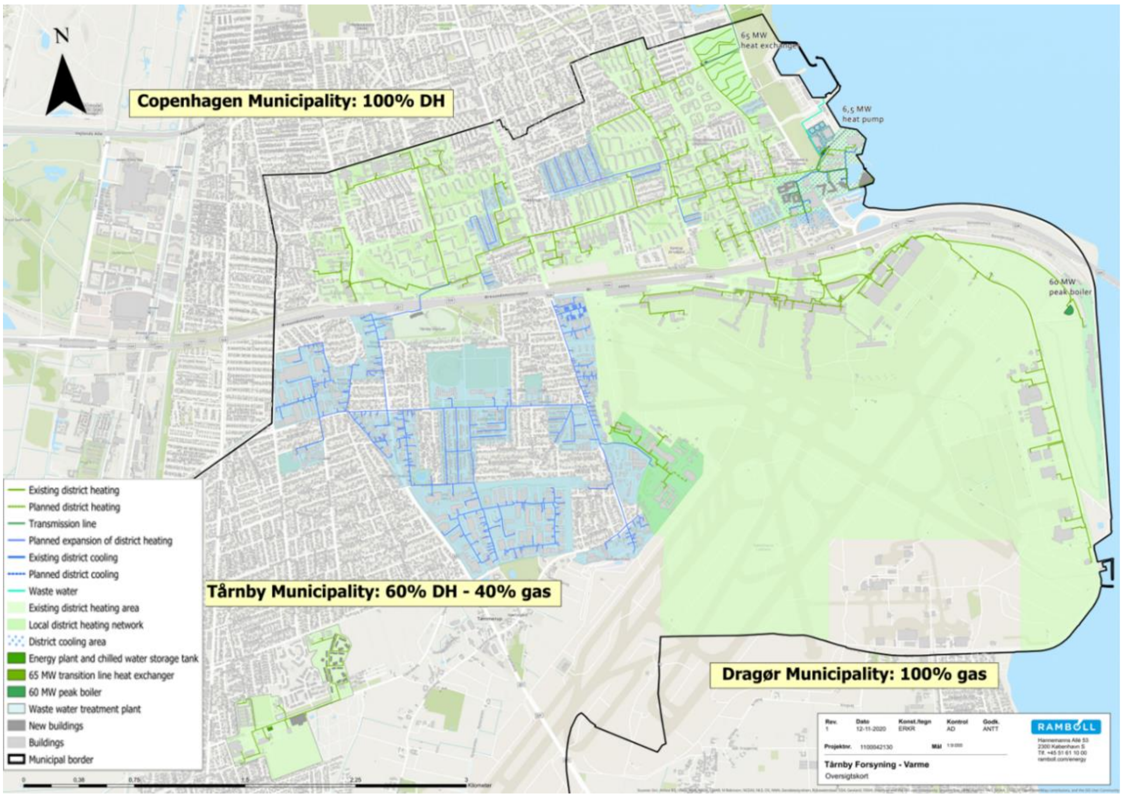


Figure 5: Market share of collective heating options in Taarnby and neighbouring municipalities

This **heat zoning prevents natural gas from supplying DH zones** (in green) **and vice-versa,** for the sake of cost-efficiency. The Heat Plan is expected to evolve in the near future, as a direct outcome of the national Climate Agreement of 2020, to enable the **transition of areas supplied by natural gas to RES-based energy supply options, i.e. DH or heat pumps**. The densest areas (in blue) are expected to switch to DH, while

[16] HOT COOL Magazine - Smart integration of Energy and Water (link to article)

areas with a predominance of individual housing are expected to switch to a combination of DH and individual heat pumps.

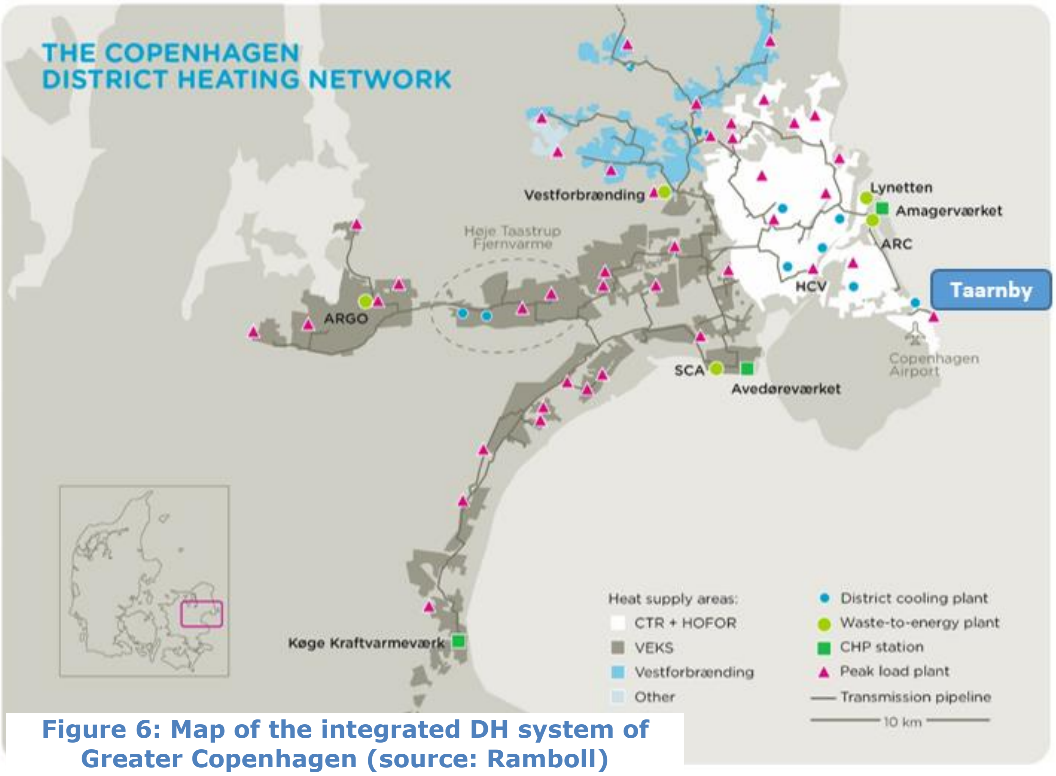


Figure 6: Map of the integrated DH system of Greater Copenhagen (source: Ramboll)

Taarnby's DHC system is integrated within the larger DH system of Greater Copenhagen (cf. Figure 6). This integrated DH system, analysed in the previous JRC report mentioned above, supplies 98% of the covered area (18 municipalities) through an interconnected system of 3 transmission companies (CTR[17], VEKS[18] and Vestforbrænding[19]), delivering heat to 24 distribution companies (the largest being HOFOR[20]), supplying more than 10,000 GWh/y of low-carbon heat to more than 1 million inhabitants.

Taarnby was indeed one of the founding municipalities of this integrated DH system, created in 1984 as part of the national energy strategy. Taarnby is also one of the 5 municipalities co-owning CTR, and before the development of the Kastrup business district all its heat was supplied from this heat transmission company.

In the first stage of Kastrup's development in 2013, the demand of cooling was not enough to justify the creation of a district cooling network. **With the arrival of large cooling consumers (hotels, offices…), DC produced through large heat pumps appeared as the most cost-efficient and environmentally performant cooling solution**, showing significant advantages with respect to alternative individual cooling solutions (electric chillers and sea water cooling), such as:

- **Lower prize,** enabling to benefit from economies of scale, and to reduce the overall cooling capacity due to the integration of a 0.9 simultaneity factor[21], which can be even lower, as measurements and experience have shown;
- **Simple, flexible and turnkey solution**, which can evolve with the demand as the district and DHC technologies develop;

[17] https://www.ctr.dk/
[18] https://www.veks.dk/
[19] https://www.vestfor.dk/
[20] https://www.hofor.dk/
[21] The ratio of the maximum coincident cooling demand to the total connected load

- The possibility to integrate a **chilled water storage tank** and more efficient heat pumps, enabled by the economies of scale;
- The possibility to value **synergies with other urban infrastructure** (wastewater, district heating, electricity and ground source cooling), resulting in higher efficiencies and socio-economic benefits;
- **The reduction of noise, vibrations and used space for cooling equipment**, enabling to use that valuable space for other purposes (e.g. rooftop, terrace, or additional usable space).

The municipality of Taarnby, through its public utility and supported by its consultants, developed in 2018 a **new heat plan for the supply of district cooling in Kastrup,** proving that the proposed solution, presented in the following sections, is the most cost-efficient. To do so, it was compared to the alternative heating and cooling solutions, following the national methodology, and approved by the Danish Energy Agency.

III Presentation of the DHC System

The new DHC system of Taarnby entered operation in mid-2020, and is **presented by its promoters as the smartest DHC system in the world**, and a world-class example of smart sector integration or sector coupling, in particular between the heating, cooling, electricity and water sectors. The technologies used are mature, but their combination constitutes a major innovation in DHC (see simplified functioning scheme in Figure 7).

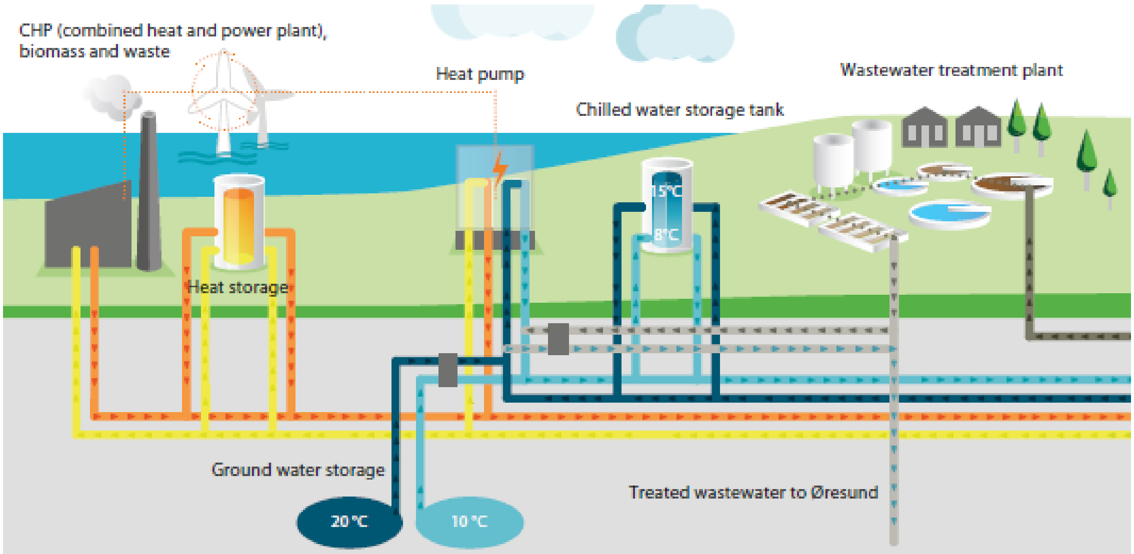


Figure 7: Scheme of Taarnby's smart DHC system, where the CHP plant and heat storage tank represent the connection to Greater Copenhagen's DH system (source: Ramboll)

Amongst its most innovative features, one could highlight:

- **The value of combined heating and cooling** and in particular in combination with the ground source cooling (Aquifer Thermal Energy Storage or ATES), which allows the heat pump to generate heat in winter while cooling the ground water, enabling to use free cooling from the ground water in summer;
- The valued **synergies with the wastewater treatment plant** (WWTP), which include the waste heat recovery of its **ambient energy,** mainly during the winter months, when the heat from the heat pump is cheaper than the heat from the CTR's DH grid. Besides, the use of the **cheaper land** at the WWTP site to build the energy plant brought 25% investment savings in this plant. Indeed, finding the right location for new DHC production facilities is very challenging in dense urban environments, while this case demonstrates how allocating space

for energy and environmental infrastructure could foster smart synergies across sectors ("smart cities have **smart backyards**").

- The **thermal storage systems** (chilled water tank and ATES in Taarnby, but also the larger heat storage facilities in the integrated DHC system of Greater Copenhagen), allow to dissociate demand and production, and to optimise the latter automatically depending on electricity prices. By doing so, the DHC system becomes a smart consumer: it contributes to a higher uptake of RES electricity, **avoiding overinvestments in the electricity grid and battery storage as well as RES curtailment** through flexible demand and thermal storage of surplus electricity, in a cost-optimal manner.

Key facts and figures*

DH market share	100 % of the supplied area
RES share	91 %
CO_2 emissions (heating)	61 Kg/MWh
Installed capacity	DC: 6.5 MW DH: 60 MW
Energy production	DC: 3.5 GWh/y DH: 45 GWh/y
Km network (double-pipe)	DH: 28 km DC: 1.5 km
Supply/return temperature	DH:75-80/45 °C DC: 8/16 °C

* Phase 1, CO_2 including CO_2 from waste

- **The integration within Greater Copenhagen's DHC system**, where the heat from Taarnby's heat pumps can be optimized in combination with heat production units and large **heat storage** facilities from this larger DH network, supplied mainly by **CHP** from biomass, wood pellets and straw at old previously coal-fuelled CHP plants, wood chips at new CHP plants, and waste-to-energy.
- The development of Taarnby's DHC project in the Kastrup business district has been organised in **3 phases**, to match capacity and demand for cooling as the district develops. Taarnby Forsyning has already signed in 2020 contracts with most of the Phase 2 consumers. The key equipment installed in each phase is presented below, while further details are provided in the following sections.

❖ Phase 0 (2013-2018)

- The aquarium and one existing building were connected to the district heating system, and the cooling to the aquarium was based on compressors and sea water cooling, as there was not sufficient market for district cooling.

❖ Phase 1 (2018-2020):

- 3 buildings connected to the new district cooling grid (a hotel, a pharmaceutical industry, and an office building), around 50% of the total demand.
- New Energy Plant at the wastewater treatment plant site:
  - 4 **reversible heat pumps** (total of 4.5 MW cooling, 6.5 MW heating);
  - **Waste heat recovery** from WWTP (4 MW);
  - **Chilled water storage tank** of 2,000 m^3 (2.5 MW cooling, 13 MWh "virtual battery"), providing peak cooling capacity and stabilising the operation of heat pumps.
- All buildings will be connected to the local district heating system in Taarnby, and thereby integrated into Greater Copenhagen's DHC system through a connection to CTR's grid via a heat exchanger (60 MW), delivering around 70% of the heat to the network, mainly through **CHP** plants coupled with **heat storage**;
- Back-up for heating provided by CTR, through a 60 MW back-up emergency boiler plant at Copenhagen's airport, which is considered as a critical heat consumer.

❖ Phase 2 (2020-2025):

- Around 8 additional buildings connected to the DHC grid (total of 11);

- **Ground source cooling ATES** (additional 2.3 MW located at the Energy Plant, for a total cooling capacity of 9.3 MW and 9.1 GWh/y, providing also **seasonal storage** capacity of around 5,000 MWh cooling stored from winter to summer).

❖ Phase 3 (after 2025):

- It is expected that an old industrial district, currently supplied by gas, in the south of Kastrup will be demolished and developed following similar standards as the new business district. The DHC grid has been designed to integrate this extension.

IV Business Model

A Governance

The DHC operator, Taarnby Forsyning, is a **public multi-utility 100% owned by the municipality**, in charge of heating, cooling, wastewater, and drinking water. It has a total staff of 32 people, with **2 FTE** (Full Time Equivalent) currently dedicated to **DHC**.

The utility follows the **typical governance in the Danish DHC model**, focusing on delivering citizens (consumers) an affordable, low-carbon heat and cold, while ensuring DHC is only deployed when it proves to be more cost-efficient than its alternative. By doing so, **Taarnby Forsyning operates following the same principles of a consumer cooperative**. The only real difference is that the Board is elected indirectly and appointed by the City Council, and that it is more likely that the DHC can value the **synergies with the other municipal services** (as this case illustrates).

B Strategy and Offer

The governance explained above, as well as the national heat planning procedure, facilitates the **alignment of objectives between the municipality, the DHC operator and the consumers.** The main objective of the utility's shareholder, i.e. the City Council, is to improve the cost-efficiency, the environmental performance and the service quality of the H&C supply.

District heating is a regulated activity, operating under the principles stated in the Heat Supply Act (non-for-profit, DH zoning, etc.). **District cooling operates under business conditions** (liberalised activity), and is therefore accounted separately from DH. The strategic logic of the City Council with regard to cooling is aligned with the principles of DH, but DC prices and services can be negotiated with each client on commercial conditions. The guiding principles retained by the utility for DC is to recover all costs, to allocate cost for reinvestment in the cooling system and to use the profit to the benefit of the energy consumers and the local community.

District cooling is therefore an opportunity for the district heating business to sell a by-product (cooling capacity and cooling energy) in a commercial way, reducing the heat price in the long run.

The project proposal for the district cooling system, publicly available[22], provides a common vision for the project's development and justifies its modular approach. Indeed, the project proposal for Phase 1 approved in 2018 includes also a presentation of Phase 2 and a preliminary estimate of its CBA (Cost Benefit Analysis), proving the interest for the utility, the consumers and the society of developing the whole project (cf. Section C).

The proposed solution for **DHC is competitive in prize with its alternatives,** and this is also demonstrated in the project proposal. Prices in Taarnby are lower than the national average, and the advantages of DHC are discussed with clients and well understood by these, despite the existing barriers imposed by the building code, encouraging individual solutions (cf. Section I).

[22] Available on Taarnby's municipality website, link here (in Danish)

The DHC operator also encourages the energy efficiency of the network, and in particular adequate return temperatures, through the bonus/malus tariff explained hereafter and **free of charge advice to costumers to reach the target return temperature**, or even improve it to get the bonus.

C Financial model

The DHC supply of the new Kastrup business district represents a **total investment of 11 MEUR** for the utility (ca. 80% Phase 1, 20% Phase 2). The breakdown of this investment per equipment and phase is detailed in Figure 8 below, in DKK[23]. It includes connection to the existing DH grid.

The investments are **mainly financed through long-term loans.** As DH is a regulated activity and benefits from a municipality guarantee, the DH investments were 100% financed through debt, which is "business as usual" (BAU) in Denmark. The situation of the DC investments is different, given the fact it is a liberalised market. In this case, debt funding covered ca. 60% of the DC investments, and the rest was funded up-front through the connection fees of the clients.

Efficient DHC systems in Denmark benefit from the environmental taxes and a national heat planning procedure which integrates socio-economic benefits in their financial model, meaning that the financial and socio-economic assessment of DHC projects converge. As a consequence, this model does not need additional investment subsidies or tariff support schemes.

In the case of Taarnby's new DHC system in Kastrup's business district, **the current facilities (Phase/Stage 1) have brought to the society of Denmark ca. 8 MEUR of benefits** (NPV[24]), corresponding to an IRR[25] of 13%. The benefits for the local utility and consumers are also significant, as shown in Figure 8, and will be much higher once Phase 2 is completed.

District cooling project		Stage 1	Stage 2
No of buildings	no	3	11
Floor area for cooling	m^2	55,000	170,000
Energy			
Cooling demand	GWh	3.5	9
Cooling capacity demand	MW	4.3	10.2
Expected capacity to network	MW	4.3	9.2
Heat pumps cold	MW	4.3	4.6
Storage tank capacity	MW	1.2	2.5
Ground source cooling	MW	0	2.0
Total installed cooling	MW	1.2	9.2
Heat pumps heat	MW	6.7	6.7
Heat from combined H&C	GWh	4	11
Heat from waste water	GWh	41	39
Total heat generation	GWh	45	50
Investments			
Building	Mill.DKK	4	4
Ground source cooling	Mill.DKK	0	9
Heat pump	Mill.DKK	38	41
Waste water heat exch.	Mill.DKK	2	2
Chilled water tank	Mill.DKK	4	4
District cooling grid	Mill.DKK	10	14
Consumer connections	Mill.DKK	2	5
Connection to DH network	Mill.DKK	3	3
Total investmetns	Mill.DKK	**62**	**80**
NPV benefit, including env. Costs			
Society	Mill.DKK	60	103
District cooling business	Mill.DKK	17	52
Consumers	Mill.DKK	5	8
Internal rate of return	%	13	41

Figure 8: Techno-economic assessment of Taarnby DHC system (source: Ramboll)

The investment costs are recovered through H&C sales. The **tariff structure** for both DH and DC follows similar principles, aiming at **reflecting real costs for the utility and remaining competitive in prize with the alternative H&C solution** (see economic considerations related to an alternative CHP production from CTR grid in Section V.C):

i. A connection fee (DKK/kW), to cover connection costs and part of the investments to be paid only once;

ii. An annual fixed term (DKK/kW/y), to cover the amortization of the investments and OPEX (Operational Expenditure). The amount is **adjusted depending on the contracted capacity** (as done, for instance, by gas companies);

iii. A variable term (DKK/MWh), to cover energy consumption. **Seasonal tariffs for cooling** are in place to optimise the system's efficiency (i.e. cooling is cheaper in winter than summer). Taarnby Forsyning is considering introducing a seasonal tariff

[23] 1DKK = 0.13 EUR
[24] Net Present Value: the value of all future cash flows (positive and negative) over the entire life of the investment (20 years) discounted for to the present (4% discount rate).
[25] Internal Rate of Return: discount rate that makes the net present value of all cash flows equal to zero in a discounted cash flow analysis

for heating too, as the cost of generating heat in summer from CTR is significantly lower than in winter;

iv. A bonus/malus term depending on the return temperature (DKK/°C/GJ), to promote system efficiency. The district heating consumers are given a **target return temperature, and a prime or penalty is applied** if the return is lower or larger. During the negotiations with cooling consumers, Taarnby Forsyning has stressed the importance of a high return temperature, i.e. above 16 °C, and is considering to introduce a similar bonus/malus tariff to encourage efficiently.

Clients are equipped with individual **smart meters**, enabling the utility to have real-time data and to act remotely. They are invoiced monthly, and apartments have sub-metering.

V Integrating RES and Waste Heat

A Technical considerations

The map below shows the new energy plan and DHC infrastructure of the Kastrup district, located close to Taarby's wastewater treatment plant.

Figure 9: Energy plan for Kastrup district and DHC infrastructure (source - Ramboll)

Connected buildings

The 11 buildings that will be connected to the DHC grid are **highly efficient**. The national building code's requirements on indoor thermal comfort and air quality have been increasing in the last years, and in practice **all new office buildings and hotels need cooling** to meet these standards. All buildings are new except for an office building in the southern part and the Blue Planet in the northern part.

The heating and cooling demand will be largely covered by RES and waste heat sources, as shown in Figure 10 below. Buildings will connect during the first 4 years of operation, and ground source cooling (ATES) will be available as of 2022.

- The **production of cooling** (left graph below) provides process and comfort cooling (the former being required by the pharmaceutical industry and the aquarium), and is mainly supplied by the heat pumps during Phase 1, and by the ATES once Phase 2 is in place. The supply temperature is **8°C** (return 16°C);
- The **production of heating** from the heat pump (right graph) is mainly based on waste heat from the wastewater plant, and the supply temperature is **75-80°C** (return 45°C).

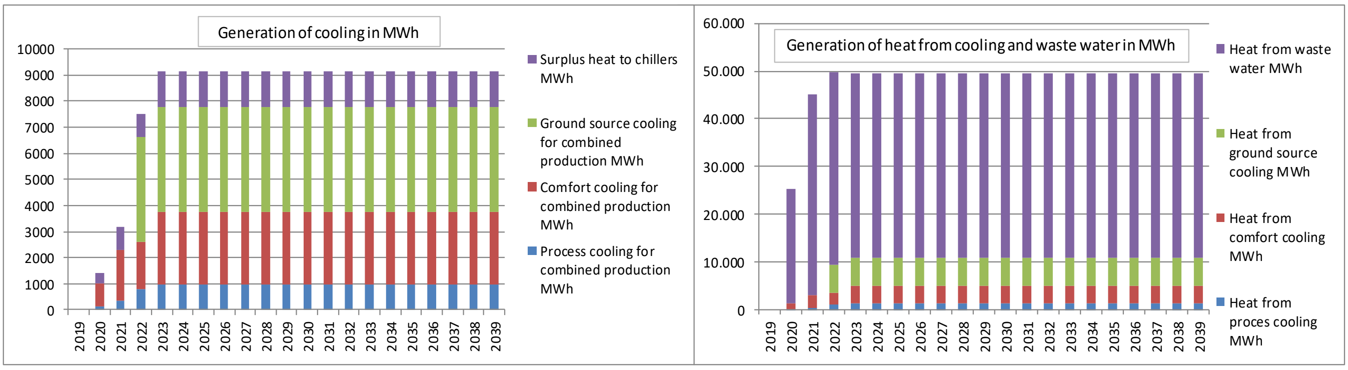


Figure 10: Expected evolution of heating and cooling production from the energy plant, including sources of H&C supply (source: Ramboll)

Flexible capacity and modular approach

Accurate heating and cooling demand forecasting is a challenge for new districts, and DHC solutions can contribute to reducing the risk of overinvestments in H&C equipment in buildings. In Taarnby, a simultaneity factor of 0.9 for cooling has been considered, meaning only 90% of the contracted capacity is expected to be used at the same time, and the utility envisages to use temporary **mobile cooling units** of ca. 1 MW if the cooling demand proves higher than expected. In case the demand in the long term increases the capacity one option will be to use more ground source cooling or drain water, or to install a new small heat pump close to the Phase 3 consumers. However, the utility expects the **simultaneity factor** to be lower than 0.9 in Phase 3 due to a large number of consumers. Indeed, experience from many building installations indicate that **there is a significant overcapacity installed in most individual cooling plants** which could be considered as "dead capital". DC reduces this dead capital in excess cooling capacity in the long term, as available capacity from one consumer can be sold to another, providing a new flexibility lever.

The **flexible and modular approach** retained will enable to deal with demand uncertainty in a cost-optimal way, and to progressively increase capacity as the district develops while integrating additional leverages of optimisation (cf. Section VIII).

Waste heat recovery from the wastewater treatment plant

The **ambient energy** from the wastewater treatment plant is a valuable resource for DHC. At Taarnby, treated water is extracted at the outlet to the sea at an average temperature of 14°C, and its energy is recovered through 2 heat exchangers of 2 MW each, located at the Energy Plant, which are **coupled to the heat pumps to produce heating and cooling** (cf. Figure 11).

The annual potential for cooling the wastewater (or extracting heat from the wastewater) has been estimated at **37 GWh (4.2 MW on average)**, based on an annual volume of 5.4 million m^3 cooled to 6°C, with external temperatures varying from 12 to 20°C. The heat plan project proposal demonstrates the economic interest of this solution with respect to its alternative, providing also a more stable temperature throughout the year.

The **sewer-external** technology retained for Taarnby's DHC system is more flexible than in-sewer, as it is independent of the sewer design, state, slope, etc., and facilitates the access for maintenance and operation. **The waste heat recovery does not impact the processes at the wastewater plant**, and does not generate any additional cost for it. In fact, the cooling of the treated wastewater in winter benefits the environment, as the water will be closer to the temperature of the sea.

B Integrating RES through reversible heat pumps and thermal storage

The waste heat from the wastewater treatment plant is valued through four **2-step ammonia heat pumps** with a Coefficient of Performance or COP of 3.5 heating, 2.5 cooling, able to simultaneously produce heating (75°C) and cooling (8°C) and to optimise their operation taking into account electricity prices. **Coproduction of heating and cooling is indeed more efficient than separate production**, and the thermal storage tank provides an additional leverage for optimisation. The heat pumps are expected to operate more than 6000 h at maximum load, and the technology retained is optimised for the use in district heating and ground-source cooling.

The system integrates at the Energy Plant a 15m-high **chilled water storage tank** of 2,000 m^3, equivalent to 2.5 MW or 13-18 MWh depending on the return temperature, and up to 10 MW in 1 hour. It provides additional cooling capacity and enables the utility to produce energy when electricity prices are low, mainly because there is a surplus of intermittent electricity (wind and solar PV), and to store it for a later use.

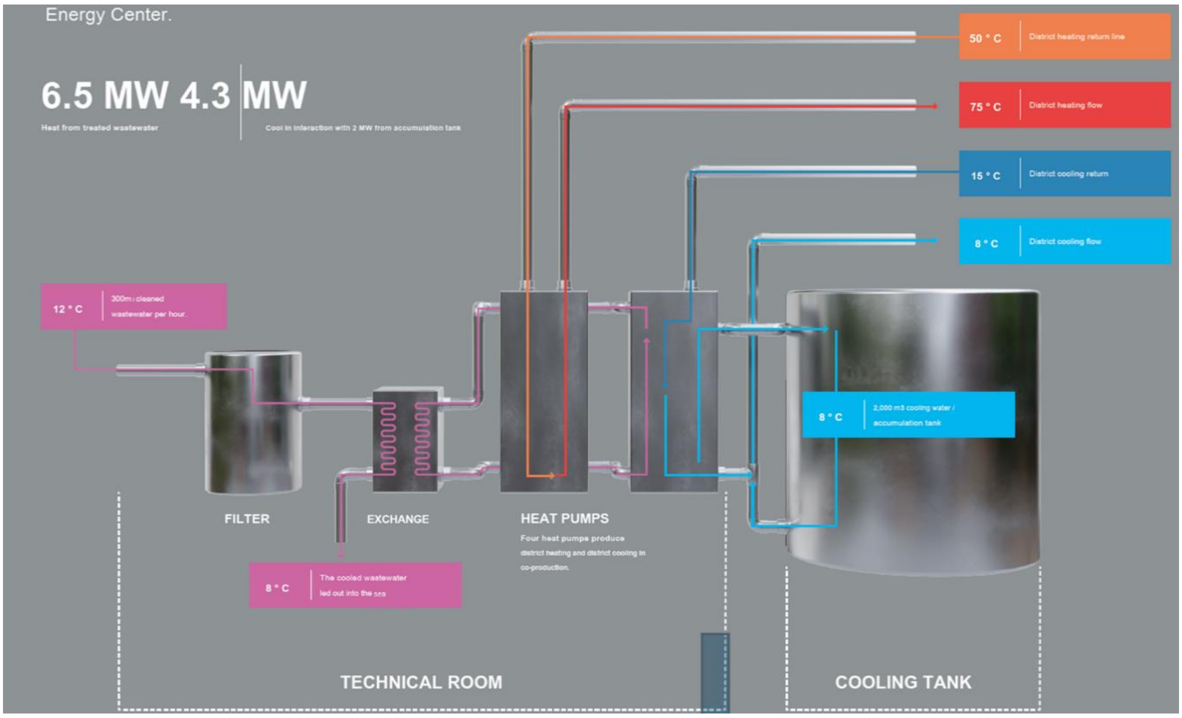


Figure 11: Functioning scheme of the Energy Plant: heat exchanger using treated water from the WWTP, heat pumps and chilled water storage tank (source: Taarnby Forsyning)

This sector coupling solution is also a remarkable example of how DHC can contribute to a higher integration of intermittent RES electricity. The use of large heat pumps with flexible production and thermal storage enables system optimisation. This will be done manually at the first stage, based on **daily price signals**, but Taarnby Forsyning and CTR plan to integrate the heat pumps in the overall **load dispatch** of Greater Copenhagen's DH system, along with many other large heat pumps. By doing so, the heat production will be optimized automatically and in real-time. This is a cornerstone of the Danish energy transition strategy, and could be largely replicated in other countries. Besides, heat pumps can also down-regulate when there is a surplus in the electricity grid due to high intermittent production, or up-regulate if needed, providing **balancing services**. At the moment, the heat pumps of the analysed DHC grid in Taarnby do not participate in day-ahead and balancing markets, which could be an option in the future.

C Economic considerations

As indicated in Section IV.C, the socio-economic assessment of the DHC project is part of the heat planning procedure, and follows a national methodology. The assessment done at project proposal stage concluded that **Taarnby's DHC project is highly profitable for the society of Denmark,** and is also profitable for the utility and for the heat consumers **without the need of any direct subsidy.**

Some of the key parameters considered for this assessment, are the following:

- The **value of the alternative source of heating** considered is the CTR variable cost of heat production, mainly from biomass CHP plants. For the socio-economic analysis it is simulated hour by hour, where the price is very low in summer and higher in winter.
- The **alternative source of cooling** is individual chillers, and the base case includes therefore all alternative investments in chillers and respective generation costs. Additional benefits of DC (e.g. value of space) are not taken into account.
- The **sensitivity analysis** shows that the most critical parameters are the electricity price and the value of the generated heat.

The electricity tax for large production of heating and comfort cooling has been recently reduced in Denmark, and will be almost zero as of 2021, improving the business case for DHC systems optimising their operation taking into account electricity prices. By doing so, the Government recognizes the role of this technology in further integrating RES electricity.

Regarding the value of the generated heat, and in general the competitiveness and complementarity of this new DHC grid with respect to the existing DH grid in Greater Copenhagen, it is worth mentioning that **the combined production of H&C, the sales of cooling capacity and the use of waste heat from wastewater have proved to present a competitive advantage.** Besides, **heat pumps and CHP are complementary technologies**, as they are driven by electricity prices and when these are high the CHP plants can increase their production while the heat pumps can be stopped, and vice versa if electricity prices are low. An integrated approach makes therefore sense.

D Contractual and organisational aspects

The **contracts between Taarnby DHC utility and its clients are long-term**, of typically 20 years. While this is BAU in DH, due to Denmark's regulatory framework and DH policies, **DC contracts must be negotiated on a case by case** basis. In the case of Taarnby's Phase 1-clients, discussions started in 2013 and contracts were signed in 2018 for **20-year** service. For both DH and DC, it is not expected to experience disconnections, due to DH zoning and the proved competitiveness of DC with respect to its alternative.

The **waste heat** recovery from the wastewater treatment plant is not contractually formalised, as the owner of all the infrastructure is Taarnby's utility and the waste heat is supplied for free. The DHC utility pays a rent to the municipality for the land which is occupied by the energy plant.

The DHC team at Taarnby's utility integrates 2 FTE, who cooperate closely with the utility's consultants and specialized service companies for equipment maintenance since the 1980s. This type of **public-private cooperation** scheme, in which all services for which there is a market are outsourced to private companies in case it is more cost-effective than internal resources, is widespread in Denmark, and **enables all utilities, independently of their size, to develop world-class projects** such as this one. The private party (consultant, supplier or contractor) brings up-to-date knowledge and additional resources, enabling also access to funding through the development of **robust business models**, while the public party remains the owner and operator of the infrastructure, and steers its development ensuring coherence with local and national policies.

E Cooperative approaches and role of digital solutions

The approach retained by the utility for this DHC project is **highly cooperative**. It has been developed taking into account the main stakeholders, namely the **municipality**, the local **utility**, **CTR**'s DH transmission network, the **building owners** and, where different to the latter, the **consumers**.

Digital solutions enable the **automatic operation optimisation**. The control unit constantly checks prices and the needs of the end-users to ensure optimal use of the resources. During periods when the **electricity price** is lower, typically at night, the heat pumps can store cold water for the following day, and heat pumps can also **down-regulate in case in case of capacity problems on the power grid.** Further work is expected in this field, in cooperation with the TSO (Transmission System Operator) and Greater Copenhagen's Heat Dispatch Unit, to integrate new optimisation parameters (cf. Section VIII).

VI Synergies with Other Urban Infrastructure and Local Value Creation

Taarnby's case is a flagship example of smart sector integration. It illustrates how **synergies between transport, DH, DC, water infrastructure and the electricity system** can be valued, and integrated in a larger urban development project. This **comprehensive approach to urban planning**, integrating environmental criteria and maximising infrastructure synergies, is an exemplary and replicable model for new districts.

The value creation for the community, the utility and the consumers has been quantified through a 20-year CBA, in the frame of the heat planning procedure, under transparent hypotheses which are applied nation-wide. Once Phase 2 is completed, the expected **return of investment for the local community is 41%**, corresponding to an economic NPV benefit of ca. **13 MEUR**. The high internal rate of return is due to the fact that the base case includes high investments in individual chillers in the buildings.

Moreover, **further non-quantified benefits** are expected, such as freeing-up space of chillers at building level, the reduction of vibrations and noise with respect to the alternative solution, no refrigerants in the building, an improved capacity of the system to adapt to real demand, etc. These are additional arguments used during the negotiation for DC.

VII Consumer Empowerment

The Danish model for DHC is consumer-focused, and protects and empowers these. The heat planning procedure ensures a very high level of **transparency** in the decision-making process, and the **policies** in place and **governance** of the utilities promote efficient cooperation of all stakeholders to foster the deployment of affordable, sustainable and cost-efficient heating and cooling solutions.

Besides, DHC in Denmark is a **mature technology**, and **citizens are aware of its benefits** and key role in achieving a higher uptake of RES.

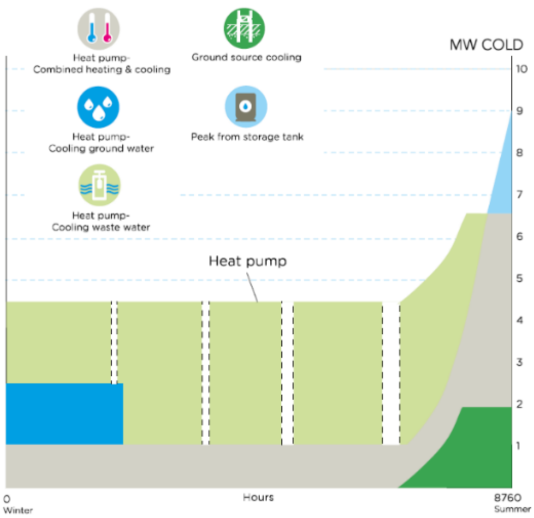
Figure 12: Example of information on DH energy consumption and return temperature made available to clients, ("Målt" = measured - source: Taarnby Forsyning)

In Taarnby, the utility clients and citizens connected to the DH grid can **visualize their consumption, temperature levels, billing and contractual information** through the utility's website, and get free of charge **advice to optimise their return temperature** in case it does not reach the target (cf. bonus/malus tariff in Section IV.C). These services will be soon offered to DC clients as well, as the smart meters used enable so.

VIII Prospects

Phase 1 of the project was commissioned in mid-2020, and the next step for the DHC system is to implement its Phase 2 (integration of ATES and connection of new buildings), and to further develop, in cooperation with TSO and neighbouring DH utilities, the systemic optimisation of the DHC network's operation.

During the project's Phase 2 (2020-2025), an ATES system using ground water will be set up to meet Kastrup's increasing demand for cooling. The heated ground water at the "hot well" will complement the heating from the wastewater plant during winter (light green area below) and store cold water at the "cold well" (cf. Figure 13) to generate cooling in summer without the co-production of heat (dark green), as heat would rather be bought from CTR DH transmission system in summer at a very low cost. Thereby, by using ground water and the chilled water tank, the cogeneration of heating and cooling from the heat pump in summer will be reduced as much as possible. The cold well will be able to store around **4,000 MWh cold** energy corresponding to 2,000 max load hours. By integrating this **seasonal storage** system, the efficiency of the DHC system will be increased, reaching a combined overall H&C **COP** of **5.6** (Vs 3.4 in Phase 1).



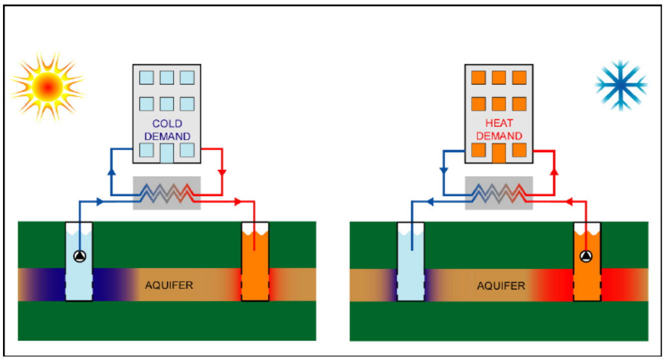


Figure 13: Annual cooling load curve (left – source: Ramboll) and ATES functioning scheme (right)

Discussions are also ongoing for a **better optimisation of the heat pumps hour by hour, depending on marginal production cost in Greater Copenhagen's DH system and on electricity prizes.** To do so, Taarnby's utility is in contact with Greater Copenhagen's heat dispatch unit, operated by CTR, VEKS and HOFOR, and also with the national TSO. One of the topics discussed with the latter relates to introducing a **special network tariff for smart consumers**, such as this DHC system.

IX Conclusion and Key Success Factors

Taarnby's new DHC system in Kastrup is **a remarkable example of smart sector integration**, illustrating the key role that DHC systems can play in building **integrated energy systems.** It has received international recognition, receiving in November 2020 an award from the European Heat Pump Association[26], recognising the most efficient, smart and sustainable Heat Pump projects at local level.

The key success factors identified for the integration of RES and waste heat sources are:

i. **The Danish regulatory and policy frame for DHC, and the resulting governance model**. The existence of significant environmental taxes, as well as the DH policies in place (non-for-profit principle, mandatory heat planning, DH zoning, etc.) have supported since the 1980s the deployment of efficient, low carbon and affordable DHC systems, which currently do not need any subsidies to be financially viable. DH policies have also shaped the sector's governance, with 95% of networks owned by

[26] https://www.ehpa.org/

municipalities or consumer associations. Such a governance model, where **consumers are directly or indirectly the utility's shareholders**, has empowered these, and facilitated the **collaboration** between the key stakeholders (in this case utility, city, consumers, national government and CTR), as all of them share the same objectives.

ii. **Mainstreaming long-term H&C planning in cities through a transparent and nation-wide shared methodology, taking into account externalities.** The project proposal resulting from the heat planning exercise is a detailed and pedagogic document, publicly available, explaining the reasons behind the DHC supply choice (and DH zoning) in comparison with the alternative, using a 20-year CBA taking into account externalities, and following the guidelines from the National Energy Agency. This method **guarantees a competitive price** against the alternative, **quantifies the socio-economic benefits for the society** (including CO_2 and other harmful emissions' reduction, energy efficiency gains…) and lists other qualitative costs and/or benefits.

iii. **Valuing cross-sector synergies with DHC to foster local decarbonisation in a cost-efficient way,** with the ultimate goal of building a more integrated and resilient local energy system. Indeed, Taarnby's case study illustrates how synergies between heating, cooling, water, and electricity can be valued. By doing so, this DHC system enables **higher uptake of waste heat and RES, including renewable electricity**, avoiding over investments in buildings (H&C equipment), in the electricity grid (reinforcement, battery storage) and renewable electricity curtailment though flexible demand and thermal storage of electricity.

iv. **The integration of district cooling in the existing DH offer appears also as an important leverage for new efficiencies and a higher RES integration**. Indeed, the cooling demand keeps growing, due to climate change and higher air quality standards in efficient buildings. Co-production of heating and cooling is more efficient than separate production, and **district cooling** has numerous advantages with respect to alternative individual chillers, such as lower costs in dense areas, lower environmental impact, better flexibility, reduced space use…Besides, DC has brought to Taarnby's utility additional revenues and the possibility to improve its energy offer and to increase the efficiency of its DH grid.

v. **Taarnby's DHC system combines an optimal mix of technologies, enabling to optimise the operation of the DHC system to maximise efficiency and RES share**. Ambient energy from the nearby wastewater plant is valued through reversible heat pumps, connected to thermal storages (cold storage tank in the local DC system and heat storage tanks and a pit in the CTR-VEKS DH transmission system) and operated in an optimal way taking into account real-time electricity prices, ultimately resulting in a higher RES uptake. The **tariff structure, with seasonal prices and a bonus/malus component**, is cost-reflective and fosters the system's efficiency.

vi. **The flexible and modular approach retained** for the DHC grid's development is particularly relevant for new districts. It allows to adjust the production to the real demand and to better integrate demand uncertainties and technology developments. Taarnby's DHC grid takes into account a simultaneity factor when evaluating the demand, avoiding its clients to overinvest in individual H&C solutions, while ensuring security of supply through back-up boilers and mobile chillers.

vii. Finally, Taarnby's case study also illustrates how **new forms of public-private collaboration** are developing, which can be particularly fruitful and needed in the **early stages of efficient DHC projects**, to jointly build a robust business model. Taarnby's utility has closely collaborated with its consulting team, suppliers and future clients to jointly develop this world-class project**. The utility's consultant reinforces and empowers the public utility's team**, but the latter remains the owner and operator of the grid, steering its development and ensuring coherence with local and national policies.

4.2 DENMARK[27]: Solar DH in Jaegerspris managed by an energy community

Established DH market 64%	Renewable Energy Sources	+ Waste Heat/Cold Sources	56% of RES share
	Solar thermal; Thermal storage; Ambient energy (from the air)	CHP (gas-fuelled)	

Jægerspris DH	
Consumer owned	
4 000 inhabitants	
DH market share	80% (in terms of nr. of clients)
CO_2 emissions	115 Kg/MWh
Installed capacity	20.1 MW
Energy production	39 GWh/y
Supply/return temperature	Summer: 67 / 43°C Winter: 67-80/38-40°C

Key Success Factors

- A supportive national context, promoting the creation of new greenfield DH grids in small communities and their progressive decarbonization
- Applying social innovation to the heating sector to foster the creation of energy communities
- The support from the municipality
- A governance maximising consumer empowerment to ensure a long-term, resilient heat supply at the lowest cost possible
- The low-temperature regimes of the heating equipment in buildings
- A modular approach to continuously adapt the grid to evolutions in the policy context, and integrate best industrial practices and technologies on the market
- A deep study on possible technical solutions for each DH grid upgrade, leading to an optimal technology mix
- Large cooperation between local actors (citizens, municipality, national DH association, consultants, suppliers…)

I Local Context

A City context: a DH system developed as a citizen project

Jaegerspris is a **4,000-population town**, part of the municipality of Frederikssund (ca. 44,000 inhabitants), in the Central Region of Denmark. The municipality, as **heat planning authority**, has contributed to the development of its DH grid, which supplies also the neighbouring communities of Gerlev (770 inhabitants) and Landerslev (250).

Jaegerspris' consumer-owned DH company, Jaegerspris Kraftvarme[28], was created in 1994 by a citizen initiative, and the resulting greenfield DH system is the largest project of this kind in Denmark (see reference to new greenfield DH networks in small communities in the 1990s in Section 4.1 I). This project was originally proposed by a consulting company, and following its good reception by the citizens, willing to steer the project and own the resulting infrastructure, it was supported by the municipality and the National DH Association.

Figure 14: Founding meeting on 31/01/1994

The **cooperative and participatory approach** retained since the early stages of the DH project enabled the different stakeholders to align their interests and to jointly build a tailor-made solution. To do so, a project office was established in the town, presenting the project, its advantages and registering interested clients. Preliminary contracts were signed at a first stage by 400 households, all public buildings and the local social housing association, and further supporting actions including a **State subsidy to switch from electric heating to DH** enabled to gain 250 additional households and reach the target demand allowing to start the construction works.

It is interesting to note that during the above preparatory phase, an alternative business model was offered by the local power utility, based on private governance. This company offered to act as a private investor on the DH system (network and production facilities), funding the project and recovering the investment through its operation. This model, which was in the end not favoured by the municipality and the founders of the DH company, was retained in many other new greenfield DH networks in small Danish communities and years

[27] Details on the **national DHC context** are provided in Chapter 4.1 (case study Taarnby) and in **ANNEX 1**, including key figures, actors and regulatory aspects

[28] https://www.jp-kraftvarme.dk/

later proved to result in higher costs for the consumers than those networks having chosen a municipal or consumer ownership.

Jaegerspris DH network entered operation in 1995, resulting in a **major switch from oil and electric heating to DH**. Since then, it keeps growing and improving its cost-efficiency and carbon footprint, and has progressively integrated state-of-the-art technologies, as explained in the following sections, proving to be a key enabler of the community's **energy transition**.

Today, it supports the municipality's aim to become **fossil-free by 2030**, and climate neutral by 2045. In 2020, Frederikssund developed a **Climate Action Plan** to this end, addressing all sectors and emphasizing the need of exemplarity from the City Council, and of a broad cooperation between the municipality, citizens and companies to achieve the common climate goals.

B Local heating market

Jaegerspris, as all rural communities in the area, has a **building stock dominated by one-family houses.** The average consumption of existing buildings is 105 kWh/m^2/y, while new houses consume about 60 kWh/m^2/y. As a consequence of the building temperature regime developments in Denmark mentioned in Section 4.1 (I), these buildings are **typically supplied at around 65°C**, which is relatively low, enabling to reach higher efficiencies at building level and to switch from oil to DH without modifying the heating equipment.

Before the arrival of DH, the local heating market was dominated by individual oil and electric heating solutions. Today, **DH has ca. 80% market share in the covered area**, with 1,448 consumers connected out of a potential of 1,745. This share was 70% in 2010, and since then the network has experienced an annual steady growth of about 30 customers (around 2% of the total potential). Today's main alternative to DH is electric heat pumps.

The implementation of the new DH network followed a **comprehensive heat planning procedure** organised by the municipality in 1994-1995, as required by the Danish Heat Supply Act (also called "project proposal" procedure). Through this national procedure, based on a **20-year CBA, DH proved to be the most cost-efficient solution for heat supply** in the analysed area. Figure 15 below shows the evolution of DH price including Value Added Tax (VAT)and the current price of the alternative heating solutions for a typical household in Jaegerspris, namely oil boiler and electric heating (two columns on the right respectively).

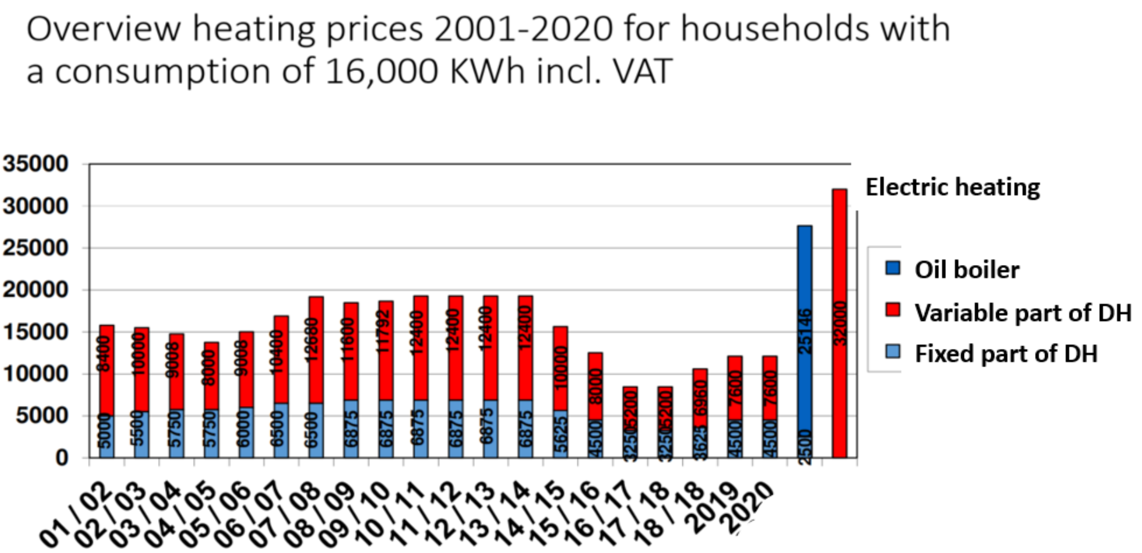


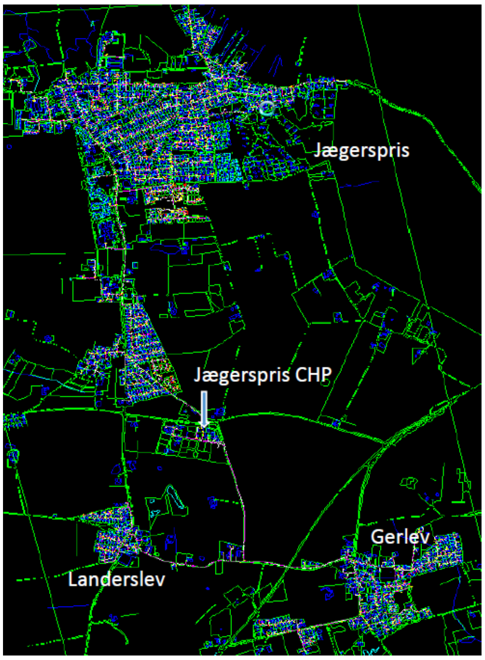
Figure 15: Price comparison between DH and individual heating solutions for a typical household (source: Jaegerspris Kraftvarme)

During the planning procedure, **the municipality decided not to make it mandatory to connect to DH.** This was actually optional in Denmark (and not done anymore), and following the heat plan approval it was decided not to activate this mechanism.

Today's connected buildings include **one-family houses, schools, and a few companies.**

II Presentation of the DH System

The DH system of Jaegerspris is a **concrete example of an energy community.** This **consumer-owned** network, interconnecting 3 neighbouring small communities, has been evolving since its creation to **progressively phase out fossil fuels** (oil and gas), **integrate RES** (namely solar thermal, ambient energy via a gas-driven absorption heat pump and renewable electricity), and **surplus heat** from combined heat and power (gas fuelled engine), improving its efficiency and reducing the heat price to the consumers.



Key facts and figures (2019)

DH market share	80 % (in terms of nr. of clients)
RES share	56 %
CO_2 emissions (heating)	115 kg/MWh
Installed capacity	20.1 MW
Energy production	39 GWh/y
Km network (double-pipe)	33 km
Supply/return temperature	Summer: 67 / 43°C Winter: 67-80/38-40°C

Figure 16: Map and key figures of Jaegerspris solar DH system

The **historical developments** on the production side were organised around 4 stages:

1995	• **Creation** of the DH network in the frame of the national heating strategy. • Heat supply mainly through **2 gas engine CHP** plants of **7.1 MW** (each 2.9 MWe, 3.5 MW heat) coupled with 2 storage tanks (750 m^3 each), covering 90-95% of the base load, peak load covered through **an 8 MW gas boiler.**
2010	• Introduction of a **new solar thermal plant** coupled with a 3,000 m^3 **thermal storage tank**, covering 17% of heat demand.
2013	• Enlargement of the solar plant (from 10,000 to 13,400 m^2).
2017-2018	• As gas engine **CHP** plants approached their **end-of-life** and end of feed-in-tariffs in 2018 and end of capacity payments in 2020, in a context of high gas prices, a **new system upgrade was needed to improve the network's resilience** to become independent from gas CHP plants in the future. • This upgrade consisted in installing a **new gas-fuelled hot water boiler** system combined with an **absorption heat pump** and an **electric heat pump**, to gain additional heat from the solar heating plant and ambient heat from the air.

Today's production capacity is therefore as follows (details on Section IV.A):

- A 4 MW **absorption heat pump** driven by a 6.2 MW **hot water boiler** fuelled with gas;
- 1 MW **electric heat pump** (average annual COP 5.5);
- 13,400 m^2 **solar** field, whose efficiency was increased by 16% thanks to the 2018 developments (see details on Section IV.A);
- A **thermal storage** tank with a volume of 3,000 m^3 corresponding to 140 MWh, which could supply a base load of e.g. 7 MW in 20 hours during a cold winter day;
- The original production equipment, namely 2 gas engine **CHP** (7.1 MW) and associated 2x750 m^3 storage tanks, which mainly offers regulation services to the power grid, postponing the time for major renovation (cf. Section III.B), and a **gas boiler** (8 MW).

The gas engine CHP plants represent currently only 5-10% of the production, as they are only used to provide **balancing services to the electricity grid**. However, as there is not more capacity payment, their future remains uncertain (further details in Section IV.B). Indeed, **there is currently no capacity market** in Denmark as the national TSO relies mainly on interconnections for security of supply, instead of encouraging investments in capacity and smart energy systems such as DHC.

The situation faced by Jaegerspris in 2017-2018 regarding these CHP engines is representative of around 200 small DH systems in Denmark. **The energy solution retained in Jaegerspris in 2018 was amongst the first in the country, and has been replicated** in other DH networks. However, the recent changes in national energy policy and the 2020 Climate Agreement have changed the priorities, and under the new framework the use of large electric heat pumps is favoured (see Section VII).

III Business Model

A Governance

The DH utility Jaegerspris Kraftvarme is **100% owned by consumers, and organized as a private cooperative** as all other Danish consumer-owned companies. By connecting to the district heating grid and entering a 20-year agreement, the building owner automatically becomes co-owner of the company and has one vote at the general assembly.

Figure 14: Jaegerspris Kraftvarme

Consumers are therefore involved in major investment and strategic decisions, as the only **shareholders.** The level of **consumer empowerment** is the highest possible.

The utility's main governance body is composed of **7 board members**: 4 appointed by shareholders, 2 by major consumers and one by the municipality, due to the fact that investments have a municipal guarantee for their debt funding, but also to have access to the local political sphere and an external opinion on the utility's management. **The level of transparency is very high**, and each consumer (shareholder) can access through its client's online portal or mobile App the minutes of board meetings, annual reports and accounting, historical DH prices, as well as consumption details, as explained in Section VI.

The company's **staff** consists in **3 FTE**: an operations manager, an administrative assistant and 2 on-call operators. For strategic choices and projects requiring higher human resources and/or a particular expertise (such as the key historical developments explained above), the utility hires **specialised consulting companies and technology providers.**

B Strategy and Offer

The main objective of the DH company is to ensure a long-term resilient heat supply at the lowest cost for consumers. All its investments and strategic decisions support this objective. In line with this, the utility supports the municipality in the common goal of **becoming fossil free by 2030.**

The national DH framework explained in Section 4.1 I facilitates the implementation of this strategy (Heat Supply Act and non-for-profit principle, environmental taxes, mandatory energy planning through the "project proposal" procedure…). When comparing potential solutions, **the main investment criterion is profitability in the long-term** (maximum NPV with respect to a base case scenario). The integration of potential RES and waste heat sources from own or third-party suppliers are assessed on a case by case basis, following this investment logic.

The services provided include district heating, domestic hot water, and related customer services (see Section VI) as well as **energy services aiming at improving system's performance**, such as free visits for balancing consumer's substations and inspections for improving the efficiency of the secondary system every 2 years (offered at a very low price[29]).

Today, the main strategic priorities **for the Board and management of the company are:**

- To revise the strategy and introduce a **new electric heat pump and an electric boiler** compatible with the installed infrastructure, operating in an optimal way with solar heating, gas CHP and storage to constitute a **smart energy system acting like an electric battery** (see Section VII);
- To **reconsider the role of the gas CHP plant**, and deciding whether to continue operating in the regulation market and be paid for a few hours of capacity, and by doing so extending the remaining lifetime, or to enter the day-ahead market and generate more income, which would require an upgrade of the CHP engines.
- To **maintain its competitiveness and attract the remaining consumers** to the benefit of the existing ones by **creating further awareness on the advantages of DH in Jægerspris compared to individual heat pumps**, which also are released from the electricity tax under the new policy framework, such as:
    - Offering lower connection costs and a turnkey solution for connection installations;
    - DH has a longer lifetime, as the connection cost of DH is a one-time payment whereas the small (individual) heat pumps need to be replaced after 15-20 years;
    - Environment aspects, as DH is silent, while small heat pumps emit noise;
    - Highlight the possibility of the DH system to **integrate green electricity and solar heat**, as individual heat pumps also use non-renewable electricity from the power market (e.g. produced by coal condensing plants).

C Financial model

The financial model is similar to other DH systems in Denmark, where the supportive national regulatory and policy framework makes efficient DH systems financially viable without the need of any direct subsidy.

[29] 300 DKK per year, or around 40 EUR/y (1 EUR=0.13 DKK on 11/12/2020)

The investment costs are **100% financed through long-term debt funding**[30], with a **municipal guarantee**, and recovered through DH sales (typical Danish DH model).

- The 2010 investments introducing **solar** energy amounted for **2.4 MEUR** (18 MDKK), and had a direct pay-back time of 10 years (for a 30-year lifespan);
- The new energy plant of 2018 introducing **heat pumps** represented **2.3 MEUR** investments (16.8 MDKK), and had a pay-back time of only 7.1 years (also for a lifespan of 30 years).

Following the Heat Supply Act's **non-for-profit principle, all profits are passed to the consumers,** which are also the DH system owners, **via lower tariffs**. Profit is therefore not distributed as a dividend but paid back to the consumers in terms of a recalculated variable heat price. However, and following the same principles, if there was a deficit the tariff would be increased. The objective of the company is naturally to offer quality services to the consumers at the lowest price and **therefore the financial objective is to be budget neutral.**

A standard house of 130 m^2 consuming 18,100 kWh/y has an **annual DH bill of ca. 1,760 EUR incl. 25% VAT** (13,097 DKK), which is amongst the 36% cheapest in Denmark (140 out of 390)[31].

The **tariff[32] structure** in general **reflects real costs for the utility** (similar to the Taarnby case study presented before) and has 4 main components:

- A connection fee (DKK/kW) to be paid only once, which in 2020 was offered for conversion from oil or electric heating. Under normal conditions, for a standard house still not connected to DH (usually heated by oil or electric heating), the connection fee is 3,360 EUR (25,000 DKK), and 6,720 EUR for a new house (50,000 DKK). The real cost for the utility is 8,067 EUR (60,000 DKK).
- An annual fixed term (DKK/kW/y), amounting to 600 EUR for a house up to 250 m^2 (4,500 DKK), and higher for houses bigger than 250 m^2.
- A variable term (DKK/MWh) to cover energy consumption, corresponding to 1,155 EUR/y for a standard house (8,597 DKK).
- A bonus/malus term depending on the return temperature (DKK/°C), to promote system efficiency. The district heating consumers are given a target interval for their return temperature (30 to 37°C), and a prime or penalty of 1% of the variable tariff term is applied if the return is lower or higher, capped at 10%.

The DH system of Jaegerspris also receives **revenues for the balancing services to the electricity grid** provided by the CHP plants. In 2020, these revenues are expected to represent around 160,000 EUR (1.2 MDKK), 5.5% of total sales. The market mechanisms for these services are further explained in Section IV.B.

IV Integrating RES and Waste Heat

A Technical considerations

The DH system in Jaegerspris is **mostly decarbonised**. The pie chart in Figure 18 shows the production mix in 2019, dominated by technologies fuelled by RES and waste heat sources. All the **production facilities are owned by the DH utility**, there is no third party supplier.

[30] Typical funding conditions: 30-year loan, 1% interest rate
[31] From national DH benchmark; https://forsyningstilsynet.dk/tal-fakta/priser/varmepriser/
[32] Detailed tariffs available on the utility's website: https://www.jp-kraftvarme.dk/økonomi/priser/

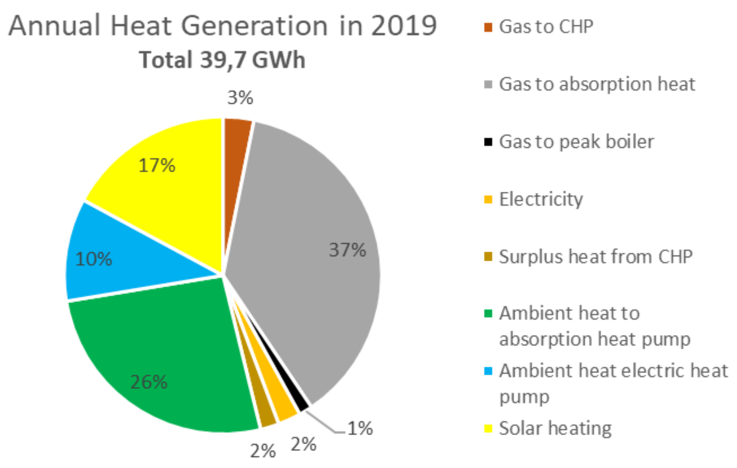


Figure 18:15 DH production mix in Jaegerspris (source: Ramboll)

First step: solar thermal energy coupled with storage

The first step towards DH decarbonisation consisted in the integration of 10,000 m^2 of **solar thermal** panels in 2010, together with **a 3,000 m^3 thermal storage tank** (around 140 MWh storage capacity), resulting in a 17% coverage of the demand through solar energy. In 2013, the solar plant was enlarged to reach its current size of **13,400 m^2 of solar collectors**. The land where the solar field is located is owned by the utility, and an **agreement with local farmers** exists allowing sheep to graze around the solar collectors, which is also beneficial for the utility to avoid shadowing problems.

Figure 19: Solar field of Jaegerspris (source: Jægerspris Kraftvarme)

Second step: smart sector integration through large heat pumps and CHP

The new energy plant built in 2018 enabled the DH grid to **improve its overall performance** and to value **synergies with the electricity grid**, becoming a **smart multi-energy grid.** To identify the preferred solution, an in-depth energy planning study or "project proposal" was undertaken, where different alternatives were analysed. This study is publicly available, as usual in Denmark after their approval by the municipality.

Figure 20 shows the key components of the retained solution, which was provided as a turnkey project by the supplier Verdo[33].

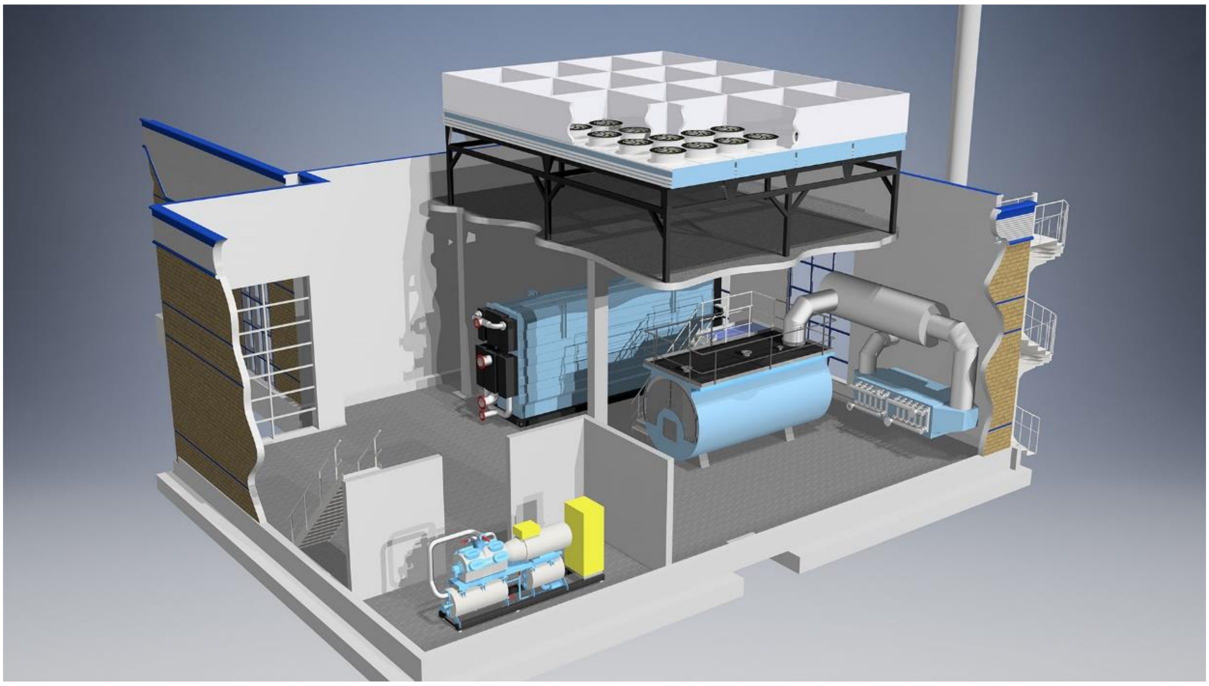


Figure 20: Energy production plant installed in 2018 in Jaegerspris (source: Jægerspris Kraftvarme)

The **key elements** of this energy production plant are the following:

i. An **absorption heat pump** of ca. 4 MW of cooling power, using the 24°C water coming from the solar plant as its cold source and supplied by hot water from a new gas boiler.
ii. The **new efficient gas boiler** (6 MW) with flue gas condensation (economizer) using cool water from the absorption heat pump at 18°C, having a 109% efficiency.
iii. A 1 MW air-to-water **electric heat pump,** allowing to economize the boiler in case solar heat is not available. It gets its **ambient energy** from 4 air collectors located on the roof of the energy plant, and heats the water from 18°C to 24°C, showing an average annual COP of 5.5.

Thanks to the absorption heat pump, the performance of the solar plant was improved by 16%. Indeed, reducing the operating temperature to the solar collectors results in **more operating hours in winter**, as the temperature difference with the outside decreases, resulting in higher efficiencies (see Figure 21 below). For example, for an external temperature of 5°C, at 35°C operating temperature the system starts when the solar radiation is 120 W/m^2 , while at 18°C (with the absorption heat pump) it starts at 50 W/m^2, resulting in 500 extra hours of operation. The efficiency improvement for an operation at 30°C with the absorption heat pump with respect to 45°C without it is illustrated by the graphic on the right below.

[33] https://www.verdo.com/int/

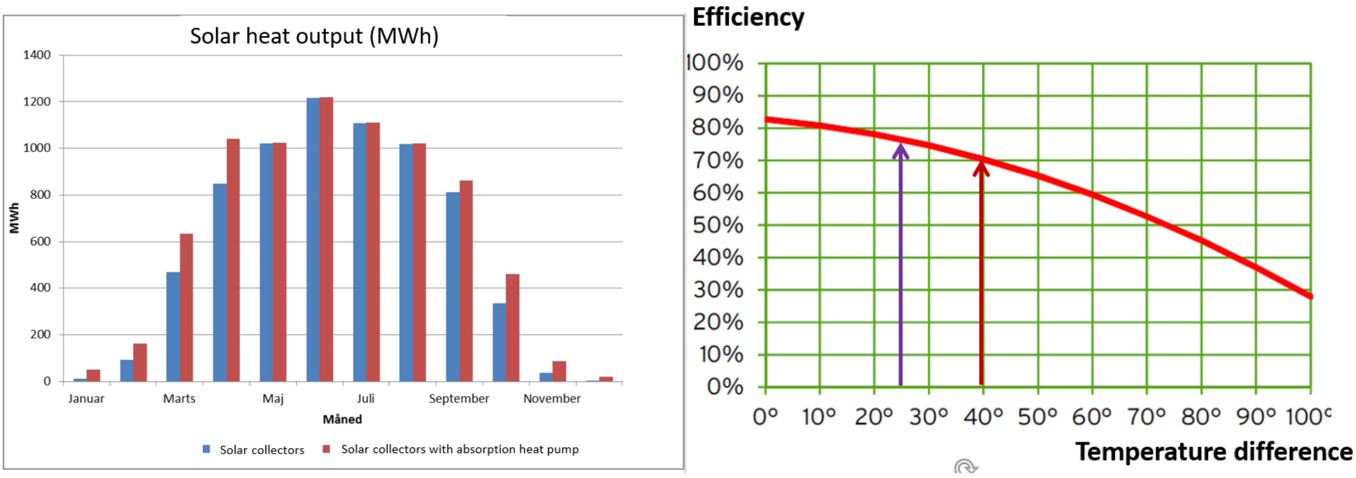


Figure 21: Solar heat production increase thanks to the absorption heat pump

As mentioned above, the energy plant has **2 operational modes**, illustrated in Figure 22 below:

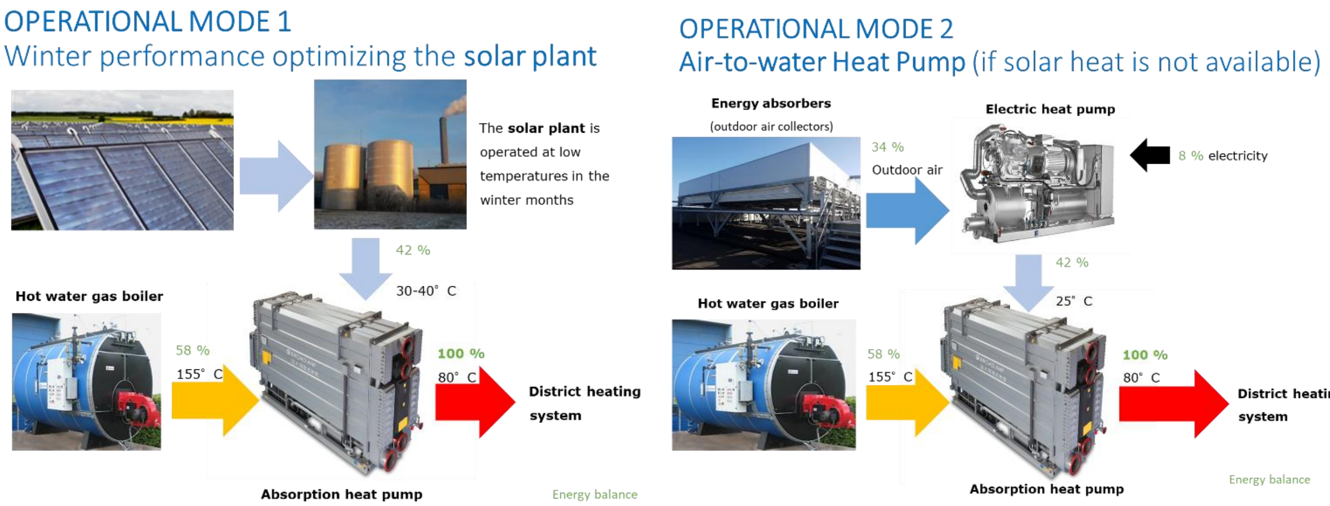


Figure 22: Energy plant operational modes (source: Jægerspris Kraftvarme)

This energy plant also provides a **new lever for smart sector integration**, bringing new possibilities of system optimization taking into account electricity prices, which usually are lower when there is a higher RES share on the grid. Indeed, **the CHP plant contributes to grid balancing** (frequency regulation), therefore facilitating a **higher integration of intermittent renewable electricity.** The new Danish energy policy presented in Denmark's national context (Section 4.1 I) promoting the substitution of natural gas with electricity, and eliminating taxes on electricity for heating, is a new opportunity to further **decarbonize the DH grid using thermo-electrical equipment** such as electric boilers and heat pumps (see Section VII). By doing so, the DH system would reinforce its role as a **flexible consumer** of electricity, acting as a virtual battery.

B Economic considerations

As previously explained, **the socio-economic assessment of the DH project is part of the heat planning procedure, and follows a national methodology**. The assessment done at "project proposal" stage concluded that **Jaegerspris' DH project is profitable for the society of Denmark**, for the utility and for the heat consumers.

<u>Interactions with the electricity market</u>

The DH utility supplies the **electricity regulation market** through the **CHP** engines. These sales constitute an additional source of revenue, as indicated in Section III.C. However, the available production capacity provided by the CHP plants is **not subject to any capacity payment**, which makes their future uncertain despite the demonstrated systemic value created.

Regarding **electricity sales** on the regulation market, the DH utility can bid at 795 DKK/MWh. Prices vary largely, usually between 795 DKK/MWh and 6,000 DKK/MWh (107 EUR and 806 EUR respectively).

To optimise the CHP operation, the DH utility uses a digital solution developed by its balance responsible party (Centrica[34]), providing 5-day-ahead estimates for electricity prices, heat consumption, solar radiation and heat in the thermal storage tanks. Figure 23 below shows the **activations** in 2020, usually of around 4 MW.

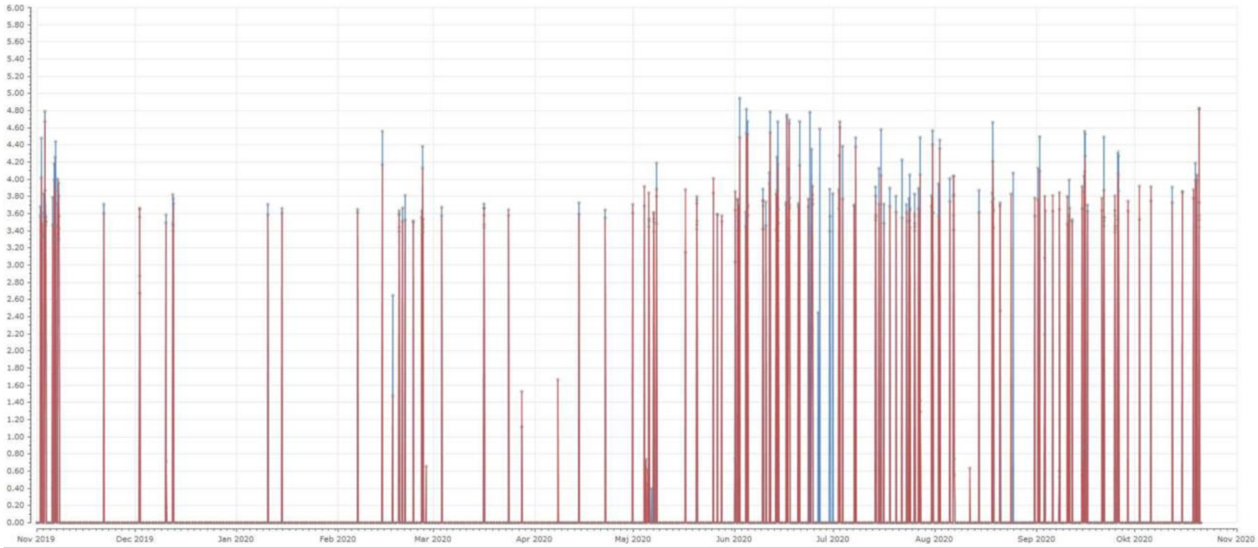


Figure 23: CHP regulation market activations in 2020 (in MW)

The current electricity network tariffs constitute a barrier for investment decision in further smart sector integration:

- The current **prices for connecting a new electric boiler and a large heat pump** are the same as for non-flexible consumers, not reflecting that the grid connection is already established to the gas CHP engines, and that those new capacities could be interrupted at any time needed for the electricity network, as the plant has 100% back-up from the gas boiler and storage tanks.
- The **electricity distribution tariffs do not take into account the demand response flexibility provided by the DH system**. Indeed, the DH electricity demand, unlike demand of normal electricity consumers, can also be interrupted at any time needed for the electricity network, because of the back-up mentioned above.

[34] https://www.centrica.com/

Interactions with the gas market

The DH grid is **still highly dependent on gas prices**, as natural gas is the main energy source. Indeed, an increase of gas prices is an identified risk: 20% gas price increase would represent 7.4% cost increase, ultimately reflected on the price to consumers.

Reducing the dependence on gas by a **higher integration of RES** will therefore contribute to **increasing the resilience** of the energy supply.

This logic is also applicable to consumers currently being supplied by gas, who could see an interest in reducing their dependence on this fossil fuel by connecting to the DH grid.

C Contractual and organisational aspects

Contracts with consumers are signed for 20 years and have a commitment period of 6 years. After this commitment period, clients can disconnect, provided they pay their corresponding part of the debt for the connection cost (40,000 DKK or around 5,400 EUR). Disconnections are however very rare, while connections keep increasing.

D Cooperative approaches and role of digital solutions

The City Council Climate Action Plan calls for **broad cooperation between municipality, citizen and companies**, and Jægerspris Kraftvarme perfectly illustrates this approach. The consumer-owned utility enables **citizens to become key agents of change in the local energy transition**, together with the municipality, the private partners (consultants, suppliers), and other organisations such as professional associations.

Several **digital solutions** support the optimal operation of the network (c.f. Section IV A), the transparency and consumer empowerment through smart meters enabling accessibility to consumption data (c.f. Section VI), and large part of the pipes are equipped with sensors to monitor potential leaks.

V Synergies with Other Urban Infrastructure and Local Value Creation

The **value created by the DH grid** has been quantified during the planning procedure ("project proposal"), and includes energy savings for the consumers, environmental benefits (CO_2 emissions reduction), and **higher community resilience**, amongst others.

The DH grid is a **shared infrastructure supplying 3 neighbouring communities**. When building the DH pipes, antenna cables for **cable TV** were also laid, valuing synergies between both infrastructures.

The **sector integration** developments in the DH grid reinforcing the links with the electricity system have already enabled to value synergies, which will probably continue in the future as the DH system increases its demand and supply **flexibility**.

VI Consumer Empowerment

Jaegerspris DH system was created as a citizen energy community, involving citizens of Jaegerspris and two small neighbouring communities in an ambitious project aiming at changing the local energy system, to improve its cost efficiency. Throughout its life, the DH grid has improved its economic and environmental performance, becoming today a **key enabler of the local energy transition**.

Its governance maximises consumer empowerment, as explained above. Consumers are responsible for the strategic decisions of the company and direct beneficiaries of all the value created, which is translated into lower energy bills.

The level of **transparency** also reaches the highest standards. All consumers have access to Board minutes, they participate in the appointment of board members and have full access to the company financial information and to their energy demand.

Indeed, the utility's **client portal "E-supply"** allows all customers to check their consumption. Annual information is provided once a year, and at any time a consumer can check its **daily real consumption** ("enter readings" option below) and compare it with the utility's estimate, or compare themselves with other similar consumers. To enable so, clients are equipped with individual **smart meters**, allowing the utility to have hourly consumption data and to act remotely. Invoicing takes place quarterly.

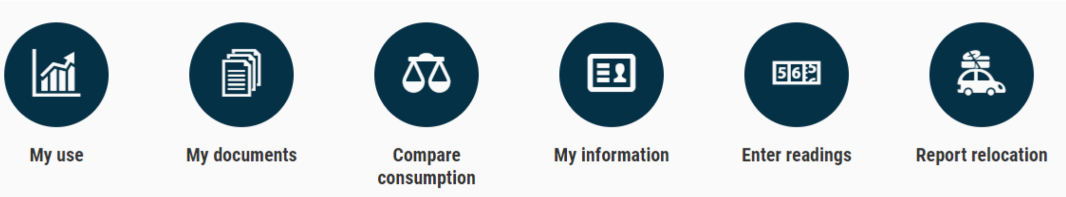


Figure 24: Options provided by the DH client portal to consumers

VII Prospects

In the coming years, Jaegerspris' DH grid expansion will **focus on densification,** aiming at connecting the missing 20% clients from the total potential in the supplied area and all new buildings. To this end, it is expected to **increase the tariff bonus/malus component**, encouraging consumers to have lower return temperatures and therefore making the system more efficient and the tariffs lower.

As previously mentioned, the new national framework supporting the phase out of gas and a higher electrification in the heating sector brings an opportunity to pursue the DH grid's **decarbonisation through smart sector integration,** enabling the system to respond to fluctuating electricity prices due to intermittent production (mainly wind). This option has actually become more interesting than the expansion of the solar field. At the time of writing this report, the **most likely future developments** are:

iv. A new 3 MW **electric heat pump (air-to-water)** to increase the heat from the solar plant;

v. A new 5 MW **electric boiler** to regulate the power market and to use low-price electricity.

It is also expected to offer **management services** to other small consumer cooperatives in the region.

VIII Conclusion and Key Success Factors

Jaegerspris case study illustrates how a **new greenfield DH grid** can be created in the frame of a **citizen energy community**, through a **consumer-owned** utility covering several neighbouring towns.

The key success factors identified for the integration of RES and waste heat sources are the following:

i. **A supportive national context, promoting the creation of new greenfield DH grids in small communities and their progressive decarbonisation.** On top of the numerous regulatory and policy measures taken by Denmark to promote efficient DH, such as high environmental taxes for fossil fuels, the Heat Supply Act (1979) or the obligation for municipalities to implement heat planning following a transparent national methodology (c.f. KSF of the case study of Taarnby above), a specific package of policies in the 1980-90s supported the development of new greenfield DH networks in small communities, in the frame of the national gas project aiming at improving security of supply. While its DHC policy and regulatory framework has already brought Denmark to a world leading position in efficient DHC, the current focus **on phasing out natural gas** and the **elimination of the electricity tax for heating** will continue to foster the decarbonisation of the heating sector through **smart sector integration**.

ii. This national framework also sets the grounds for **higher social innovation in energy**. In particular, the non-for-profit principle of the Heat Supply Act resulted in a **heating sector dominated by energy communities**, where 35% of the market is held by consumer-owned utilities like the one in Jaegerspris.

iii. The successful creation of the DH grid and its progressive integration of RES also relied on the **support from the municipality** (which includes the neighbouring communities supplied). The City Council supported the citizen initiative since its origins by connecting all municipal buildings, and providing a municipal guarantee for the loan funding. Today, the **DH system is one of the key contributors to the municipal climate action plan,** aiming at becoming fossil free by 2030 and CO_2-neutral by 2045.

iv. **The low-temperature regimes of the heating equipment** in Jaegerspris, which is the result of the national efforts in the 1980-1990s to find a compromise between efficiency, good quality domestic hot water and costs (resulting in a typical DH supply/return of 65°C/35°C), facilitated the switch from oil to DH, as no changes were needed on the building heating equipment, and the achievement of higher efficiencies.

v. **The governance of the utility maximises consumer empowerment**. Consumers are at the same time clients and the only shareholders of the utility. Their main objective is to **ensure long-term, resilient heat supply at the lowest cost possible**, which currently means gradually phasing out gas and integrating RES in a cost-effective way.

vi. The willingness to continuously improve the DH system's performance has resulted in 3 main upgrade projects. This **modular approach** has allowed the DH operator to continuously adapt the grid to evolutions in the policy context, and integrate best industrial practices and technologies on the market. As a result, RES were integrated in all of these projects, progressively increasing their share.

vii. For each of those upgrades, **a deep study on possible technical solutions** was performed, **leading to an optimal technology mix.** For instance, the new energy plant integrated in 2018 significantly increased the system's efficiency, enabling a 16% higher output from the existing solar plant, introducing a gas boiler plant of 109% efficiency and an electric heat pump with a COP of 5.5 valuing ambient energy. This solution has proved very successful and other grids in Denmark and abroad have decided to replicate it.

viii. Finally, it is worth mentioning the important role of the **large cooperation between local actors** (citizens, municipality, national DH association, consultants, suppliers…). Some private actors, notably **consultants,** played a key role in building the initial business case for a consumer-owned utility, and advising it during its implementation, upgrade projects and continuous operation optimisation, **ultimately reinforcing the consumers' empowerment** by providing their expertise to enable better informed decisions and a more performant DH service.

4.3 FRANCE: A semi-centralised geothermal DHC system fed by a mid-temperature loop in Paris-Saclay

A previous JRC report on Efficient DHC systems published in 2016 presented the Paris-Saclay smart DHC network as one of the most innovative DHC grids in Europe. At that time, the construction had not started yet. Today, all system installations have been built, supplying 25 main buildings with efficient and low carbon heating and cooling. This analysis focuses on the means used by the ***Land Planning Public Authority for the Paris-Saclay urban area (or EPAPS[35])*** *to fulfil its main objectives, and to integrate RES and waste heat sources in its DHC system.*

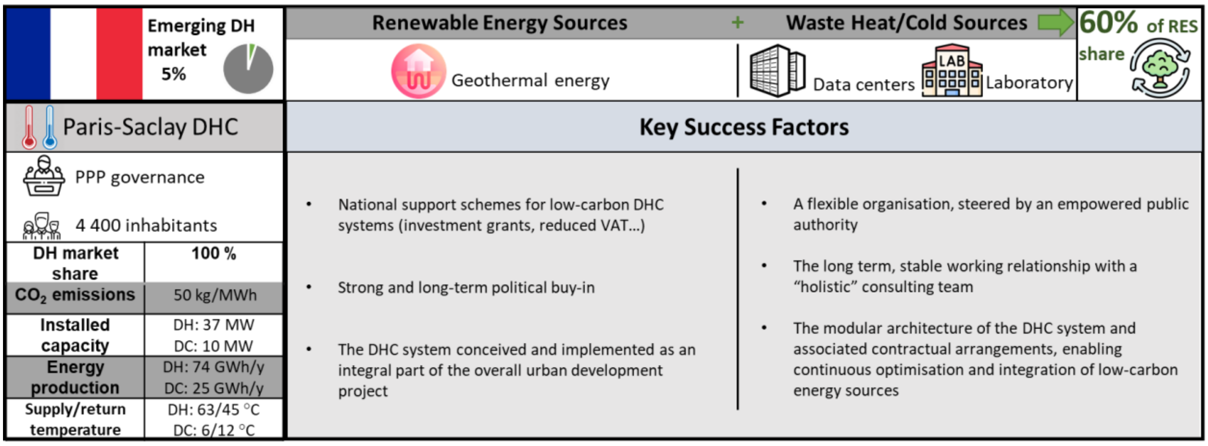


Figure 25: Paris-Saclay DHC installations. From left to right: centralised plant, geothermal room and cooling tower

I National Context[36]

France aims to become climate neutral by 2050 and has transposed this ambition to all sectors, including heating and cooling which still relies mainly on fossil fuels. The deployment of low-carbon DHC systems is one of the pillars of the French energy transition strategy, with an objective of multiplying by five the amount of renewable and waste heat and cold supplied through DHC systems by 2030, with respect to 2012, and achieving 65% RES and waste heat in DH by the same time horizon.

Even if French DHC sales and their low-carbon share have been growing moderately in the last years, **further efforts are needed to reach those national objectives** set by the Energy Transition for Green Growth Act (LTECV in French) and the Multi-annual Energy Plan or PPE[37]. National support schemes such as reduced VAT, CHP feed-in tariffs, investment subsidies by the Heat Fund (*Fonds Chaleur*) or the possibility to impose DHC connection under certain conditions[38] (i.e. DHC zoning) have proved relevant to drive

[35] Etablissement Public d'Aménagement Paris-Saclay (https://www.epaps.fr)
[36] Details on the national DHC context are provided in **ANNEX 2**, including key figures, actors, and regulatory and policy aspects
[37] An summary of both policies is available in English on the following links: LTECV, PPE
[38] These conditions include, amongst others, a DHC energy mix with more than 50% RES and waste heat/cold sources. It is however possible to avoid connection if another solution reaching the same environmental performance proves a better economic performance in the long-term

investments towards DHC systems with more than 50% RES and waste heat and cold sources, but yet insufficient. To tackle this issue, the Government set up a task force in 2019 with the main DHC stakeholder associations, resulting in an Action Plan with 25 actions to be implemented as of 2020[39].

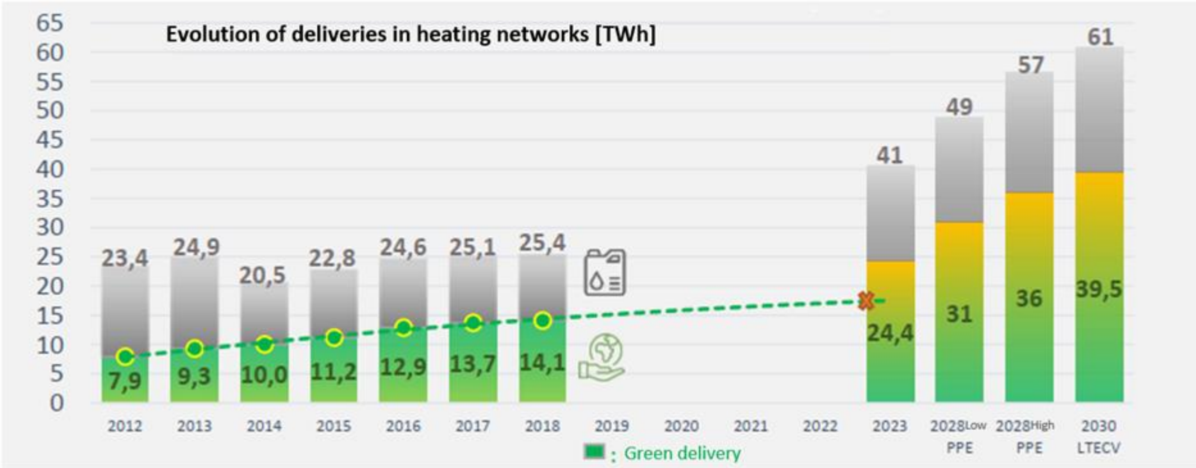


Figure 26: French 2030 objectives in DH development (total and low-carbon/green)

Moving to the market trend, **in 2018, 57% of district heating supply was based on RES and waste heat sources.** The main RES used is biodegradable waste, followed by biomass and geothermal energy, while waste heat use is increasing and represents 2% of total supply (cf. Country Profile in Annex 2). The Energy Transition for Green Growth Act has also obliged all DHC systems to develop a long term **Master Plan** (203O vision or beyond, cf. Section IV) showing their energy strategy and how they will reach national targets, and this is required to receive Heat Fund grants.

District cooling sales are also growing, placing France as one of the leading countries in Europe. Support schemes initially developed for DH have been extended to DC, enabling for example DHC zoning for heating, cooling and domestic hot water, as illustrated by this case study.

Municipalities remain the key actors in France for DHC development, as they decide whether to integrate this energy vector in their local energy and territorial strategies. Around 90% of DHC systems are publicly owned, most of them operated through a PPP scheme, mainly concessions. An increasing number of cities and communities are including the development of low-carbon DHC systems in their energy transition strategies, and aligning their urban planning procedures to facilitate so.

II Local Context

A City context: place of DHC in urban regulations and other local policies

The Paris-Saclay new district and innovation hub is located 20 km south west from Paris and represents **1,800,000 m²** to be built between **2015 and 2030** on this plateau, with its associated infrastructure (cf. Figure 27).

Paris-Saclay so-called Urban Campus is France's main scientific and university cluster project and is one of France's major development programmes. The **EPAPS is the principal contracting authority for the urban planning and development of this area.** This autonomous governmental agency works closely with the local authorities to implement a balanced project in terms of housing (around 10,000 households), transport,

[39] The resulting Action Plan was presented in October 2019: *Réseaux de chaleur et de froid: une filière d'avenir* (link to Press release)

amenities and services. The EPAPS’ scope covers **11 municipalities** for a limited life time (initially 15 years, recently extended to 20). Its role consists mainly in:

- Buying and selling the land to real estate developers, organizing the tenders, studying real estate projects, checking compatibility of these projects between each other; and
- Organizing and building the local infrastructure: roads, pipes, including energy networks (natural gas, electricity, heating and cooling).

Declared as **Operation of National Interest**[40], the EPAPS is commissioned to federate all the real estate projects on the plateau in an area covering more than 500,000 inhabitants. The Paris-Saclay **urban campus project** brings together scientific ambition, economic development and sustainable development to strengthen the Paris Region's position as a world-class innovation hub.

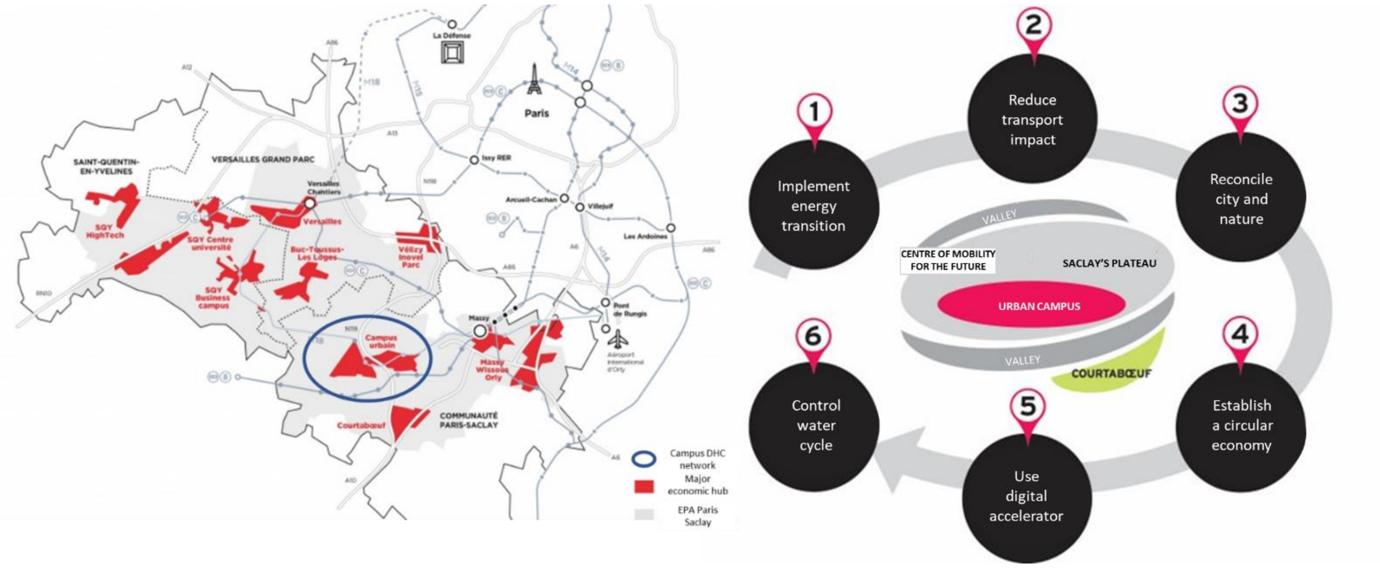


Figure 27: Map of the area covered by the EPAPS and location of the DHC system (left) and Eco-territory strategy of Paris-Saclay (right)

This project presents the opportunity to implement a **new sustainable energy model** in response to the objectives set at COP21. Paris-Saclay's energy strategy, integrated within a larger “eco-territory” strategy (cf. Figure 27), is based on 3 main objectives:

- Energy efficiency and energy sobriety, thanks to the construction of highly efficient new buildings, operated at optimum temperature as well as the valorisation of the energy processes in place on the plateau;
- The use of local renewable and low-carbon resources (50% RES share target for heating);
- The implementation of an innovative energy ecosystem, through intelligent energy management, the use of networks, supply/demand balance, and the involvement of local actors.

The DHC network, which supplies most of the living and industrial buildings in the plateau (around 90%) with heating and cooling, is the cornerstone of this energy strategy.

40 This status is accorded by the State to territorial projects which are aligned with the national strategies and objectives, and with a national impact given by their importance.

B Local heating and cooling markets

The public urban agency, EPAPS, is fully responsible for planning and implementing the energy infrastructure of Saclay's plateau, ensuring coherence with its development roadmap and its energy strategy.

To do so, it follows a three step approach, explained hereafter.

1. **Upstream building and infrastructure planning**, and regular update of these plans during the implementation phase;
2. Integration of **DHC connection obligation** during land transfer with real estate developers and constructors, connection conditions and system performance objectives;
3. **Monitoring the performance prescriptions** of buildings and the overall DHC system during construction, to ensure the RES share target of 50-60% is respected.

Infrastructure planning

The first two areas concerned with building programming are the Moulon district and the Ecole Polytechnique district, represented in the map below. Expansion plans are planned following a similar approach, and detailed in the following sections.

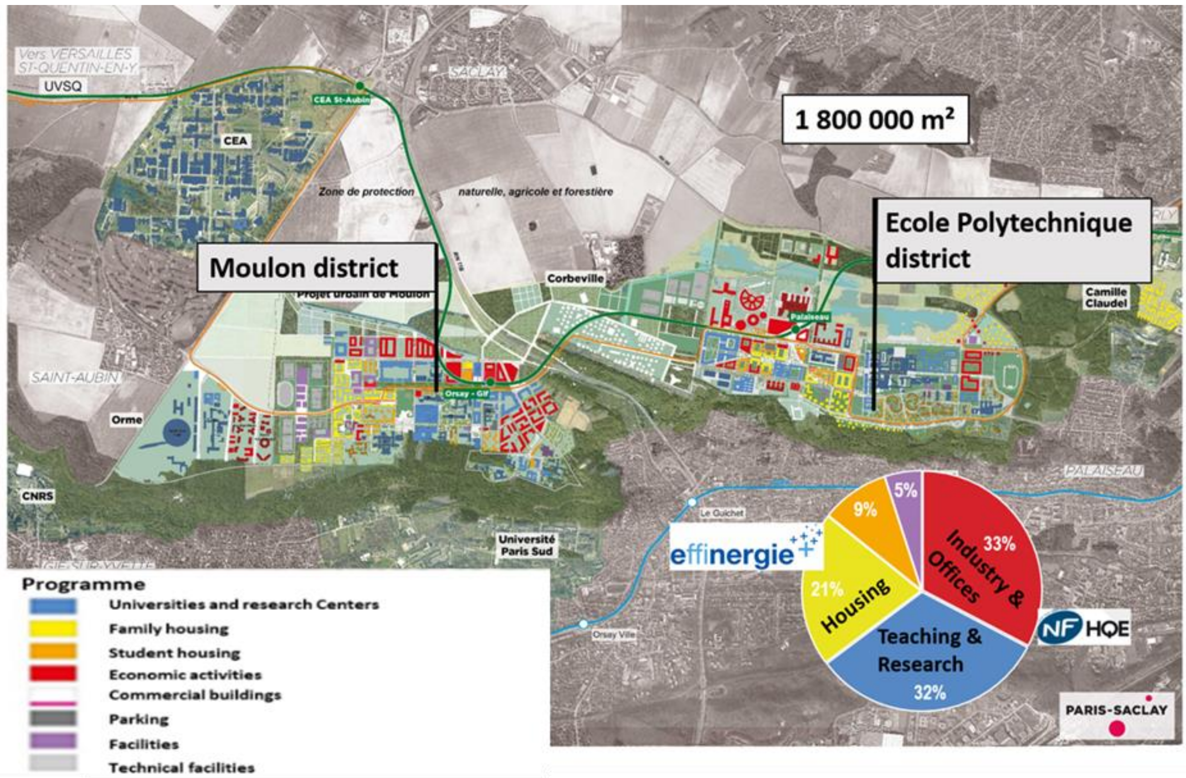


Figure 28: Type of buildings and land use in the areas covered by the DHC system

As shown in the above chart, both districts integrate **various types of new building and uses** such as prestigious universities, research centres and laboratories, student and family housing, big company offices and local shops. All buildings shall, at least, fulfil the national **thermal regulation for buildings — RT 2012** requirements. Thresholds set in this regulation have been considered to estimate the levels of consumption and peak demand for heating, cooling and domestic hot water per type of building[41]. Existing buildings could be connected to the DHC grid if the operating temperature of the heat emitters is below 55°C or can be adapted to work at this temperature level.

[41] The expected values per type of building were presented in the 2016 JRC report mentioned in the opening text (e.g. 40 kW/m2 peak and 40 kWh/m2/y consumption for family housing heating)

Based on the expected consumption, the EPAPS carried out an **energy planning study** comparing possible options to fulfil its energy objectives, **leading to the choice of DHC**. The combination of high energy performing buildings and specific heating and cooling demand (from RDI centres and laboratories) favoured the DHC solution, which proved to be economically more competitive in the long term than alternative standalone solutions (gas boilers, cf. Figure 30).

Preliminary results on real consumption proved different from the initial estimated values for certain usages. While real heating consumption is in line with the initial projections, this is not the case for domestic hot water (double than expected) and cooling (lower than expected). It is **strategical for an optimal DHC design and operation** to have in advance the most accurate consumption estimates while assessing associated uncertainties, as their impact on load and temperature differentials will condition the pipes design. As a certain degree of uncertainty is unavoidable during the early planning phases, the project should be conceived and monitored in a way that provides for later adjustment to real demand.

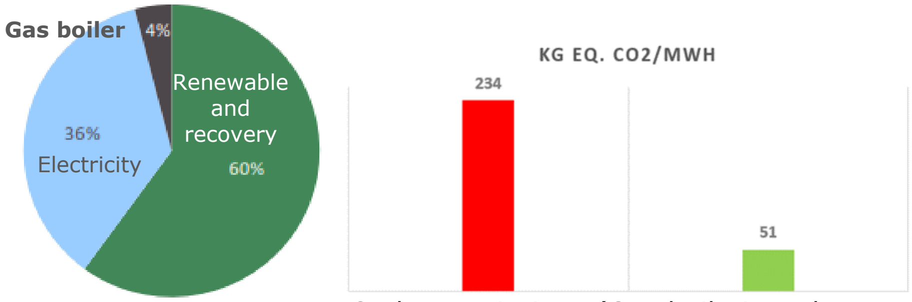
Land transfer and connection to the DHC system

The energy planning exercise enabled the EPAPS to establish a DHC zoning, making it mandatory for buildings to connect under the conditions agreed during the negotiation process explained in Section III.B. To do so, the EPAPS inscribes in its building construction prescriptions for real estate developers a formal obligation to connect to the DHC network for heating, domestic hot water and cooling, including **performance prescriptions** such as:

- Low temperature heating systems (heat emitters), below 55°C;
- Incentives on temperature regulation:
  - by limiting the return temperature to increase the energy exchange (i.e. higher ΔT);
  - by connecting buildings and DHC monitoring and control systems, and sharing automatic signals indicating whether heating and/or cooling is needed, to avoid overconsumption.

Despite the DHC connection is part of the land transfer conditions to any real estate developer or constructor, the EPAPS ensures their adhesion through the **arguments below in favour of DHC**, which have proved effective:

- Over **50% renewable energy** and very low GHG emissions (cf. Figure 29)



DHC Energy mix *Carbon emissions (Gas boilerin red Vs DH in green)*

Figure 29: DHC energy mix and CO2 emissions compared to individual gas boilers

- **Multiple energy supply** (heating, domestic hot water and cooling) for several usages through a low temperature (30°C) ambient loop;
- Building access to several **energy efficiency labels** (cf. Figure 30);

- **Competitive price** for both heating and cooling: 2015 general commissioner report underlined the DHC competitiveness (green line below) compared to individual fossil solutions (red line in Figure 30)

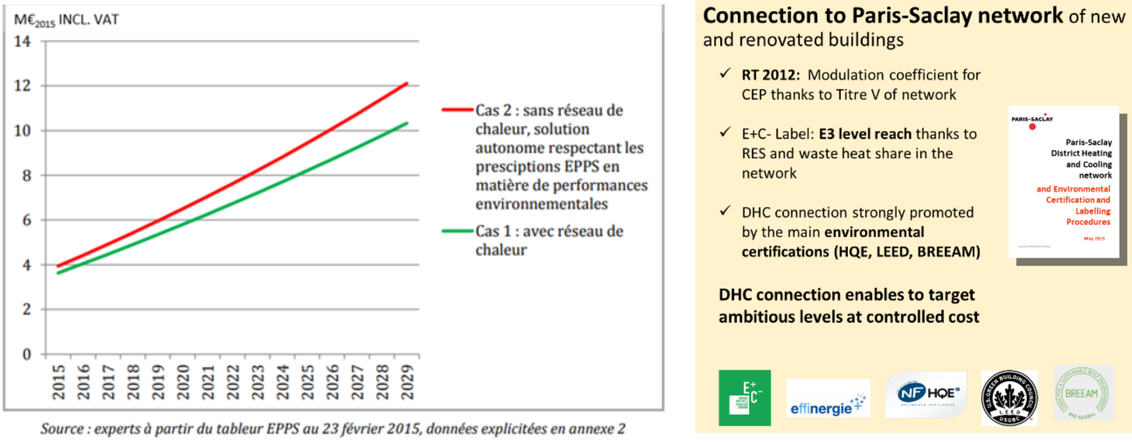


Figure 30: DHC competitiveness against alternative solution (left) and labelling benefits (right)

C Presentation of the DHC System

Initially built to supply the needs of the districts "Moulon" and "Ecole Polytechnique", the DHC system reproduces the **same technological solution for both districts**. It is composed of several interconnected networks, as illustrated in Figure 31:

- A **geothermal network** connecting two drillings and transporting water from the Albien aquifer, the geothermal resource, to a centralised installation.
- A **mid-temperature network** (loop) running from the centralised installation to supply semi-centralised substations where the heat-pumps are located. This network aims at valorising very low temperature energies.
- Several **distribution networks** of heat and cold water supplying decentralized substations from the semi-centralised substations.

Key facts and figures

DH market share	100 %
RES share	60 %
CO_2 emissions (heating)	50 kg/MWh
Installed capacity	DH: 37 MW DC: 10 MW
Energy production	DH: 74 GWh/y DC: 25 GWh/y
Km network (double-pipe)	25.4 km (DH and DC)
Supply/return temperature	DH: 63/45 °C DC: 6/12 °C

Each block of the network features specific technologies:

- The **centralised installation** mainly contains exchange substations with the geothermal resource, gas boilers and cooling towers.
- The 3 to 4 **semi-centralised substations** comprise heat-pumps and a power transformer station. Supplied by the geothermal network they produce hot water (63°C) and cold water (6°C), then distributed to the decentralised substations.

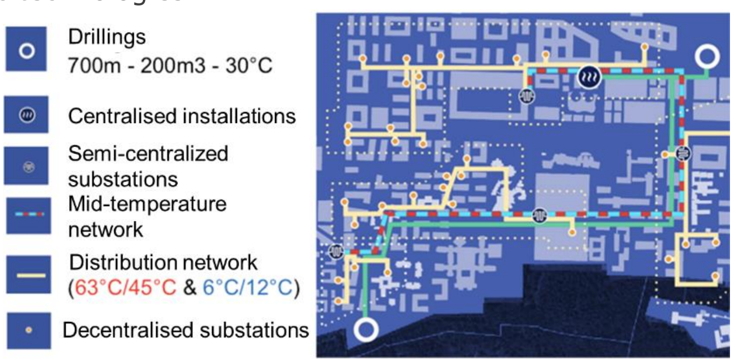


Figure 31: DHC scheme of Moulon district

- Every building constructor has to provide an empty room to host the **decentralized substations** which include connection equipment and exchangers.

This architecture enables to **mutualize and optimize the means of heat and cold production** and enables a higher renewable heat/cold fraction Furthermore, the EPAPS plans to install additional energy production capacity to meet the increasing demand of the districts supplied by DHC. Connections with surrounding networks is also a studied alternative.

The Paris-Saclay DHC system is the **first step towards a multi-energy smart system**. An advanced demand management demonstrator is to be implemented on one of the two districts as part of the D2Grids Interreg North West Europe (NWE) project, described in Section IV.D. This project will enable to control the DHC network in adequacy with user needs while reducing peak demand over time and potentially reducing user consumption through awareness raising actions.

III Business Model

The overall business model and governance of Paris-Saclay DHC system was thoroughly explained in the 2016 JRC study mentioned above. This section therefore focuses on its operational implementation.

A Governance

The DHC system is operated under a **Public-Private Partnership scheme**, in particular a **Design – Build – Operate** (DBO) contract (*Conception – Réalisation – Exploitation & Maintenance, CREM* in French), awarded in 2015 to the consortium Idex-Egis until September 2022.

In 2013, EPAPS made the **choice of such a contractual scheme** because of its role as urban area developer, committed to develop buildings and attract potential clients, which has a significant influence on heating and cooling volumes needed. It allows the EPAPS to bear part of the risks, while ensuring full coherence between the infrastructure development and the overall innovation and climate strategies for the plateau.

The **main differences between a DBO contract and more classical concession** contracts are that, in the DBO:

- The EPAPS bears the financing charge and risk of the investment and construction phase and is responsible for the heating and cooling sales and customer management. The volume and billing risk is not transferred to the DBO consortium;
- The chosen consortium, Idex-Egis, has technical and economic performance targets to fulfil within the commissioning and initial operation phase, which is rather short and aimed exclusively at the optimisation of the system in its early operation phase (until September 2022).

The **current organisation** is represented in Figure 32. The typical process for new connections is as follows:

1. As the area planner and DHC operator, EPAPS interacts with all implicated stakeholders and first evaluates, with the help of its Assistance to the Contracting Authority (ACA), the feasibility and potential issues of each connection.
2. Then, EPAPS gives the **DBO contractor an assignment to design, build and operate** within new operation characteristics (for projects arriving until 2021).
3. The EPAPS sets up a **specific task force** around its Project Director (head of DHC operation), integrating technical and contractual support within EPAPS staff and its consultants (ACA).
4. This task force will remain the interface between the real estate developer and the DHC grid, both during the initial construction phase until 2021 and also for post-DBO operations (as of 2022).

Figure 32: Governance scheme of the DHC system

Currently the above presented organization, highly independent, flexible and working with a long-term vision, has brought concrete operational achievements, such as:

- **Post-DBO provisional measures** anticipated during the construction of DHC installations regarding building programming as of 2022 (space for future heat-pumps or boilers, oversized pipes at specific locations, etc.);
- Design and build **adaptation to integrate building programming evolution**: it happened twice since the beginning of the contract and implied new heat-pump rooms and new network architectures;
- **Major extension projects** around initial DHC areas related to the National Interest Operation, like the new Paris metro line, the construction of which shall start in 2020, synergies with Ecole Polytechnique (connecting buildings, new developments) or urban development projects such as the new district of Corbeville standing between the two initial ones (cf. Figure 46).

B Strategy and Offer

As previously explained, the EPAPS integrates DHC connection in its **negotiations with real estate developers and constructors** while awarding the building parcels, in particular the technical and economic aspects to consider regarding the construction project and the DHC connection.

The **connection of new buildings** is organised around 3 stages (cf. Figure 33):

1. **Building programming**: consisting in setting up a master plan with building lots or parcels and their characteristics (type of buildings, surface, energy demand per use) as well as the implementation schedule. It enables a preliminary design of DHC equipment. The first programming was established in 2013 and has been updated since then.
2. **Building connection**: during deed of sale, the designated real estate developer or constructor for a parcel agrees with the EPAPS on the connection conditions, including energy demand (peak loads and usage) and construction calendar. This launches the design studies made by the DBO contractor.
3. **DHC contractual subscription**: six months at least before building delivery, the designated real estate developer or constructor signs up a subscription agreement

where he confirms the connection conditions. This enables to launch execution studies made by the DBO contractor and the subsequent construction works. When the real estate developer or building constructor is not the final customer, EPAPS general service conditions and obligations are transferred to the latter.

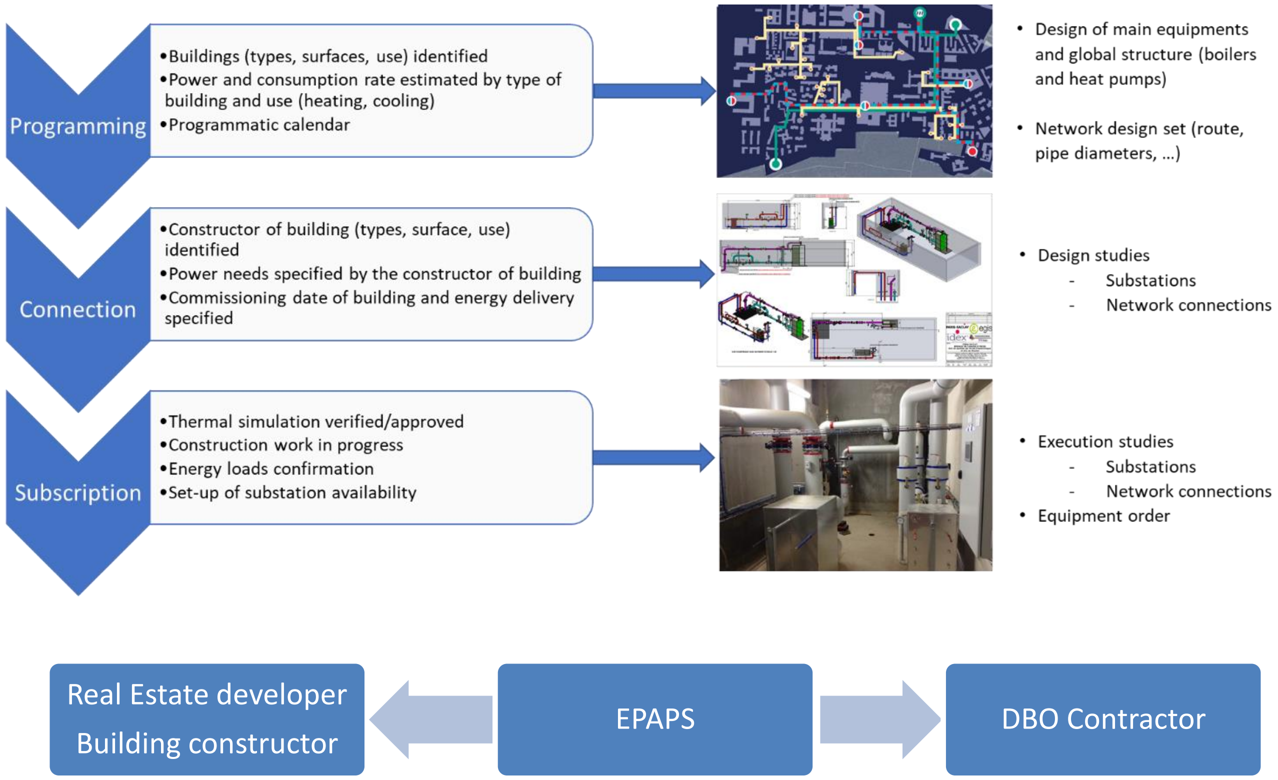


Figure 33: Main operational steps for new connections to the DHC grid, and role of each party

The type of contractual subscription depends on the building load profile, as illustrated in Figure 34 below.

- **Universities, research centres or laboratory buildings** have specific energy needs, such as very high peak loads, different levels of temperature for processes, full redundancy or back-ups required. They have, *in situ*, DHC heat-pump rooms (400 m²) but also other technical rooms (boilers or refrigeration units) connected to the DHC system. DHC covers the base load, while local installations cover peak loads and can be used as back-up in the remote case of DHC supply default.
- **Housing and office buildings** have standard energy needs (heating for both and cooling for offices only). The DHC network fully covers these needs.
- **Commercial buildings** represent a marginal share of the connections. They are usually integrated to housing building programmes. However, differences between initial cooling demand estimate (often over-estimated) and final contractual demand is an issue.

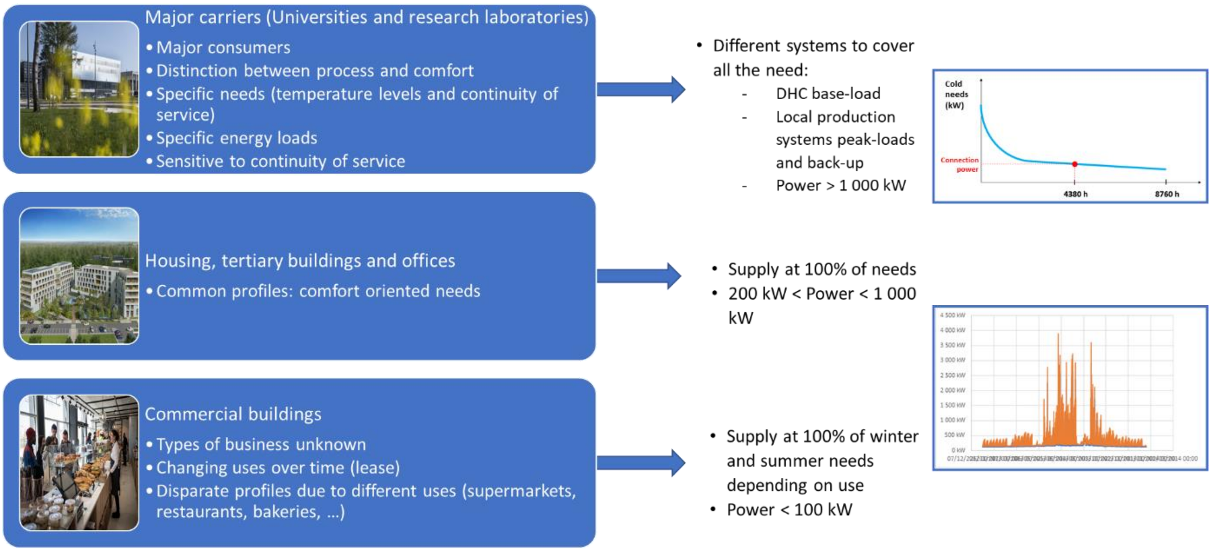


Figure 34: Type of contractual subscription, depending on load profile (type of building)

C Financial model

EPAPS bears the financial and commercial risks of the DHC system, and also sets the tariffs. The main financial flows are illustrated in Figure 35 below.

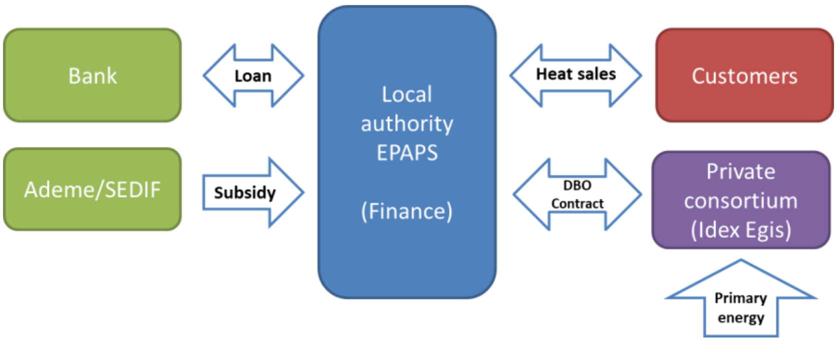


Figure 35: Paris-Saclay Smart DHC system financial flows (Source: Tilia)

At the time the DBO contract was signed, the investment level for the DHC network was around EUR 50 million. It has increased to **55 MEUR** to integrate building programming update and growth, impacting the DHC system (new heat-pump rooms, bigger boilers and network pipes…).

The level of subsidies (10 MEUR) initially granted by ADEME's *Fonds Chaleur* was completed by a 2 MEUR investment subsidy from the water service operator in Ile de France, SEDIF (*Syndicat des Eaux d'Ille-De-France*), which might use part of the Albien underground aquifer water resource as "ultimate back-up".

Structure of the tariff

Paris-Saclay **DHC tariff** is based on two components, as all DHC systems in France:

- A **fixed component called** "**R2**", calculated as a function of the installed capacity and equal to EUR **58/kW/y** excluding taxes, for heating, domestic hot water or cooling. R2 is composed of four terms R21 + R22 + R23 + R24 detailed below:
    - R21 represents the energy consumption of auxiliary equipment (electrical consumption of circulation pumps mainly), which is allocated to consumers

based on the contracted capacity. R22+R23 is the cost of operation and maintenance of the network.

- R21 + R22 + R23 = EUR 31/kW/y excl. VAT;
- R24 represents the yearly capital costs covering the investments in the grid and all its equipment. R24 = EUR 27/kW/y excl. VAT.

- A **variable component called** "**R1**" (cf. Figure 36), which depends on
  - the consumed energy (EUR/MWh);
  - the flow that went through the heat exchanger (EUR/m^3);and
  - the season of consumption, i.e. winter, summer, or mid-season, incentivizing the heat consumption during summer and the cold consumption in winter and mid-season to optimise the network performance.

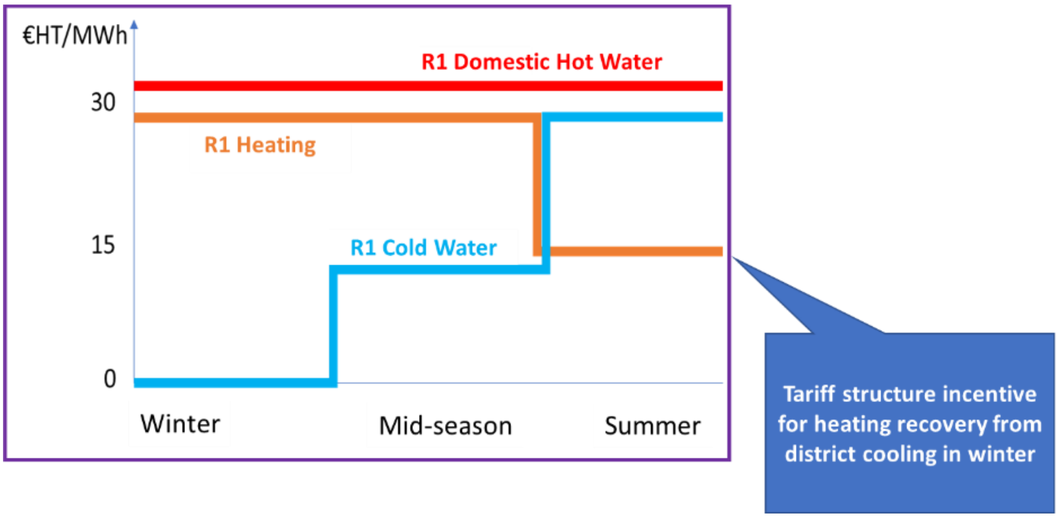


Figure 36: DHC R1 tariff levels, per season

Additionally, the **costs of connection ("R0")** are paid once to the EPAPS and are proportional to the installed capacity with a special discount for consumers using both heating and cooling.

The EPAPS makes available to real estate developers, constructors and customers all documentation necessary to a full operation understanding, summarized below:

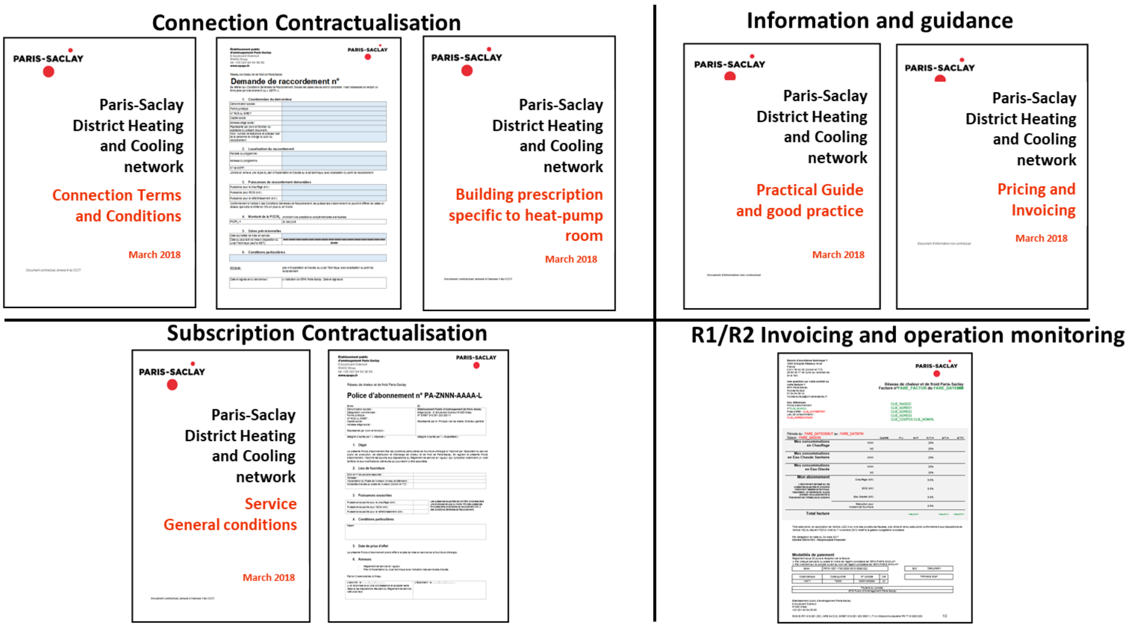


Figure 37: DHC information for real estate developers, constructors and consumers

IV Integrating RES and Waste Heat and Cold

A Technical considerations

The connected buildings are new and highly efficient, and will be built gradually as the urban campus develops. The expected rise in energy demand is shown in the graph below.

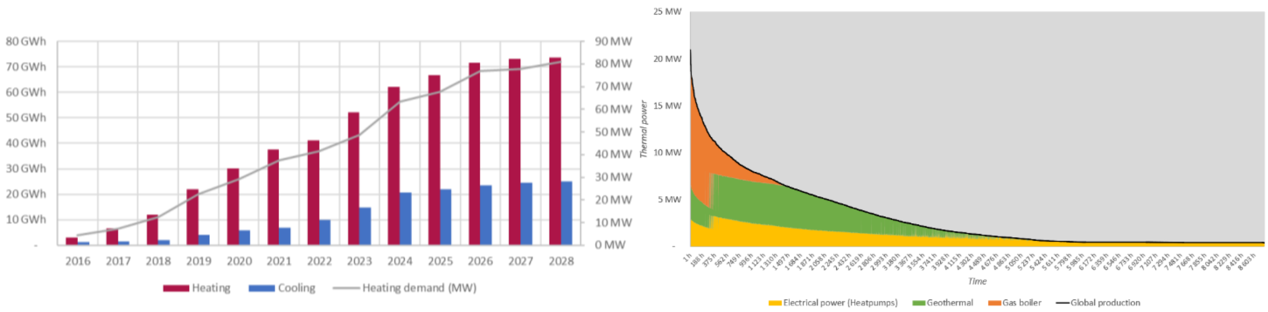


Figure 38: Evolution of the energy needs for the 2 districts supplied by DHC (left) and Load curve for Moulon district (right)

Furthermore**, an additional district is expected to be connected to both areas supplied by DHC, and to their networks**. This new district (Corbeville), also located on the plateau, will have a hospital with major needs in heating and cooling, which will strongly influence the DHC design strategy. The hospital will have its own gas boiler, which will be connected to the DHC network and work as a back-up heating production unit for the whole DHC system.

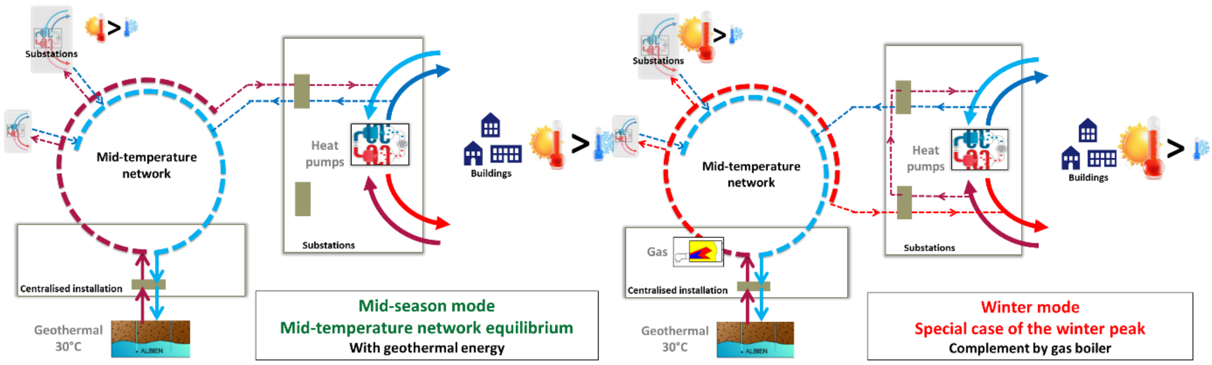
Keeping its renewable share above 50% is a key parameter for Paris-Saclay's DHC network, to impose connection and remain eligible to subsidies and reduced TVA. In 2019, the renewable sources used were (cf. Figure 29 and load curve in Figure 38):

- The **geothermal** resource at 30 °C and 700m depth, with a maximum output of 10 MW (ca. 30%) for both existing districts.
- The **recovery energy** from the heat-pumps (ca.30%).

This energy mix appeared as the optimal one during the energy planning phase, as explained in Section II.B. It allows using the local geothermal energy, and in particular extracting from the Albien aquifer a flow of 200 m³/h at 30°C, which is an adequate temperature regime for heat pumps, enabling to supply both the heating and cooling demand at a competitive price for end-users. Peak supply is provided by gas boilers.

The network has **different control modes influencing the use of RES**, depending on whether the heat demand overrides cooling demand (winter or mid-season mode) or the opposite (summer mode). Each control mode allows an optimized use of the network infrastructure by adjusting parameters such as the temperature differential of the mid-temperature network. Those modes are presented in the Figure 39 below.

- In **winter and mid-season**, the mid-temperature network, at a temperature of 10/29°C, will allow all users to benefit from geothermal energy. The excess cold produced by the substations is then evacuated into the Albien groundwater aquifer. If the capacity of the groundwater aquifer is not sufficient, additional heat will be provided by the gas boilers of the centralised installation.
- In **winter**, in the event of very high demand (peak consumption), the centralised boilers complement the heat produced by the heat pumps in the substations. The heat production is then distributed at a temperature of 70/100°C through the mid-temperature network.



- In **summer**, the excess heat from the production of the substations is recovered by the mid-temperature network. It can be recovered by another substation in the case of heating needs (e.g. domestic hot cold water). If it is not recovered, it is evacuated by the cooling towers of the centralized installation ("TAR" in Figure 39).

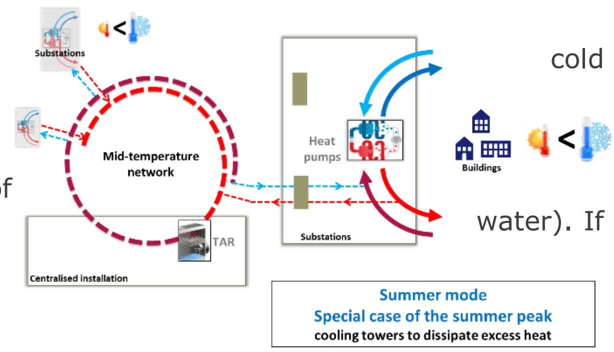


Figure 39: DHC operating modes, depending on the season

With the increasing demand, **the current solution will have to evolve to keep the RES fraction above 50%**. Multiple scenarios have been studied by the Master Plan of Paris-Saclay's DHC network. This **Master Plan** aims at anticipating the network's future in the long-term, following Ademe's national methodology "EnR'CHOIX"[42], which is required to apply for subsidies. The objective is to define a long-term strategy for the network and to establish a shared vision of the project and its development with all stakeholders (institutional parties, national associations and agencies like ADEME, etc.). Ademe's Heat Fund's subsidies are calculated to ensure the final price to DHC consumers (incl. all taxes) is 5% lower than alternative fossil solutions, following a 20-year economic analysis.

[42] http://www.enrchoix.idf.ademe.fr/ (in French)

The guiding principles established by Ademe for DHC Master Plans are the following:

1. **Reducing energy consumption**, through energy sobriety (e.g. though energy management systems) and energy efficiency measures (e.g. building retrofitting);
2. **Mutualising means and infrastructure.** When possible, connect to a DH/DHC network with >50% low-carbon energy sources. If not possible, study the possibility of developing one. If still not viable, develop a low-carbon supply solution at building level.
3. **Optimising and prioritising the use of RES and waste heat/cold sources**
    - Priority is given to the use of existing untapped energy sources, i.e. waste heat/cold sources (wastewater, data centres…);
    - Secondly, RES that cannot be delocalized should be used, i.e. geothermal energy;
    - Finally, other RES that can be delocalized (biomass, biogas, solar…) are studied and prioritized from a techno-economic perspective.

The energy scenarios of the latest version of the master plan (2019) illustrate **the need to implement additional RES sources** to maintain the 50% RES target. Following Ademe's "EnR'CHOIX" methodology, the EPAPS identified the following local complementary RES and waste heat, whose implementation is currently under discussion:

- The **waste heat recovery** from research facilities (such as super calculators equivalent to **data centres** and a **particle accelerator**), and from the **wastewater** network;
- A potential **biomass** heating plant to be hosted in the new hospital facility in the Corbeville district with a hydro-accumulating storage and a recovery boiler;
- Production of **biogas** from a local methanization unit to increase the renewable fraction of the gas consumed in the nearest centralised installation (foreseen in the north of Corbeville district);
- **Photovoltaic** energy to provide renewable electricity to the heat-pumps in a self-consumption scheme (30% of total roof surfaces to be covered with PV panels).

The evolution of the RES fraction is expected to be maintained above 50% through the integration of these RES and waste heat sources, as shown in the graph below.

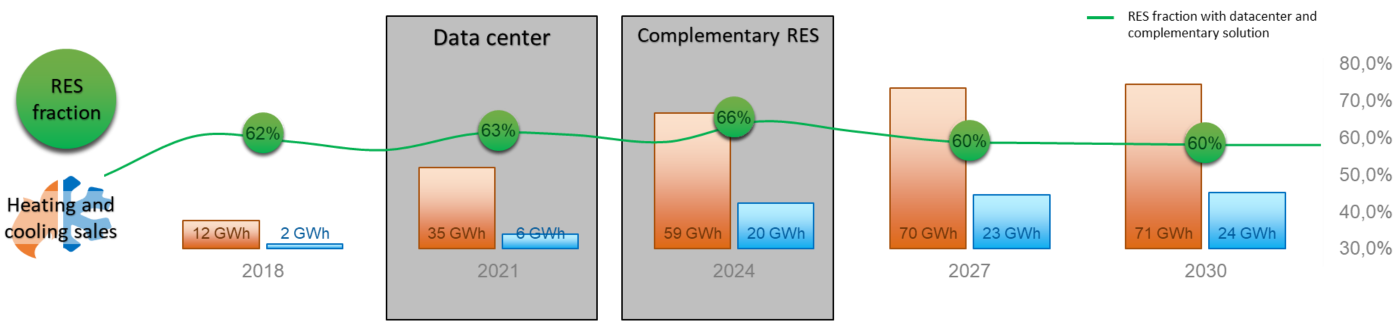


Figure 40: Expected evolution of the RES share in Paris-Saclay DHC system

These developments capitalize on the **modular architecture** of the network, which took into account development possibilities since the initial design stage.

In the short term, the EPAPS plans to recover the waste heat from two research facilities:

1) The cooling units of the **super calculator** owned by the Institute for Development and Resources in Scientific Informatics (IDRIS[43]).

   By 2021, the IDRIS's supercomputer will have an average operating power of around **1.2 MW** for cooling, which means a waste heat recovery potential of the same order. The cooling system will supply supercomputers with water at ca. 20°C and recover an output temperature of around 48°C.

   The EPAPS estimates that the recovery of heat from the IDRIS is about **3.5 GWh**, 1/3 of the total potential identified.

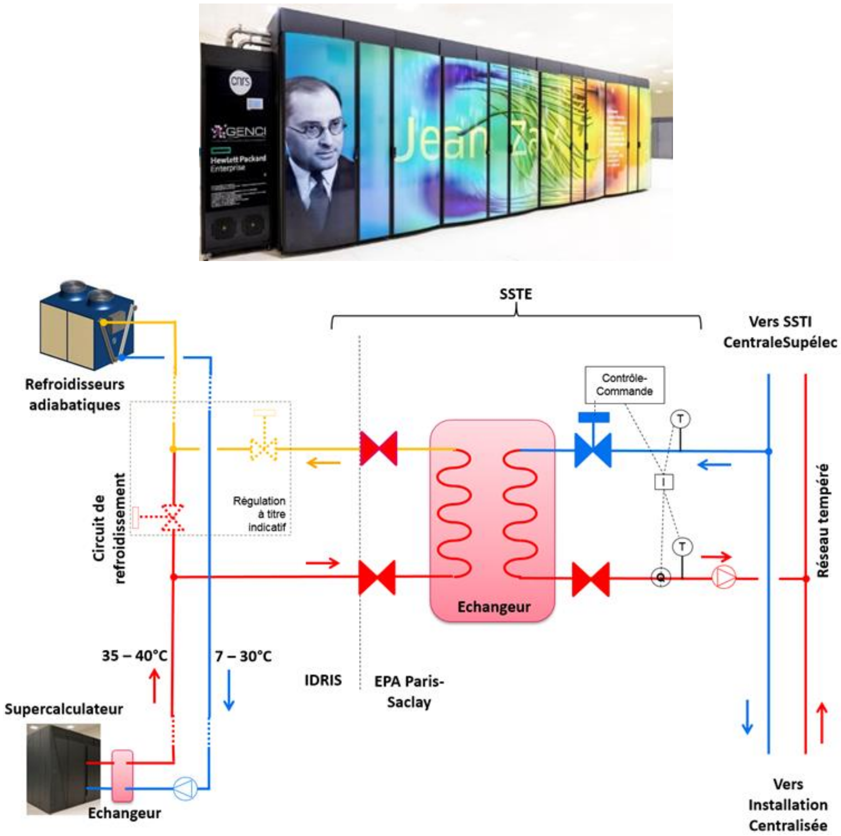


Figure 41: Picture (© Photothèque CNRS/Cyril Frésillon) and Waste heat recovery scheme from the IDRIS supercomputer (equivalent to a data centre)

2) The cooling units of the Synchrotron-Soleil's **particle accelerator** (joint venture between CNRS[44], CEA[45] and other partners).

   Located at 2 km from the nearest centralised installation, this particle accelerator requires constant cooling, provided by cooling units. The heat is currently dissipated by air cooling towers.

   As a renovation is planned in 2026, a discussion was launched on the energy recovery of the calories currently dissipated in the atmosphere. The available power is estimated at **2.5 MW** and a valorisation rate of 30% of the waste heat generated would allow around **5.25 GWh** of heat to be recovered for DHC.

[43] Institut du Développement et des Ressources en Informatique Scientifique
[44] National Centre for Scientific Research
[45] The French Alternative Energies and Atomic Energy Commission

B Economic considerations

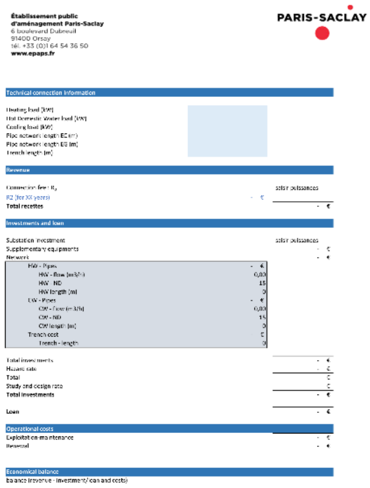
The main financial objective of EPAPS is to propose the lowest possible price to final consumers while **ensuring the economic viability of the network in the long term**, meaning that tariff revenues should cover capital and operational costs. This is part of the general service conditions of the subscription contracts, which include the possibility of a tariff revision to reach the target.

The EPAPS studies, upstream, every extension, new connection and real estate project technically and economically. To do so, the EPAPS has created a specific form, summarizing all **technical and economic aspects** (cf. Figure 42).

For specific connections such as **new RES or waste heat recovery** injected into the existing system, the EPAPS evaluates the impact on the energy mix, primary energy costs and tariff.

The key economic considerations retained are:

1. The new energy source shall substitute mainly the most expensive and pollutant energy of the existing system (gas boilers);
2. The operating costs (primary energy and operational costs) and investments shall be compensated by an important volume of energy injected at a low price;
3. Investment subsidies shall be required to finance this new connection (mainly *Fonds Chaleur* or European funds from the ERDF[46]).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PARIS-SACLAY

Technical connection information
Heating load (kW)
Hot Domestic Water load (kW)
Cooling load (kW)
Pipe network length EC (m)
Pipe network length EG (m)
Trench length (m)

Revenue
Connection fee : R1 — saisir puissances
R2 (for XX years) - €
Total recettes - €

Investments and loan
Substation investment — saisir puissances
Supplementary equipments - €
Network - €
HW - Pipes - €
HW - flow (m3/h) 0,00
HW - ND 15
HW length (m) 0
CW - Pipes - €
CW - flow (m3/h) 0,00
CW - ND 15
CW length (m) 0
Trench cost €
Trench - length 0
Total investments - €
Hazard rate - €
Total €
Study and design rate €
Total investments - €

Loan - €

Operational costs
Exploitation-maintenance - €
Renewal - €

Economical balance
balance (revenue - investment/loan and costs)

Figure 42: Techno-economic form for extensions and new connections

Figure 43 below presents the DHC system load curve and production mix, influencing this optimisation process.

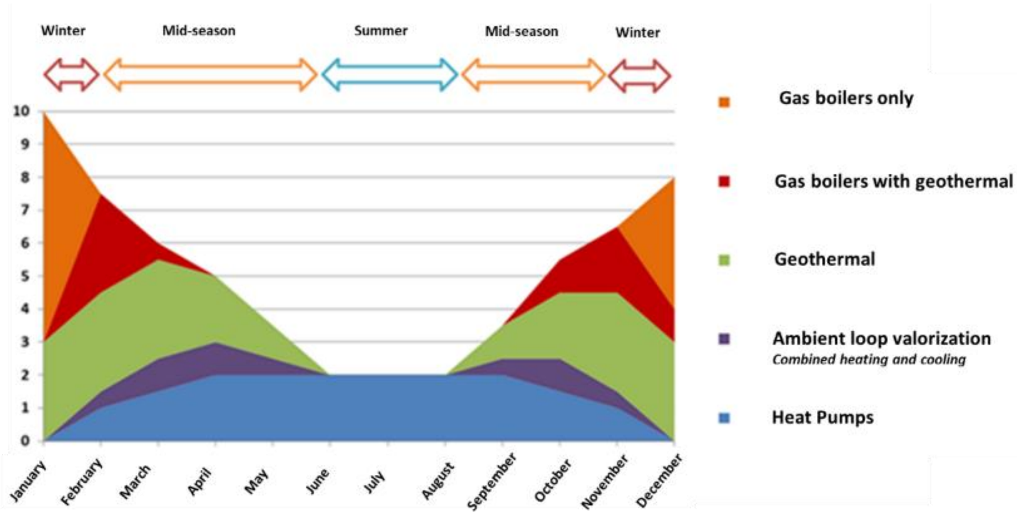

Figure 43: Annual load curve of Paris-Saclay DHC

C Contractual and organisational aspects

The main contractual and organisational arrangements of the DHC system operation have been presented before (cf. Figure 32 regarding governance).

[46] European Regional Development Fund

The **energy supply to customers** (including new building connections) is contractually regulated through commercial subscriptions (15-year contract), namely the service general conditions and its specific conditions (load subscriptions essentially).

For the integration of new RES or waste heat recovery energy into the existing system, an **energy supply agreement** is set to regulate technical and economic aspects, such as:

- Expected quantity of energy (peak loads, consumption per year);
- Service conditions (expected temperatures, service continuity);
- Delivery boundaries.

The expected duration of this agreement is around 15 years.

D Cooperative approaches and role of digital solutions

The operational processes described above and interactions between the EPAPS and the stakeholders involved in the DHC operation are highly cooperative.

Innovative approaches towards a more integrated energy system are also part of the response to new connections. They aim to increase the thermal flexibility of the network to limit the use of non-renewable auxiliary energy (heat pumps electricity or gas boilers) and to optimise the use of renewable energies and existing infrastructure. Today, those innovative approaches are reflected in the integration of 2 new elements, paving the way towards a multi-energy **smart grid** (cf. Figure 44):

- An advanced demand management, through interactions between the network control systems and those of connected buildings plus the introduction of dynamic pricing;
- Thermal storage.

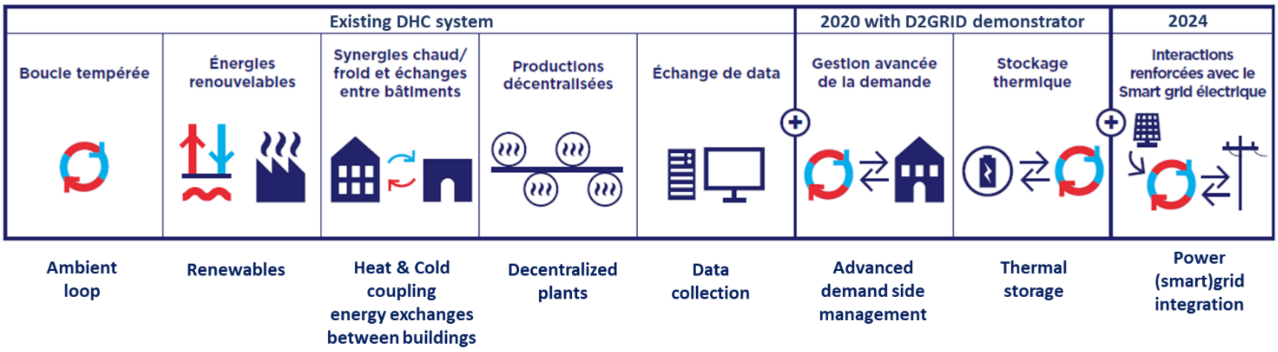

Figure 44: Smart grid roadmap: towards a smarter and more integrated system

These two smart solutions are being tested by pilot demonstrators on the Paris-Saclay DHC network as part of the European **D2Grids project**[47], which aims at developing **5th generation district heating and cooling networks** in Europe and gathers a consortium of 12 European partners led by Mijnwater.

Its objective is to maximize the share of renewable energies and waste heat and cold in local energy systems, through an industrialization of the approach, a standardized technological model, and a clarification of the business model to strengthen the interest of these projects for any third party investor and to encourage them to participate and be part of it. The Paris-Saclay heating network will be the only pilot site in France and is, at this stage, the most important in terms of infrastructure capacity.

[47] Link to D2Grids project, which is part of the Interreg North West Europe and financed by European Regional Development Funds

V Consumer Empowerment

To set-up its advanced demand management system, the EPAPS considers to run different test scenarios **involving consumers and other local partners**. Indeed, applying a participatory approach is considered a key success factor for the smart grid, where the final purpose is to commit all DHC users to interact with the global system (buildings and network) to enable its optimisation. The specific objectives are:

- To include the impact of consumptions on the operation of the heating and cooling network and vice versa;
- To encourage customers, and through them the final consumers, to use energy sparingly or at least to use the energy available on the Saclay plateau in an informed manner;
- To associate at each stage, and at all levels, these local partners and beneficiaries of the services implemented by EPAPS.

Hence the EPAPS counts on integrating in the process the following stakeholders:

- **Builders**, who design and construct the buildings where systems' energy exchanges and interfaces exist;
- **Customers** of the DHC network who have taken out a subscription to the network and who also have local energy management systems in their buildings;
- **Final consumers**: these users expect a certain level of comfort regarding H&C and continuity of service. They are also an integral part of the system, meaning they can influence in any way its performance. They shall therefore be involved in every step of the process to conciliate their own individual expectations with collective objectives;
- **Other local actors** present in the plateau (municipalities, local associations, private and public organisations…).

VI Synergies with Other Urban Infrastructure and Local Value Creation

The long-term objective of the EPAPS is to develop a "positive energy" territory, and valuing synergies between local infrastructures is central to reach this target. **As the urban planner, the EPAPS centralizes all initiatives and possible partnerships considering urban infrastructures** (energy production and distribution, waste collection and recovery, mobility, etc.), **innovation and digitalization**. Several examples have been previously provided of such synergies (cf. Figure 45), and continuous discussions with the electricity distribution system operator (DSO) are part of the overall energy optimisation process.

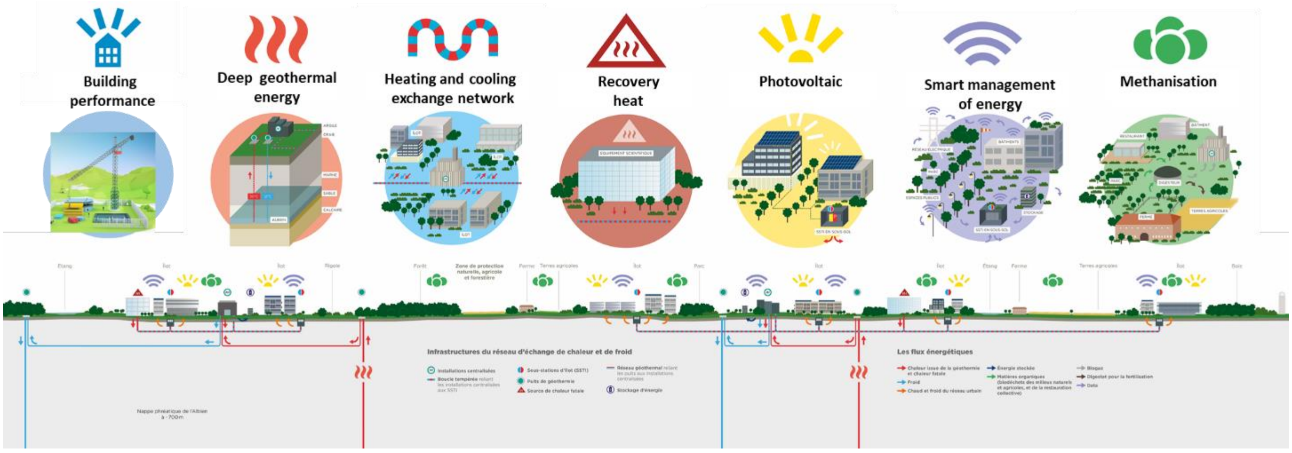

Figure 45: Energy strategy of Paris-Saclay, the DHC system being its backbone

VII Prospects

The main prospects of Paris-Saclay smart DHC system are summarised in its Master Plan for 2030 (cf. Figure 46 below), which is a living document considering all future potentials, technically and economically.

Figure 46: Master Plan Paris-Saclay DHC system 2030

In the short term, the choice of the DHC operational mode and governance following the end of DBO contract (end 2021) is a key milestone for the system's future. The EPAPS will in any case remain the main planning and contractual authority.

VIII Conclusion and Key Success Factors

The case of Paris-Saclay showcases how low-carbon DHC systems can develop in **new urban areas**, and evolve with these while continuously optimising their operation and energy mix.

The key success factors enabling the integration of RES and waste heat can be summarised as follows:

i. **National support schemes for low-carbon DHC systems**. For Paris Saclay, this support mainly took the form of a reduced VAT for DHC sales, significant investment subsidies (around 20%), the possibility to impose connection if the RES share is above 50% (DHC zoning), and the consideration of the DHC networks as a means to reach building regulation's energy requirements.

ii. **Strong and long-term political buy-in.** As an Operation of National Interest, the development of Paris-Saclay as a world-class innovation hub with the highest environmental standards is a national, regional and local priority. There is a common long-term vision of the territory amongst key stakeholders.

iii. **The DHC system is an integral part of the overall urban development project**. The results of the energy planning study demonstrating the competitiveness of DHC have been reflected in the urban planning procedures and regulations. The overall coherence is facilitated by the fact that the EPAPS is in charge of the urban development programme and all the associated projects, including the DHC system development. A common 2030 vision, valuing to the extent possible synergies between different urban infrastructures, is formalised through the DHC Master Plan, a living document regularly updated. The guiding principles established by ADEME for DHC Master Plans and efficient integration of RES and waste energy sources are highly replicable in other EU contexts.

iv. **The flexible organisation retained, with an empowered public authority**, has also proved successful. Steering such an ambitious and complex project is a challenge, but the human and material resources have been assigned accordingly. The EPAPS counts on a highly qualified team, reinforced when needed by additional technical, financial and legal expertise. The organisation retained is flexible, and can adapt to the operational reality while keeping in mind the long-term objectives of the urban development project.

v. **The long term, stable working relationship with a "holistic" consulting team (ACA)** has enabled EPAPS to develop new know-how and capacities, and empowered the internal EPAPS staff through a joint, project-learning team, the experience of which is now paramount to the successful handling of new extensions, needs and supplies. Continuity in the core team, involving embedded external consulting support, appears as a key factor of success for such complex, multi-stakeholders projects.

vi. Finally**, the modular architecture of the DHC system and associated contractual arrangements** enable a smooth planning and integration of low carbon energy sources. The network extension and optimisation is continuously studied in the frame of the Master Plan, ensuring the RES share is kept above 50%. Besides, the possibility to adapt the DHC tariffs to take into account the network's evolution secures the economic viability of the system.

4.4 SPAIN: Using geothermal energy from the closed Barredo coal mine in Mieres

Emerging DH market <1%	Renewable Energy Sources	98% of RES share
	Geothermal energy from a closed colliery	

Mieres DH	
Public governance	
38 000 inhabitants	
DH market share	36%
CO_2 emissions	5 kg/MWh
Installed capacity	4.1 MW
Energy production	3 GWh/y
Supply/return temperature	50-80/40-60 °C

Key Success Factors

- High political and societal support at all levels (local, regional, national), as part of the transition of this coal region
- A diversification strategy of the historical operator of coal activities in the region, in the frame of coal phasing out
- Valuing the closed colliery as a local renewable energy source, seizing the opportunity of its location near urban areas
- Financial support through investments subsidies (EU funds)
- Ensuring price competitiveness against the alternative (natural gas) through a guaranteed discount in the heating bill
- Efficient collaboration and continuous communication between the main stakeholders
- High quality service, essential in emerging markets to prove the reliability of DHC solutions

I National Context[48]

Spain has established a strategic roadmap towards carbon neutrality in 2050, through its Integrated National Energy and Climate Plan 2021-2030 (NECP, or PNIEC in Spanish). Its 2030 objectives include 23% carbon emissions' reduction with respect to 1990, 42% RES use in final energy consumption, 39.5% energy efficiency improvements with respect to 2020, and 74% RES in electricity production.

RES and waste heat/cold use in heating and cooling is explicitly addressed in the national energy strategy, and DHC is expected to contribute to it. Identified measures to do so include, amongst others, the feasibility analysis of a DHC system in new urban developments (not mandatory), financial support to low-carbon DHC networks, a revision of the national building code, or the establishment of a specific legal framework for DHC.

The heating and cooling market is completely liberalised in Spain, where the predominant H&C source is natural gas. The absence of a specific legal framework for DHC and its production facilities has been identified as one of the main barriers to its deployment, and discussions are currently ongoing at national level on the relevance of creating such a framework (i.e. law and/or technical standards).

The Spanish DHC sector is still an emerging market, with less than 1% market share (0.15% in 2015[49]). It is experiencing a steady growth, and the success of some of the first larger networks has increased the political interest in DHC, as it has proved to be powerful tool to reduce the energy bill, use local renewable resources and reduce dependency on fossil fuels. The regions of Catalonia, Madrid, Castilla y León and Navarra represent 80% of the installed capacity (see Figure 47). A particularly high uptake is being observed in medium-size and small cities and communities, led by regional and local authorities.

The installed DHC capacity was 1,576 MW in 2019, with a significant part of district cooling (25%). The market is mainly concentrated in 20 larger networks, representing 60% of the total installed capacity. Most of these larger networks include heating and cooling, with 36% of the total sales corresponding to cooling.

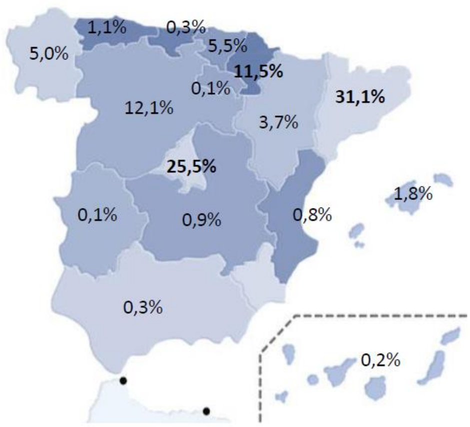

Figure 47: Geographical distribution of DHC in Spain, in terms of installed capacity (ADHAC, 2019)

[48] Details on the national DHC context are provided in **ANNEX 3**, including key figures, actors and regulatory aspects
[49] NECP / PNIEC

The energy mix in DHC networks has switched from a deep reliance on fossil fuels in 2013 to a mainly biomass-based mix since 2017. In 2019, biomass was the main energy source for 41% of the total installed capacity, and 80% of the networks included some RES. Waste-to-energy, geothermal energy and waste heat recovery are, after biomass, the main low-carbon sources used.

With regard to ownership, a balance exists, in terms of installed capacity, between public, private and PPP (32%, 35% and 33% respectively). The latter is the main option retained for the biggest networks in operation, usually through concessions. Higher investments are required for such networks, and these have been realised mainly by the private parties.

Autonomous Communities (the regions) are playing a key role in DHC deployment in Spain, often setting the financial support needed by the city councils and operators to develop new DHC grids. This funding mainly consists of investment subsidies, and to a minor extent technical assistance.

The two Spanish case studies analysed hereinafter show how the cities of Mieres and Barcelona successfully established their DHC networks, which are some of the flagship projects in the Spanish market. The first constitutes the biggest geothermal DH grid in the country and an example of the ESCO[50] model for DHC, while Districlima Barcelona is the biggest DHC system, and a good example of how the concession model works.

II Local Context

A City context: Mieres, a coal region in transition

Mieres is a 38,000-population town located in the region of Asturias, in the North of Spain. The economy of this region has been traditionally closely linked to coal mining, with more than 70 mining shafts and more than 2,000 mountain mines, and currently 4% of the GDP related to coal activities.

In 1967, the main coal mines in Asturias, which were privately owned, were integrated in a new State-owned company, **Hunosa**[51], in charge of coal extraction and commercialisation, and also operating a 50 MW coal power plant, "La Pereda", still in operation. The evolution of the employees of Hunosa showed in Figure 48 illustrates the decline of the mining activities in the region. Today, only one coal mine is still operating, the last one in Spain, and it is expected to close in 2021.

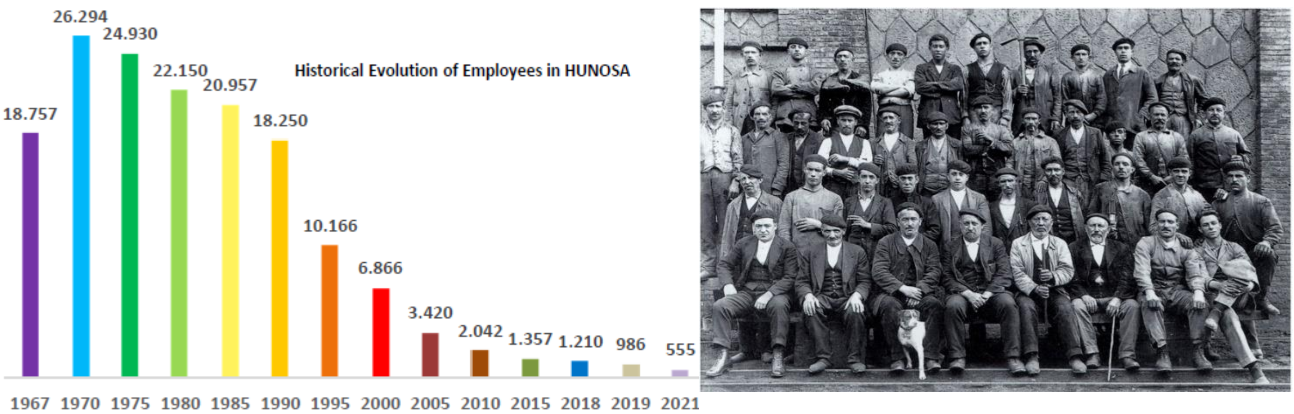

Figure 48: Hunosa staff evolution and image of mining workers in Mieres, Barredo shaft (source: Hunosa)

[50] Energy Service Company
[51] https://www.hunosa.es/

Mieres is part of the Caudal area, one of the most affected by the 2010 EU decision of closing all unprofitable coal mines by the end of 2018. Its population has followed the decline of mining activity, and has been reduced by almost half since 1960. The Barredo shaft, nearby the city centre, closed in 1995, and the interconnected Figaredo shaft, a few km away, closed in 2007, enabling the start of the coal mine flooding process, explained in Section V.A.

As a response to the closing of the coal mines, **Hunosa has put in place a long-term strategy to diversify its activities and minimise the social impact of the coal phase out,** namely its 2019-2027 business plan. A number of new activities, presenting synergies with coal mining, are therefore being developed, enabling to maintain ca. 15 FTE:

- Geothermal facilities using mining water for heating and cooling;
- Biomass activities, from forestry use to installation of biomass boilers;
- Adaptation of the coal power plant to other types of fuels (mainly biomass);
- New uses of the coal washing facilities, such as iron and steel separation, or production of high quality coal;
- New energy services related to the energy transition (energy efficiency, supply, maintenance, etc.).

This diversification strategy is shared amongst key actors in the region, and supported by the regional government, local authorities, local companies, unions and by the local population in general. All of them are aware of the need of a strong collaboration to face the common challenge and to re-shape the local economy through an inclusive and socially fair energy transition. Since 2019, **a joint committee is in place to assess the impact of the energy transition in Asturias**, including the key stakeholders of this structural transformation, and coordinated by the Asturian Energy Foundation (FAEN[52]). The results of the analysis and studies undertaken within this joint committee were published in July 2020[53], showing the energy situation in the region and expected impact of the energy transition on its main economic sectors, proposing 2030 scenarios in line with the national objectives and providing a set of recommendations to build a regional energy transition strategy.

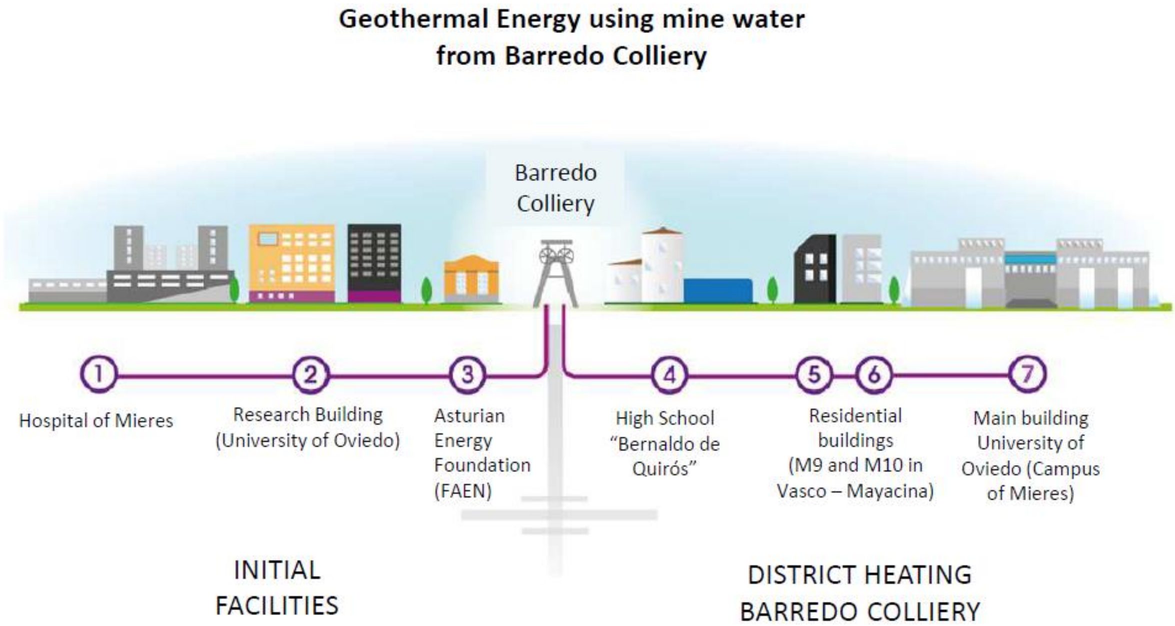

Figure 49: Overview of buildings connected to Mieres' geothermal installations: initial facilities and district heating network (source: Hunosa)

[52] http://www.faen.es/
[53] Results available on FAEN's website (link to the public report, in Spanish)

Mieres geothermal project is one of the flagship projects of this strategy, and will be replicated in 2021 in Langreo, a 40,000 population-town 12 km away from Mieres in a similar context (see Section VIII). The use of mining water from the non-active Barredo coal mine for heating and cooling is being studied by Hunosa since 2009, when the mine flooding process ended, as such an exploitation could value the permanent pumping process needed to maintain a security level of water (see Section V A) and generate revenues compensating those pumping costs, while bringing **a "new life" to the closed coal mine**, which is a historical heritage of the community, and to some extent part of its identity and families' history.

The project was developed in two phases, and concerns 7 buildings, as illustrated in Figure 49 above.

i. Phase 1 (2009-2016) concerned the so-called "initial facilities", including the first geothermal installations, based on individual solutions: pumping stations, heat exchangers and heat pumps at building level for the 3 connected buildings (4,67 MW in total):

   - the Hospital of Mieres (1), currently the biggest consumer of Hunosa to whom it supplies heating and cooling from the mining water;
   - a Research building of the University of Oviedo (2); and
   - the office building of the Asturian Energy Foundation, FAEN (3).

   These first clients enabled Hunosa to prove the reliability of its geothermal solution and its benefits, detailed in the next sections.

ii. Phase 2 (2017-2020) concerns the DH network (4.1 MW), which is the focus of this case study and started its first heating season in October 2020. The main reasons why the DH solution was retained instead of the previous individual solution scheme include the following:

   - The development of heat pump technologies, enabling to increase the supply temperature to reach 85°C, required by the heating systems of some nearby buildings such as the high school (4) and the University building (7);
   - The space limits in the coal mines making it technically difficult to add new heat exchangers, providing strong arguments for a shared infrastructure;
   - The difficulties found when installing heat pumps at building level, such as space limits or electric capacity;
   - The ratio consumption/distance of the potential clients, improved thanks to DH development;
   - The possibility to optimise the overall operation and maintenance of the network through the connection of 2 low-temperature fuelled residential buildings, i.e. M9 (5) and M10 (6), and an optimal network layout.

   District heating was therefore found to be the most efficient and profitable way to extend the use of the local geothermal resource. The project was awarded in 2019 the Global District Energy Climate Award by the International Energy Agency (IEA), under the category "emerging markets".

B Local heating and cooling markets

Mieres has an oceanic climate, with an average of 1,224 heating degree days[54]. During the heating season the average temperature is 10.3°C, while during the warmer months (April to September) the average temperature is 18.4°C. Cooling systems are not typically used in dwellings in Asturias, and in the case of the area covered by the geothermal facilities, only the hospital has a cooling demand.

The current market share of DH is 36% in the covered area. The heating market is dominated by natural gas, with most of the buildings having individual gas solutions, therefore not compatible with DH. Centralised gasoil boilers are also present, but most of these are too far from the DH grid to make the connection viable.

Compatible secondary heating systems including heat emitters at building level are indeed a requirement for integrating the DH system. All the connected buildings were previously heated through central gas boilers. The main building of the University of Oviedo and the 2 residential buildings are quite recent, and the latter integrated already compatibility with geothermal facilities through low-temperature heat emitters (radiant floor, needing 45°C heat supply).

The **fuel switch from gas to DH of the 4 connected buildings was also enabled by the commercial strategy of Hunosa, guaranteeing 10% savings in the energy bill** with respect to the gas tariff in place for each client, as well as other associated energy services further explained in Sections IV.B and IV.C.

As illustrated on the left part of Figure 50, almost all the heating demand of the connected buildings is covered by the DH network, while gas boilers are used at the residential buildings (called M9 and M10) to heat the low-temperature DH supply from 45-50°C to around 60°C, for domestic hot water.

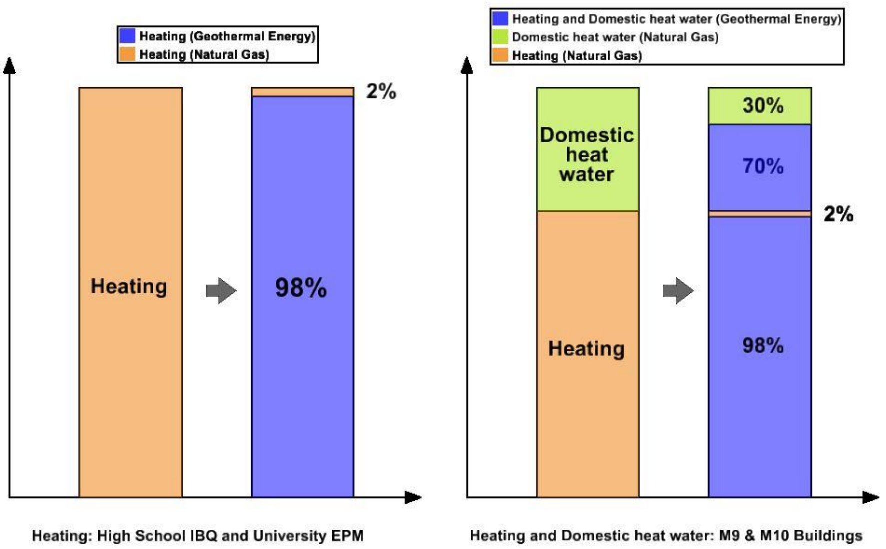

Figure 50: Fuel switch from gas (left column) to DH (right column) of the tertiary and residential buildings connected to Mieres DH network (left and right side, respectively) (source: Hunosa)

The public authorities are the main consumers of Mieres geothermal installations, and have played an essential role not only supporting the project administratively and financially, but also **committing to connect their public buildings and therefore securing the demand.** They are paving the way towards the decarbonisation of the heating and cooling market, becoming exemplary in this field.

[54] Spanish Institute for the Diversification and Saving of Energy (IDAE): Technical guidelines for external climate conditions in buildings projects, Oviedo

III Presentation of the DH System

As introduced before, the DH network in Mieres supplies heating and domestic hot water to the 4 connected buildings. The main components of the DH network are the following:

- **Mine shaft (used as a geothermal well)** and a **heat exchanger**, recovering heat from the mining water at 23°C on average;
- A generation plant with 2 **heat pumps** (2 MW in total), and additional 2.1 MW at building level (substations). Connected buildings also have their previous gas boilers that can be used as back-up of the DH grid;
- 2 **high-temperature networks** at 70-80°C (for the high school and university);
- A **low-temperature network** at 45-50°C (for the 2 residential buildings M9 and M10, for a total of 248 dwellings, heated through radiant floor).

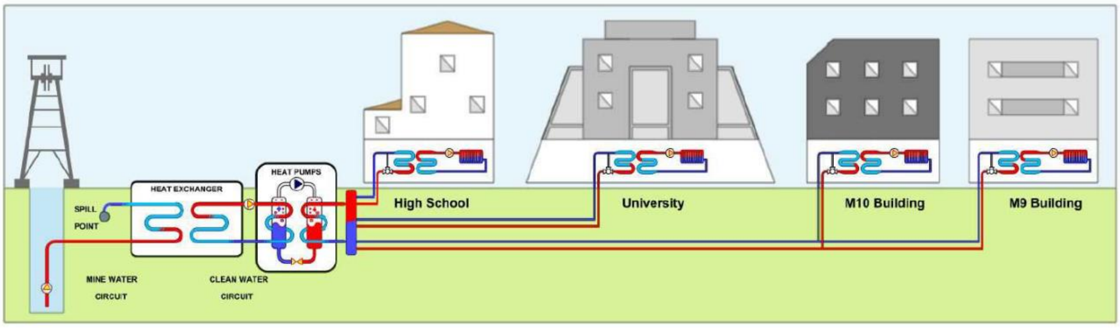

Figure 51: Mieres DH network scheme (source: Hunosa)

The details of the technical architecture of the DH network are explained in Section V.A, and Figure 52 shows the geographical location of the DH system components, as well as those of the initial facilities.

The DH network is owned and operated by Hunosa following an ESCO model, where Hunosa is responsible for designing, financing, building and operating the DH network, and selling its energy through **energy efficiency contracts** (including energy supply and associated services), as explained in Section V.C.

Geothermal energy and renewable electricity (with certificates of origin) **cover 98% of the heating and domestic hot water supply**. It could go up to 100% by pre-heating the buildings to avoid simultaneous start up in the morning, or through the use of thermal storage.

Key facts and figures

DH market share	36 %
RES share	98 %
CO_2 emissions	5 kg/MWh
Installed capacity	4.1 MW
Energy production	3 GWh/y
Km network (double-pipe)	1.2 km
Supply/return temperature	50-80/40-60 °C

The DH network, as the overall geothermal project, has been **built in a modular way enabling to extend the network** and to add new production blocks to meet demand increase. The extension of the DH system in Mieres is currently under study, mainly through the connection of public buildings in the Northern part of the city, which would be supplied by a biomass boiler (see Section VIII).

Figure 52: Map of Mieres geothermal facilities, including those of the DH system (in orange) (source: Hunosa)

IV Business Model

A Governance

Hunosa is a **Spanish public company** and a holding of the State Corporation for Industrial Holdings (*Sociedad Estatal de Participaciones Industriales* or SEPI), a sovereign wealth fund controlled by the Ministry of the Treasury.

Hunosa is structured around one President appointed by the Ministry of Finance and 7 Directors appointed by the President, all contracted by the SEPI. This General Management team usually changes when there is a change of Government in Spain. The rest of the company is composed by Head of Departments and labour staff, all directly contracted by Hunosa.

After decades as a reference in the mining field in the region of Asturias, Hunosa has organised the cessation of this activity (the last coal mine will be closed in 2021 as per national requirements) and has **reoriented its focus on energy, energy services and the environment**, with a vocation for leadership in the energy transition process.

As regards Mieres DH network, Hunosa **owns, fully operates and handles the commercialization of the network**.

B Strategy and Offer

In order to develop its new business in DHC, Hunosa adopted a **wise step-by-step approach**. The concept of reconversion of an abandoned coal mine into a geothermal plant for district heating has been tested first to supply a few individual clients, including some of the current largest customers (Mieres hospital, for example). This allowed to prove the technical reliability of the solution as well as its economic interest, and thus to gain the trust of new clients to establish a new DH network. At present, Hunosa looks at extending the current network and creating new ones in the region, by using the local geothermal potential or developing new renewable energy sources such as biomass or excess heat recovery.

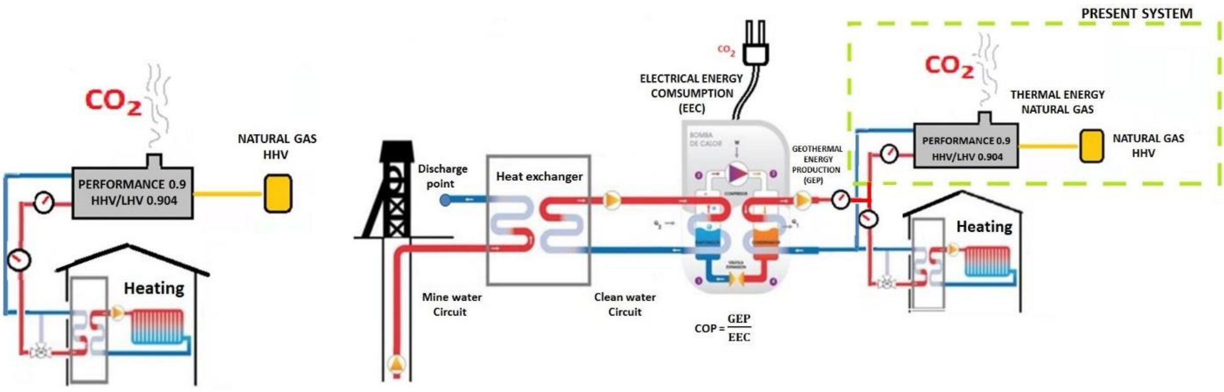

Figure 53: Switching from natural gas supply (left) to DH (right) (source: Hunosa)

The commercial strategy of Hunosa's DH network in Mieres is simple: in order to attract new clients, **Hunosa guarantees a tariff below the clients' contracted gas tariff**. The discount is negotiated with each client and usually goes around -10%. This is possible due to the fact that the DHC market is not regulated by any public authority, so there is no obligation for equal treatment of the customers. In this context, Hunosa stands as an **ESCO**, bearing the whole investment of the infrastructure and selling energy services to clients on a case-by-case basis.

The contract duration is also negotiated on a case-by-case basis. Large public customers (like the hospital or the university) usually have long-term energy procurement strategies and signed a 10 to 25-year contract with Hunosa. The connected private residential buildings have chosen shorter-term contracts (5-year).

For DH network customers, Hunosa offer includes the maintenance of the substations. Hunosa also offers to handle the maintenance of the back-up gas boilers for some clients (e.g. the university), while other clients chose to handle this themselves, and also operate and maintain rooftop solar thermal facilities in some cases (e.g. residential buildings).

C Financial model

As introduced earlier, Hunosa indexes the DH tariff to the gas tariff contracted by the client, so the tariff structure is made of **one single variable term expressed in €/MWh**. The DH tariff is calculated by applying the negotiated discount rate to the gas tariff contracted by the client with its gas supplier (each client maintaining its gas connection for back-up and peak loads). In order to compare exactly the same things for both solutions (gas Vs. DH), the calculations:

- include the 0.904 factor to convert the quantity of energy supplied by gas (expressed in higher heating values) into useful energy (in lower heating values);
- include the mean yield of the gas boiler to effectively compare the final energy delivered at the client's secondary network;
- exclude costs related to construction, operation and maintenance of the gas boiler since this infrastructure is kept in both cases.

These calculations are performed every year, based on the gas invoices over the previous year communicated by the client. Invoices adjustment are then made at the end of the year by taking into account real gas tariffs observed over the year.

Therefore, **the profitability of Mieres DH network is directly correlated to gas prices**: the higher the gas price for the clients, the higher the revenues for Hunosa. While the inverse is also true and could put Hunosa activity at high risk, it is important to take into account that Hunosa is forced to pump hot water out of its abandoned mine anyway (see Section V.A), so any revenue that can be generated from this hot water is globally seen as a bonus. Moreover, the company also ran business plans for worst case scenarios (with low gas price), and the project still remains profitable. Finally, it can be observed that the risk or opportunity generated by such a tariff structure is partially mitigated by the fact that electricity price (which is the main fuel charge for Hunosa on this DH network based on geothermal energy) is relatively closely correlated with gas prices, so if revenues increase, operational charges will increase as well (and vice versa).

In its efforts to attract new clients, **Hunosa has not applied connection fees** to its first customers. The connection costs are borne in the total CAPEX (Capital Expenditure) envelop. This position might evolve in the future.

With such an aggressive commercial strategy (made possible by the ERDF[55] subsidy as presented in Section V B), **Mieres DH system is profitable**. The individual operations undertaken during the first phase (for the first 3 individual clients) are also profitable separately. In 2019, the annual turnover for the geothermal business of Hunosa was 293 k€ (Mieres Phase 1), from which sales to the hospital, the largest individual client for Hunosa to date, represent 265 k€. The new DH network (Phase II) is expected to generate 155 k€ in 2020.

V Integrating RES and Waste Heat

A Technical considerations

Geothermal energy

Geothermal energy is the unique energy source used in Mieres DH network to date (apart from gas used by individual gas boilers kept by the clients on their own site for back-up and peak loads). The use of the geothermal resource in Mieres relates to a specific geological and industrial context, but with a **very high replicability potential for all the coal mining regions that are facing colliery closure nowadays**.

Indeed, as coal mines are abandoned, the water that was once pumped out in order to allow the underground mines exploitation is now flooding the different geological formations (galleries and permeable rocks), as depicted in Figure 54. As the water table rises, it is necessary to start pumping water again in order to avoid the water table going back to its initial natural equilibrium, which may cause damages to the city infrastructures built at surface (as these were built when the mines were already operated, this new hydrological equilibrium may cause structural failure of the soil). Therefore, **operators of abandoned mines like Hunosa are obliged to keep pumping water out continuously to maintain a safe water table** determined according to local geological conditions.

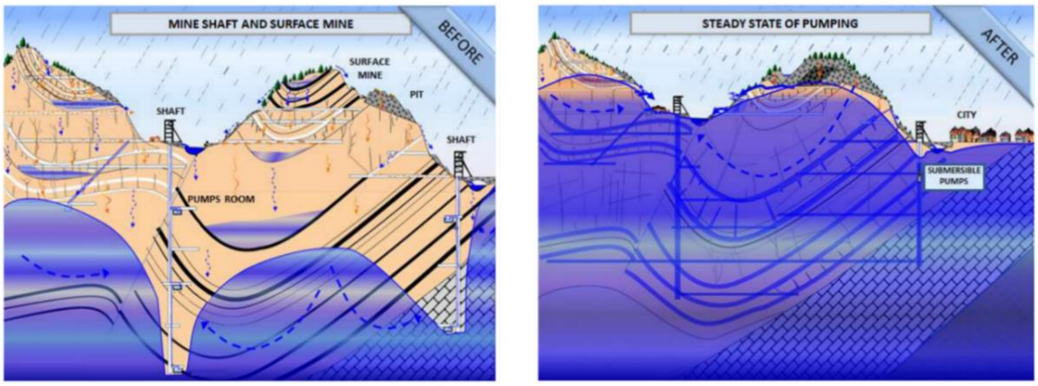

Figure 54: Mines flooding process and steady-state pumping obligation (source: Hunosa)

In order to convert this ever-lasting charge (3.0-4.0 Hm^3 of pumped water are extracted annually from Barredo coal mine) into a benefit, Hunosa decided to take advantage of this pumped water to supply a DH network. Indeed, **the average temperature of the**

[55] European Regional Development Fund

pumped water is 23°C, which makes it ideal for geothermal use with heat pump technology (discussed below).

To recover this hot water from the subsurface, two submersible pumps are hanged at the bottom of self-supporting flexible pipes (8-inches diameter) at about 90 m depth down the historical shaft of the coal mine (see Figure 55). Each pump has a capacity of 83 kW and produces 330 m^3/h, maintaining the water table at 37 m below surface (four other pumps and flexible pipes are installed in this shaft to supply the three initial individual clients). Surface equipment such as well head and pipes are made of stainless steel to avoid corrosion problems.

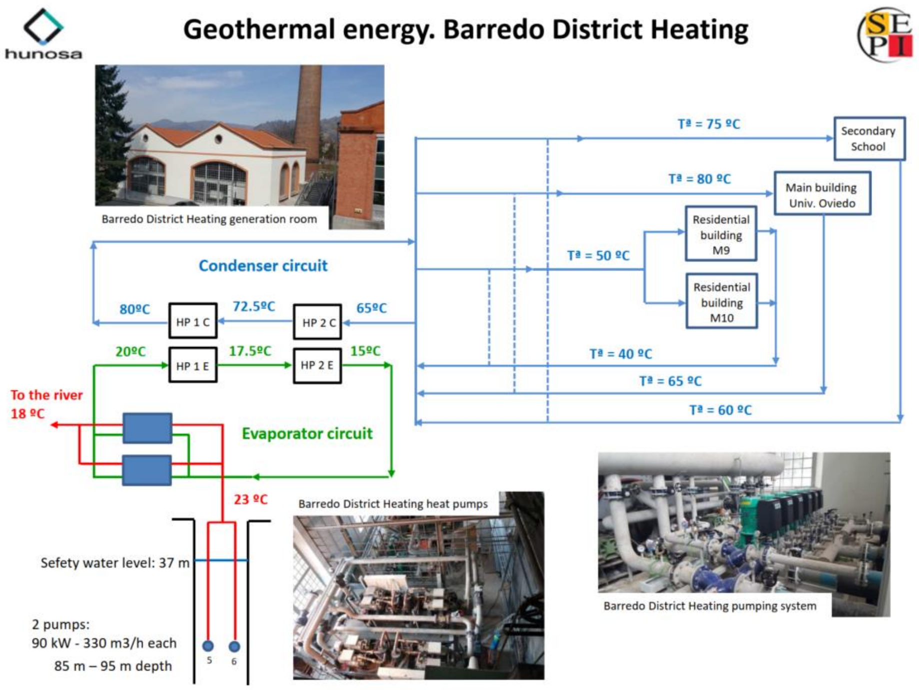

Figure 55: Technical principle for Mieres DH production facility and network (source: Hunosa)

One key difference from other open loop geothermal projects in aquifer is that the pumped water is not reinjected back into the same geological body. In the case of Mieres project, the pumped water, after having left its calories to the DH network, is reinjected in the river nearby at about 18°C (chemical and temperature controls are performed to ensure environmental integrity of the operation). This has the **strong advantage of not having significant risk of cooling down the underground resource over time** (as the river is not directly connected to the abandoned mine galleries).

As geothermal energy covers 98% of the demand and as electricity (for the different pumps and heat pumps of the system) is purchased with green certificates, the CO_2 content of Mieres DH network is 5 kg_{CO2}/MWh. The refrigerant used, **R1234ze** (made from hydrofluorocarbon products), is also environmentally friendly, reducing by 80% the greenhouse emissions compared to CFC[56]-based refrigerants such as R134a. In addition, Hunosa is assessing the feasibility of building ground-mounted photovoltaic plants or wind farms on its land in order to produce its own electricity in the near future.

With a total of six submersible pumps, the Barredo shaft is already exploited at its full capacity in order to maintain a safe water table in the abandoned mine. Other similar projects are foreseen by Hunosa in other closed shafts in the region for DHC networks, like in Langreo (see Section VIII).

[56] Chlorofluorocarbons

Connected buildings

After the initial phase enabling the individual supply of heat to clients (all supplied at low temperature levels), Hunosa had to investigate and invest in a new **heat pump** technology to raise the temperature at the well head (23°C) up to 80°C in order to supply high temperature customers (the university and high school), as depicted in Figure 56. Hunosa can regulate return temperatures via 2-way valves on the primary network in order to achieve a good COP (3.5 to 4.0) of the heat pumps.

Given the limited number of customers on this network and their respective location, preventing from the possibility to direct returns from high temperature clients to supply low temperature ones, Hunosa designed the network with **three separated circuits**, supplying clients at three different temperature levels (see Figure 55 and Figure 56).

Figure 56: General layout of the 3 separated networks (source: Hunosa)

It is interesting to add that low temperature customers (M9 and M10 buildings) have been connected with pipes designed for low temperature in order to optimize costs (since they are located almost 1 km away from the heat plant).

Finally, it is worth mentioning the relevance of the **complementary demand profile of the connected buildings**: public buildings (the high school and university) are heated only during working hours, while residential buildings require a constant supply, resulting in an overall relatively flat demand (see Figure 57) and an improved energy efficiency, as higher COP of the low-temperature network compensate lower ones of the 2 high-temperature grids.

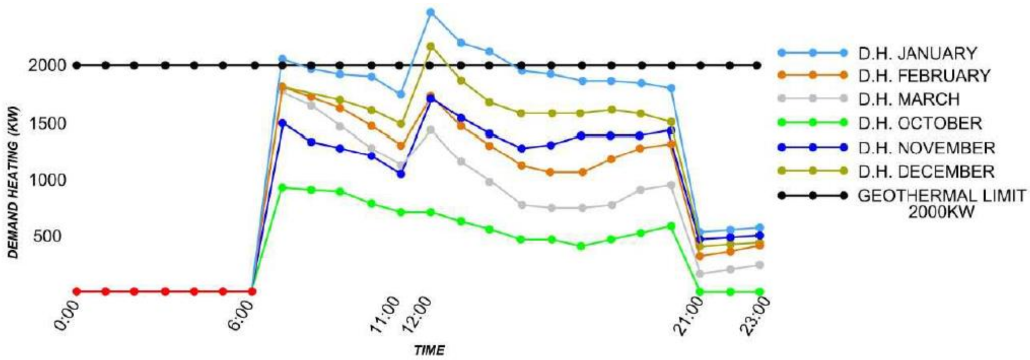

Figure 57: Expected heat demand during the year (source: Hunosa)

Integration of additional renewable and excess energy sources

As Hunosa owns significant surface of forest lands in Asturias, the company has integrated **biomass exploitation** as one of its new activities in its strategic realignment to compensate the cessation of the mining activity. Hunosa ambitions to build a biomass cluster with its own resources and with partners in order to satisfy several needs:

- The **extension of Mieres DH**. In this case, an additional heat plant with 6 MW biomass boilers shall be built in another location (the available space at the current heat plant will not be sufficient and nearby buildings have individual gas solutions), probably closer to the targeted clients. As the current network already benefits from individual decentralised gas boilers for back-up, and the demand of current clients is not expected to grow in the future, the new network supplied by biomass would most certainly not be interconnected with the current one. More details on this project are discussed in Section VIII.
- Creation of a **DH network in Langreo**. This could lead to a network supplied by both geothermal energy and biomass. More details on this project are discussed in Section VIII.
- **Installation of individual biomass boilers for buildings**. Hunosa already provides this type of offer for some clients. The business model is that clients pay for the energy and amortization of the installation, which belongs to them after a certain number of years.
- **Conversion of the current coal power plant (50 MWe) into a biomass-mix fuels plant**. This could bring some potential of **excess heat** from power generation processes. However, the uncertainty on the amount of excess heat that could be recovered is still high, as the fuel switch and change in operating regime will take place in the next 2-3 years. The potential clients for this waste heat are located about 4 km away, which could be a challenge to reach economic viability.

B Economic considerations

For Mieres DH system, Hunosa has invested and built the geothermal plant, network and substations. **The total investment for this project amounts to 1.4 MEUR.**

As the project was mobilising a local renewable energy source in a flagship project (conversion of abandoned coal mines) through a circular economy approach, Hunosa received an EU **subsidy of 500 kEUR from the ERDF**. This subsidy was necessary to reach a minimal profitability and to allow an aggressive commercial strategy to attract clients in a rather unfavourable environment for DHC solutions, as discussed in Section B.

At the time of writing this report, the extension project of Mieres DH network had not reached financial close. This project could be funded by the Spanish "Mining fund[57]" (for the network and substations, channelled through the City Council) and by ERDF (for the 6 MW biomass plant).

In parallel, Hunosa also applied to ERDF funding for the project of a new DH network in Langreo from geothermal energy. The total investment here would be 2.2 MEUR and the targeted subsidy would be about 1.1 MEUR.

C Contractual and organisational aspects

The contractual agreement signed individually with each customer of the DH network **does not allow them to disconnect before the end of their contract**. Therefore, unlike concession models driven by municipalities, the clients here make relatively medium- to long-term commitments according to their profile and to their energy procurement strategy (as discussed in Section II B).

On the other side, **Hunosa contractually commits to annually supply the same amount of energy as the client's average consumption in the years previous to the connection to the DH grid**. This means that if Hunosa experienced heat production

[57] "Marco de actuación para la minería del carbón y las comarcas mineras en el período 2013-2018"

shortages and could not meet this agreed amount, the company would have to compensate the clients by paying the difference between the DH tariff and the gas tariff for the corresponding amount of energy that got defaulted. However, if the real demand exceeds the contractual amount, Hunosa will only supply the extra demand if technically possible, at the agreed tariff.

It is worth also highlighting the **green procurement practices used by the public authorities to be supplied by the DH grid**, where an exclusivity clause was used to require the use of geothermal energy from mining water.

D Cooperative approaches and role of digital solutions

As previously mentioned, all key stakeholders agree on the benefits brought by the geothermal DH network, and **the communication and cooperation between pubic authorities at different levels, Hunosa and its clients is continuous and fruitful**.

The **City Council** facilitated the delivery of permits, and the public organisations connected to the DH grid are also promoting the project and collaborating with Hunosa on related issues:

- The **University** of Oviedo, through its Mieres Campus located a few meters away from the Barredo shaft, has been involved in the geothermal project since the beginning, and took part in the first phase using an individual geothermal solution between 2014 and 2019. The fuel switch brought to the University **18-20% savings in their energy bill** during this first period, with respect to its previous gas supply. Hunosa has a Chair at the University, leading common research projects.
- The **Asturian Energy Foundation** (FAEN), also located in the Mieres Campus, followed a similar approach, also participating in the first phase and **saving 15%** of its energy bill. Connecting to the geothermal facilities in 2016 allowed the Foundation to experience first-hand the reliability of the solution, and it is today one of the leading actors promoting its replicability. FAEN is also one of the most demanding clients of the DH grid in terms of performance and transparency, and has integrated in its contract with Hunosa clauses such as **monthly COP monitoring and real-time remote access to the control room** to view its installations (through computers and a mobile app).

Hunosa also participates in several **EU projects** such as RECOVERY[58] or REWARDHeat[59], and has built an international network with other coal regions, with whom it shares the return of experience of its projects.

VI Synergies with Other Urban Infrastructure and Local Value Creation

Mieres project and Hunosa's diversification strategy showcase **synergies of mining activities with district heating and RES generation.**

The project's positive impact on the community includes environmental benefits (653 ton CO2eq/y saved), maintaining or creating local jobs at Hunosa (ca. 6 FTE working on Mieres' geothermal projects), its suppliers and indirectly impacted companies, reductions in the energy bill of over 10%, additional revenues for the City Council in form of fees (construction fees), reducing the energy dependance by using local renewable resources, maintaining a historical heritage and sharing it through several educational initiatives (visits for schools and highschools, 2 educational centres...), etc.

[58] RECOVERY of degraded and transformed ecosystems in coal mining-affected areas
[59] https://www.rewardheat.eu/en/

VII Consumer Empowerment

Clients are invoiced monthly, and have a **continuous communication with the DH operator, facilitating consumer empowerment**. Indeed, as mentioned before, the public buildings connected to the grid had a key role in the project development, and in the case of FAEN the current level of operational transparency is almost total. Each customer is free to negotiate the conditions of their contract, and they are highly satisfied with the services provided by Hunosa.

VIII Prospects

The DH project of Mieres is expected to keep growing and to be replicated in the region, and abroad. The main future DH developments were introduced before, and include:

- The **extension of the DH grid through a new network supplied by a biomass boiler**, connecting firstly the public buildings in the North of the city (additional 1.8 km connecting 31 public buildings, including social housing) and at a later stage private residential buildings. This project was under discussion at the time when this report was written (cf. Figure 58).
- A **new geothermal DH network in Langreo** following a similar scheme to Mieres, which is expected to enter operation in 2021, supplying geothermal energy from the Fondón coal mine to 4 buildings: an elderly residence, a sports centre, a residential building and a health centre (2.3 MW in total, 3.4 GWh/y supply and a reduction of 840 ton CO2eq/y).

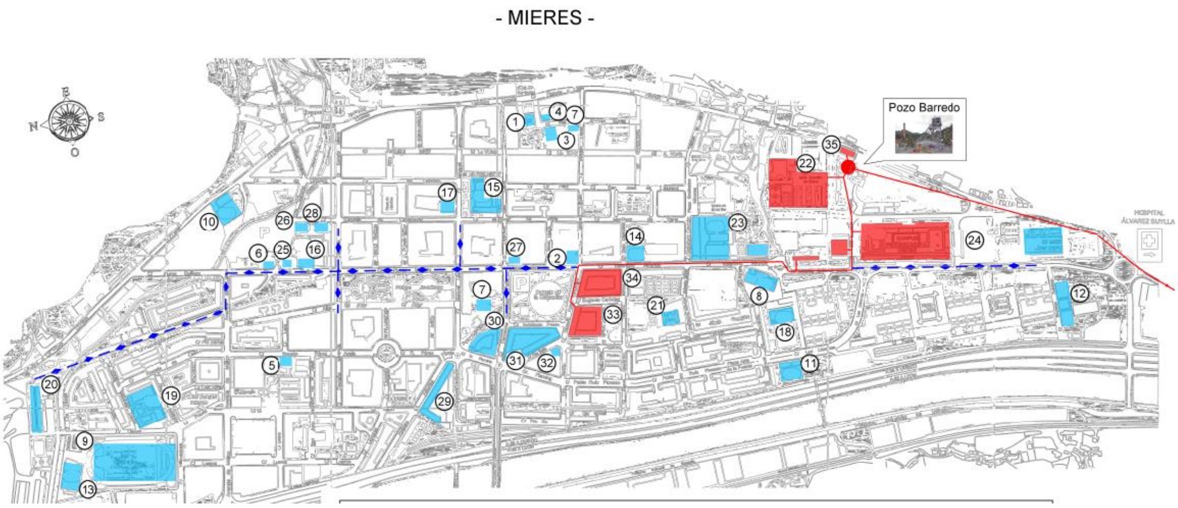

Figure 58: Map of the extension project of Mieres (existing grid and connected buildings in red, extension project in blue) (source Hunosa)

IX Conclusion and Key Success Factors

The geothermal DH network of Mieres is **a successful example of how coal regions can re-shape their economies through energy transition projects**. It is a pilot project potentially replicable in other coal regions in transition to cleaner forms of energy, and has received international recognition (IEA 2019 Global District Energy Climate Award, under the category "emerging markets").

The identified key success factors enabling the integration of RES and waste heat can be summarised as follows:

i. **High political and societal support**: A territorial project supported at all levels (local, regional, national) and by the citizens, as part of the transition of this coal region, providing also a "second life" for the mine, which is part of their history.

ii. **Hunosa diversification strategy**, and the willingness of this coal mining operator to re-think its business and develop new activities related to the energy transition and innovation, minimising the social impact of the coal phase-out.

iii. **Presence of a local renewable energy source**, that could have been an ever-lasting charge (pumping cost) and that finally turned to be a key asset to bring value to the society within a circular economy approach.

iv. **Proximity of the consumers to the main local resource** (in this case the Barredo shaft, providing geothermal energy from the mining water), which is not the case in all coal mines. The replicability of this scheme would rely on the existence of an urban centre or industrial area near a closed mine shaft.

v. **Financial support through investments subsidies** (ERDF funds in this case), needed for the viability of the project, justified by its positive economic, environmental and social impacts.

vi. **Ensuring price competitiveness against the alternative**, especially in a market dominated by fossil fuels, without specific environmental tax incentives. In this case, the main tool to address this barrier was the tariff formula and service model following a simple principle: Hunosa guarantees about 10% decrease on the heating bill compared to the contracted gas tariff and deals with all the operation and maintenance of the infrastructure. This was possible thanks to the financial support mentioned above, and the mixed customer base also contributed to it.

vii. **Efficient collaboration and continuous communication between the main stakeholders** (mainly Region, municipality, operator, and clients). The commitment of public organisations to connect to DH, enabled by green public procurement best practices, secured the demand and the viability of the project.

viii. **High quality service**, essential in emerging markets to prove the solution and attract new clients, provided through an engaged and professional team.

4.5 SPAIN[60]: Districlima Barcelona, a growing DHC system based on waste-to-energy and ambient energy

A previous JRC report on Efficient DHC systems published in 2016 presented how the city of Barcelona has integrated DHC in its urban planning since 2004, opening the market for large DHC networks in Spain. While that report focused on the second DHC network built in the city in 2011 (Ecoenergies Barcelona), this one presents the first one, Districlima Barcelona, which is the biggest in the country, and keeps growing.

Emerging DH market	<1%
Barcelona-Districlima DHC	
PPP governance	
1 602 000 inhabitants	
DH market share	5% of the city
CO_2 emissions	DC: 0 kg/MWh DH: 8 kg/MWh
Installed capacity	DC: 113 MW DH: 79 MW
Energy production	DC: 110 GWh/y DH: 53 GWh/y
Supply/return temperature	DH: 90/60 °C DC: 6/14 °C

Renewable Energy Sources + Waste Heat/Cold Sources → 97% of RES share

- Renewable electricity
- Thermal storage
- Ambient energy (from the sea)
- Waste-to-energy

Key Success Factors

- A pioneering role of the City, integrating energy planning into their urban planning activities to reach its climate goals, and establishing a DHC market
- The development of an efficient public-private partnership
- Applying the energy-efficiency-first principle at district level, and imposing the most energy efficient solution to the buildings
- An optimised technology and energy mix, combining local energy resources and storage, and continuously seeking operational optimisation
- The use of digital solutions to enhance the network's performance
- The smooth cooperation between the local actors, partly facilitated by the utility's governance
- The dynamic urban development context of Barcelona, as well as the high price of the m2, improving the business case for DHC

I Local Context

A City context: place of DHC in urban regulations and other local policies

Barcelona is one of the densest cities in Europe, with ca. 16,000 inhabitants/km^2, and has developed a world-class model on holistic urban planning. The city's population growth has been integrated in its urban development policies since the 19th century, paving the way for modern city planning. Indeed, the visionary compact and block-based urban model envisaged for the city's expansion (*Eixample*) by Ildefons Cerdà in 1859[61] started a new model of urban planning: "urbanism". It aimed at reaching a high level of wellbeing and quality of life for the population by planning an efficient service distribution, mixing land use and social classes, and minimising the distance to essential social services such as hospital, schools and markets, with the ultimate goal of increasing the "social justice" in the city. While Cerdà's plan was not implemented as he proposed, his holistic and humanistic approach finds today its contemporary version in the city's project "Superblocks"[62] (see Figure 59).

Barcelona's urban development has also been driven by some major events hosted by the city, such as the 1992 Olympic Games or the 2004 Universal Forum of Cultures. The City Council implemented an urban regeneration strategy around these events, seizing the opportunities to enhance the city's infrastructure, attract private investment, and associating each of these events to a large urban project. For instance, **the Forum and 22@ districts, where the DHC system of Districlima operates, were developed in the frame of the Universal Forum of Cultures**. This urban project sought at transforming 200 ha that used to host factories of the 19th century into an attractive area for 21st century companies, and included sustainability criteria.

[60] Details on the **national DHC context** are provided in Chapter 4.44.1 (case study Mieres) and in **ANNEX 3**, including key figures, actors and regulatory aspects
[61] Plan for the. Urban Expansion of Barcelona, 1859
[62] See Superblocks project, designed by the City of Barcelona in collaboration with its Urban Ecology Agency (link)

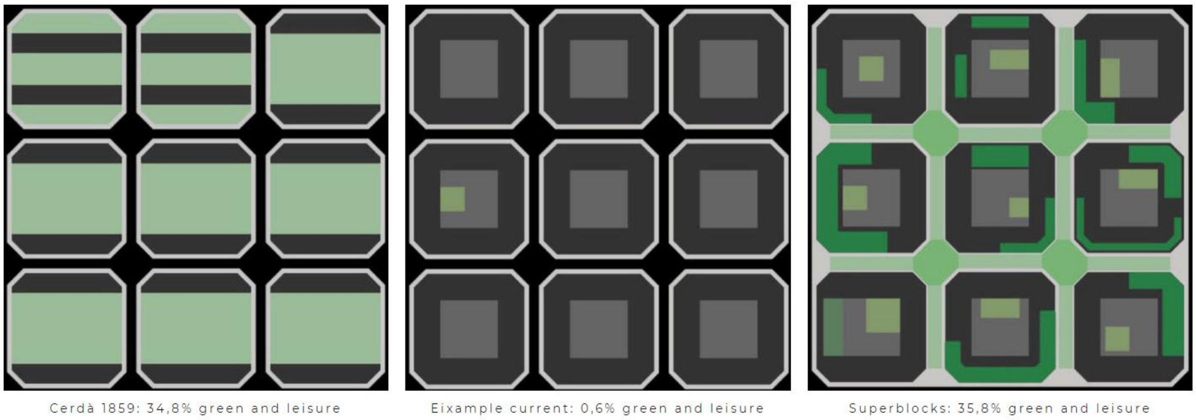

Figure 59: Comparison of share of green and leisure areas: Cerdà's initial plan, today's situation and Superblock proposal (source: Agència d'Ecologia Urbana de Barcelona)

Indeed, sustainability has been placed high on Barcelona's agenda in the last decades, and today **the city aims at becoming carbon-neutral by 2050.** Barcelona is currently implementing its 2018-2030 Climate Plan[63], composed of 240 measures contributing to the goals summarised in Figure 60. In line with this strategy, the city launched in July 2018 **its own public electricity retailer**, *Barcelona Energia*[64], which is the largest in Spain of these characteristics, and is being replicated in other Spanish cities, mostly supplied by private retailers. The aim of this flagship initiative is to promote and stimulate local, renewable energy generation (mainly solar) both for municipal facilities and for Barcelona's citizens, while tackling energy poverty through social tariffs.

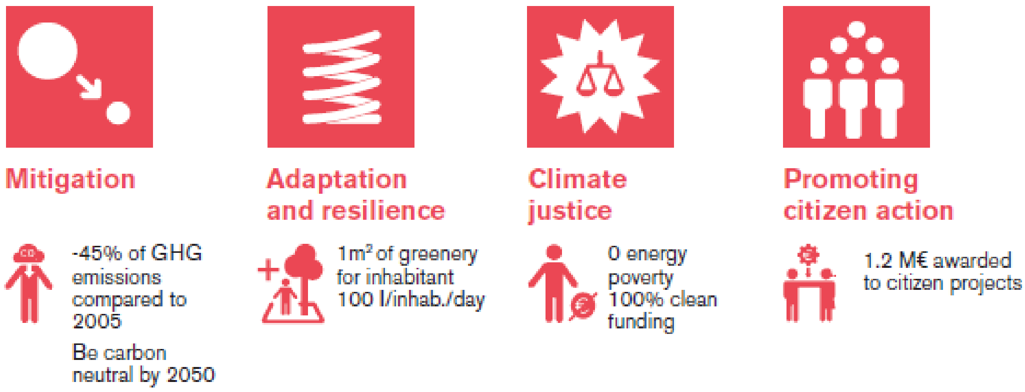

Figure 60: Main objectives of Barcelona's 2018-2030 Climate Plan

On 15th January 2020, the city of Barcelona declared a Climate Emergency[65], conceived through a participative approach to accelerate and step-up some of the measures envisaged by its Climate Plan, in order to avoid 1.5 °C increase by 2030. Through this Declaration, the City Council highlights the **need of a change in its urban model to further mainstream the climate variable in all urban management and**

[63] Barcelona Climate Plan available on this link
[64] https://www.barcelonaenergia.cat/
[65] https://www.barcelona.cat/emergenciaclimatica/en

transformation processes. The actions identified in this strategy are expected to save ca. 1.8 million tons of CO_2 eq. by 2030, through a 563.3 MEUR budget.

The Climate Emergency Declaration includes an action **supporting the development and consolidation of DHC grids in the city**. Indeed, 41% of the city's CO_2 emission in 2017 came from the residential and service sectors, and DHC is one of the technologies enabling their decarbonisation, while **contributing to reducing urban heat islands**. Amongst the new measures included in this action, one could highlight the higher flexibility in the concession perimeter, allowing buildings nearby to connect even if outside the original geographical scope of the grid. These add up to other measures already in place to support DHC, such as:

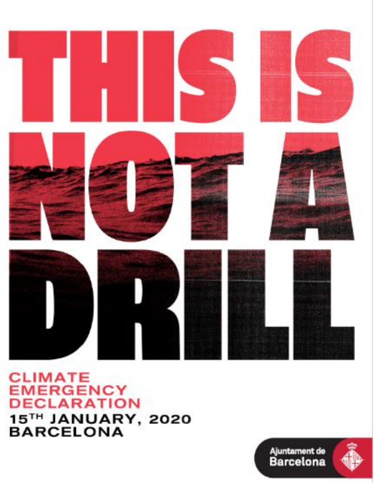

Figure 61: Barcelona's Climate Emergency Declaration

- Urban planning measures aiming at **mainstreaming energy efficiency in buildings**, such as imposing the implementation of the most efficient energy supply solution in terms of primary energy use, which usually is DHC where existing. In practice, this means that most new buildings, as well as many existing ones, in the areas supplied by Districlima DHC grid are connecting to the grid;
- The **mandatory setting of underground service galleries** in buildings to host utility infrastructure (IT, electricity, and DHC pipes) in the 22@ district, which minimises the DHC connection cost.

B Local heating and cooling markets

Barcelona has a Mediterranean climate, with mild winters and hot summers. The heating market is dominated by individual **natural gas** solutions, while the cooling supply is mainly done through **electric chillers** or individual (electric) split units in the residential sector. These existing individual solutions constitute a barrier for DHC deployment in existing buildings, and new connections to the DHC system consist mainly of new buildings, in the frame of the **22@ urban renewal project**[66], transforming a former industrial area into a mixed-use area, integrating new residential and tertiary buildings (incl. hotels).

In 2017, **services and commerce represented the main sectors in terms of primary energy consumption** (35.2%), **followed by the residential sector** (29%). The potential of efficient DHC to decarbonise these sectors, especially given the density of the city, is high. Figure 62 illustrates this by showing the energy use for different service buildings, where heating, cooling and domestic hot water represent around 50% of the energy consumption, at least.

Figure 62: Typical energy consumption of service buildings (source: Districlima Barcelona)

Districlima's DHC system meets ca. 5% of the heating and cooling demand of the city, and around 80% of the connected buildings are **new construction**. Indeed, most of the new buildings in the area covered by the DHC network are connected to it. Where implemented, Districlima DHC solution is the most **competitive supply option**, taking into account not only financial aspects (typically up to 10% **cost reduction** with respect

[66] Additional information on the urban project available on this link

to conventional solutions, taking into account both CAPEX and OPEX), but also the additional benefits brought, such as:

- **Environmental** benefits, enabling to obtain **building eco-labels** such as LEED or BREAM (see Section III.B), more and more demanded by building promoters;
- **Reducing noise and freeing up valuable rooftop space,** particularly interesting for hotels (see Figure 63);

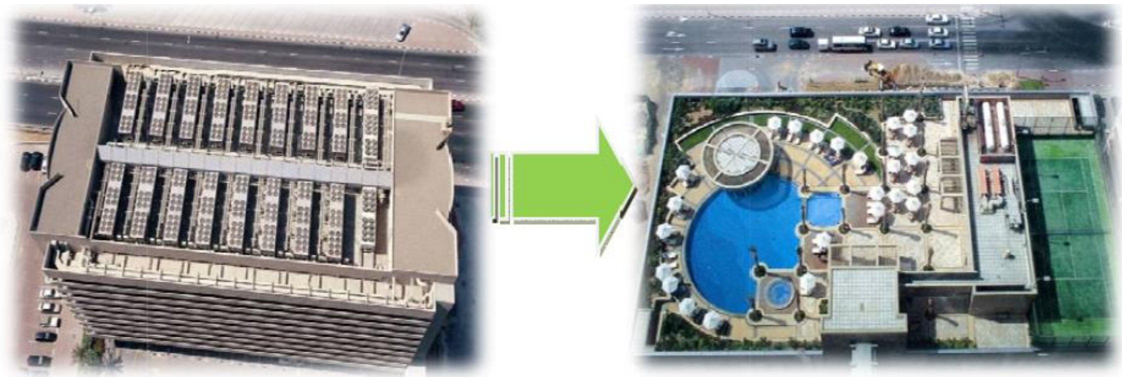

Figure 63: Illustration on how switching to DHC could free up valuable rooftop space (source: Districlima Barcelona)

- **Reducing EHS[67] risks** associated with legionella and with the presence of gas fuels;
- Obtaining a **simple turnkey solution** for heating and cooling supply.

These benefits are being sought by building promoters, and **Districlima's DHC new connections have been growing since its commissioning** in 2004 (see details in Figure 64). This growth stagnated after 2008/09 economic and financial crisis, but was later overcome through the additional joint efforts of the DHC operator and the City Council.

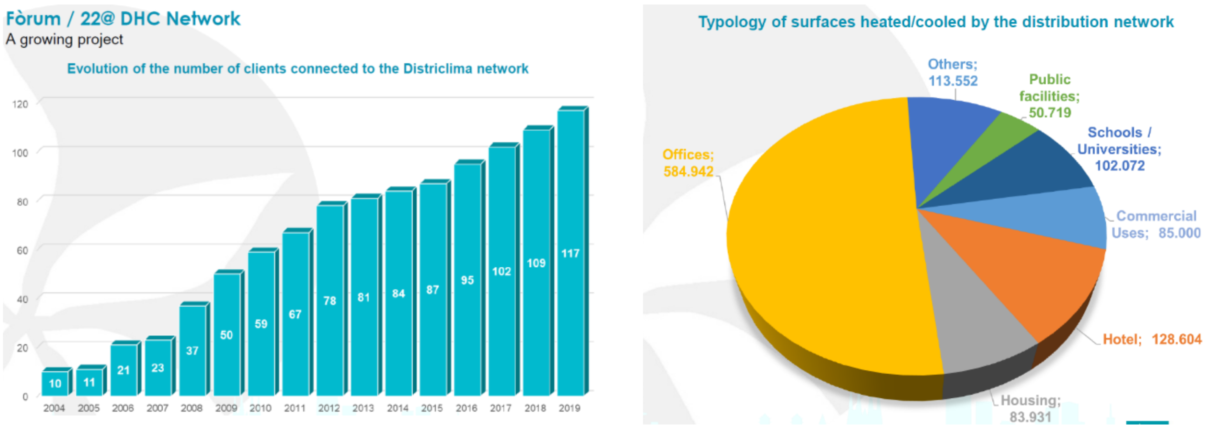

Figure 64: Evolution of Districlima's DHC connected clients, and breakdown per type of building (source: Districlima Barcelona, 2020)

The main demand of Districlima DHC system is cooling (see Section II). This demand is mainly driven by tertiary buildings, even if most new residential buildings, including social housing, also include cooling systems.

[67] Environment, Health, and Safety

II Presentation of the DHC System

When commissioned in 2004, Districlima DHC system covered the **Forum district** (bottom-right part of Figure 65), fuelled by the "Forum" production plant. It has gradually expanded towards the **22@ district** (left part of the map below), where a second production plant ("Tanger") was commissioned in 2012. As indicated in Section VII, the network keeps expanding, mainly in the 22@district and in the maritime districts near "Hospital del Mar".

Figure 65: Map of Districlima DHC system, and type of connected buildings (source: Districlima)

Key facts and figures

DH market share	5 % of the city
RES share	97 %
CO_2 emissions	DC: 0 kg/MWh DH: 8 kg/MWh
Installed capacity	DC: 113 MW DH: 79 MW
Energy production	DC: 118 GWh/y DH: 69 GWh/y
Km network (double-pipe)	20.2 km
Supply/return temperature	DH: 90/60 °C DC: 6/14 °C

The DHC system is **97% supplied by waste-to-energy, renewable electricity and ambient energy from the Mediterranean Sea**, with back-up supply being provided by gas boilers.

Tersa, the municipality-owned waste utility, supplies Districlima with steam from its CHP unit, which is used to produce heating and cooling.

The main elements composing the DHC system are the following (further explained on Section IV.A):

- Production facilities: 2 production plants, integrated in their urban environments (see table below and Figure 66);
- Distribution networks: pre-insulated pipes transporting heating and cooling from the production plants to the consumers;
- Building substations, where heat exchangers transfer the heating and/or cooling to the secondary networks for the buildings.

	Forum Plant (Forum district)	**Tanger Plant** (22@ district)
Heating	○ **Waste-to-Energy** (steam from Tersa's CHP plant): 4 steam/water exchangers of 5 MW each ○ 1 **gas boiler** of 20 MW (back up)	○ 2 gas boilers of 13.4 MW each

	Forum Plant (Forum district)	**Tanger Plant** (22@ district)
Cooling	○ 2 **absorption** machines (Broad), 4.5 MW each ○ 1 cold-water storage tank of 5000 m^3 ○ 4 **electric chillers**: 2 x 4 MW each (McQuay), 2 x 7 MW each (Johnson Controls) ○ Ambient energy refrigeration system: - 3 exchangers of sea water / cooling water, machines of 12.5 MW each; - 1 sea water collection station of 5000 m^3/h	○ 2 **negative cold compression chillers** (-7ºC) of 6.7MW each, producing glycated water (Friotherm) ○ 1 **positive cold compression chiller** (+4ºC) of 6,7MW–producing cold water (Quantum) ○ **Ice storage system**, enabling to decouple cold production and demand

Figure 66: The Forum (left - ©Josep Loaso) and Tanger (right) plants, examples of urban integration of production facilities (source: Districlima Barcelona)

III Business Model

A Governance

Districlima S.A. is the project company that develops since 2004 the DHC network in Barcelona, in Forum (Eastern part) and 22@ (Western part) districts, through **two different concessions of 25 years and 27 years**. The company is in charge of production, distribution and sales of heating and cooling to the customers located in the perimeter defined by the 2 concessions.

The **shareholder structure** is made of:

- 50.8% Engie, the private partner operating the network;
- 20% Tersa, the public company (owned by the City Council) operating the waste treatment plant of Barcelona (see Figure 65) that exports steam to the DHC system;
- 19.2% Agbar (*Agua de Barcelona*), a public-private company managing drinking water and wastewater treatment in Barcelona;
- 5% IDAE (Energy Institute of Spain), a public institution;
- 5% ICAEN (Energy Institute of Catalonia), a public institution.

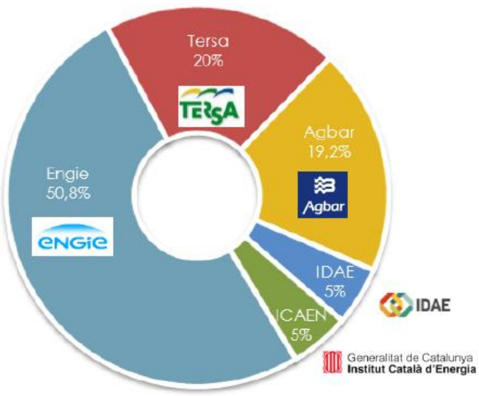

Figure 67: Districlima S.A. shareholders structure (source: Districlima Barcelona)

As required by the Municipality in the first concession tender, this structure thus integrates both the DHC operator and the waste-to-energy operator. This allows to strengthen and ease the obvious synergy that can be established between these two sectors.

B Strategy and Offer

As discussed in Sections I B and VII, Districlima network keeps developing and follows a **very good dynamic** correlated to the urban development of the area. To date, **the total CAPEX spent on the network amounts to 67 MEUR**.

To meet the variety of the demand (some clients already having their own heating or cooling system), Districlima offers the possibility to its clients to **contract for cooling, for heating or for both heating and cooling**.

The key points of Districlima's offer to its clients are the following:

- As the land price is very high in Barcelona, **saving space** for control room in the cellar or for fans on the roof is a key issue for buildings' owners (indeed, in Barcelona, a building implementing an energy solution with renewable or waste energy sources is exempt of the obligation to install rooftop solar thermal facilities set by a 1988 municipal ordinance).
- In addition, the energy efficiency brought by the DHC system usually enables these owners to **increase two energy levels or even more** (see Figure 68), which is also a key parameter for them as the customers are increasingly eager for green building labelling (A-F label is not sufficient anymore, clients focus on additional specific certification such as LEED[68] and BREEAM[69]).
- Finally, the DHC solution is proved to be in many cases (at least for new buildings) the **most competitive solution**. For each client, Ditriclima makes and presents the calculations to draw the global economic balance of the connection to the DHC grid for both new and existing buildings.

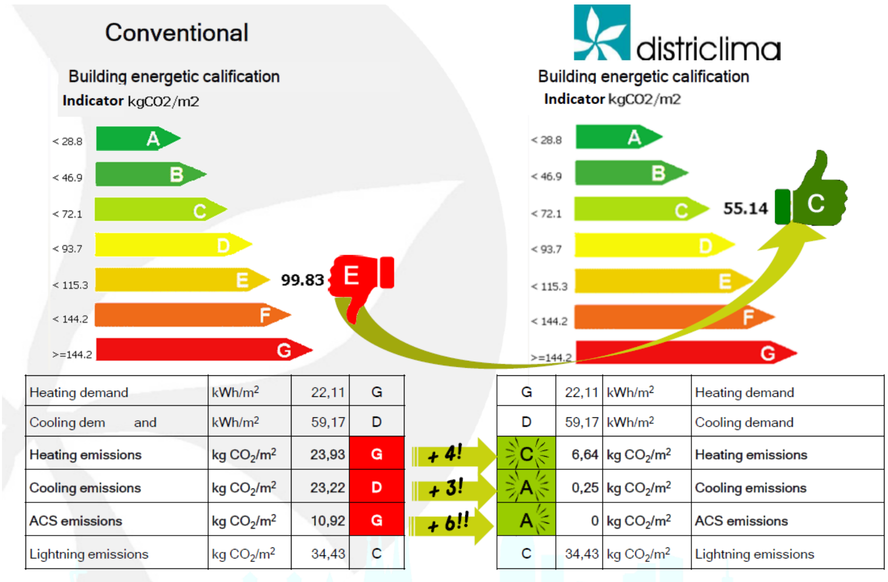

Figure 68: Example of energy level improvement gained through the connection to Districlima DHC network

Despite these strong arguments, the commercialization of DHC in this part of Barcelona was not straightforward, and special efforts had to be done to **launch the start-up phase** (guarantee to connect a minimum volume of buildings in order to make the first investments on Forum plant and feeder) and to **face the financial crisis of 2008** (which partly interrupted the commercial development of the newly commissioned network and put its profitability at risk during 3 years). To overcome these difficulties, Districlima was

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able to rely on its ability to contract with real estate consortiums and on the comprehensive and consistent urban planning from the city of Barcelona.

Districlima **contracts with building managers (and not with final end-users)** in order to limit the number of direct clients and to reduce their own General & Administration costs. The number of clients to date is 109 and keeps growing steadily. Contracts' duration is usually **10 or 20 years** since the clients (hospital, hotels, malls…) usually have long-term strategies for energy management. Clients are invoiced monthly.

The cooling offer is particularly a convenient and competitive solution for the clients (space saving, technical efficiency…), and **no disconnection has been observed so far**.

According to the contract, heat exchange substations (SST) are owned, built and maintained by the clients or by Districlima. If the clients choose the first option, Districlima provides **technical specifications** for the construction and operation of the SST and secondary network. Districlima performs yearly inspections and has captors to monitor the efficiency of the SST (e.g., pressure drop detection indicating that the heat exchanger shall be replaced).

In order to maximise the efficiency of the production facilities and to optimize the sizing of the network, it is important to maximise the delta of temperature (temperature difference between the supply and the return) for heating and especially for cooling (where the delta of temperature is lower). Therefore, **the contract allows Districlima to automatically adjust the closing of the valve at the clients' SST in order to minimize the return temperature for heating and maximize it for cooling** (or if the clients do not agree, they have to adjust it themselves in order to avoid financial penalties).

Figure 69: Illustration of the network supply and return pipes for DC (larger diameter, in blue) and for DH (smaller diameter, in red)

C Financial model

Two different tariffs apply on the two concessions, but the tariff structure is the same according to two options:

- **Long-term tariff** (called "LU"), with a higher fixed component and a lower variable component;
- **Short-term tariff** (called "CU"), with a lower fixed component and a higher variable component.

Clients can choose different options for cooling and for heating, and Districlima always assists them in choosing the most suitable option according to their profile and forecasted needs.

For the concession on the 22@ district, the tariffs observed in 2020 are:

Cooling	Prices observed in 2020 (excl. VAT)	
	Min	Max
Long-term tariff (LU)		
Fixed component	*59,4 €/kW*	
Variable component (energy)	*27,8 €/MWh*	*27,8 €/MWh*
Variable component (volume)	*0,092 €/m^3*	*0,092 €/m^3*
Short-term tariff (CU)		
Fixed component	*37,0 €/kW*	

Variable component (energy)	*43,9 €/MWh*	*43,9 €/MWh*
Variable component (volume)	*0,145 €/m^3*	*0,145 €/m^3*
Heating	**Prices observed in 2020 (excl. VAT)**	
	Min	Max
Long-term tariff (LU)		
Fixed component	*37,0 €/kW*	
Variable component	*21,1 €/MWh*	*24,7 €/MWh*
Short-term tariff (CU)		
Fixed component	*11,4 €/kW*	
Variable component	*42,6 €/MWh*	*49,7 €/MWh*

These tariffs are **actualized monthly** based on national indexes taking into account the evolution of gas and electricity prices (according to the energy mix).

In addition, **connection fees** are applied to new clients in order to cover the cost of connection to the existing network infrastructures.

While limited financial support was provided by the Municipality for the first connections in Forum district, the overall economic feasibility of the project **did not rely on any investment subsidy**. Districlima business is **self-supporting and profitable**, showing a reasonable project IRR, in line with industry standards.

IV Integrating RES and Waste Heat and Cold

A Technical considerations

As pictured in Figure 64, most of Districlima's clients are from tertiary sector, but with different profiles (offices, hotels, education or business centres…). This segment is completed by housing. Therefore, Districlima has a **wide range of different load profiles**, which contribute to flatten peaks of demand.

In addition, most of the connected buildings are recent or new, which allowed to **operate the DH network at relatively low temperature (90-60°C)** and to maintain a good efficiency between the primary network (operated by Districlima) and the SST and secondary network (operated by the clients themselves or Districlima), as discussed in Section III B. **The DC network is operated at 6-14°C.**

Figure 70: Overview of some of Districlima's clients

The energy mix of both DH and DC is extremely decarbonized at Districlima. As presented in the table below for the year 2019, **91% of the heat delivered was produced from the steam imported from Tersa waste treatment plant** (the remaining 9% coming from natural gas boilers during steam shortage from Tersa). In DC, **6% of the cold is produced through Tersa's steam using absorption heat pumps, while the remaining 94% is produced from green electricity (bought with green certificates) through compression chillers**.

The CO_2 emissions generated by both DH and DC are therefore almost null (it would be 6,792 tons of CO_2 without the green certificates for electricity). In total, **Districlima's DHC network allows to avoid 29,792 tons of CO_2 each year**. This of course allows Districlima's DHC solution to be very efficient compared to alternative solutions in Barcelona, which is **key to enforce connection of new buildings to the DHC network**.

Table 1: Details on the production facilities for DC (blue) and DH (red) in 2019

	Name	Type of equipment	Primary energy used
FORUM PLANT	Broad 1	Absorption heat pump	Excess steam
	Broad 2	Absorption heat pump	Excess steam
	McQuay 1	Compression chiller	Electricity
	McQuay 2	Compression chiller	Electricity
	York 1	Compression chiller	Electricity
	York 2	Compression chiller	Electricity
	Tersa import	Steam/water heat exchangers	Excess steam
TANGER PLANT	Friotherm 1	Compression chiller	Electricity
	Friotherm 2	Compression chiller	Electricity
	Quantum	Compression chiller	Electricity
	Gas 1	Gas boiler	Gas
	Gas 2	Gas boiler	Gas
Total production	Cold	118,390 MWh	
	Heat	69,002 MWh	
RES share	Cold	6% from excess steam 94% from green electricity	
	Heat	91% from excess steam	

As depicted by this table, **the excess heat imported from Tersa's waste treatment plant**, which is located right next to the Forum plant (see Figure 65), **is the first priority energy to produce heat, as well as cold when this is technically possible** (see discussions below).

Due to Districlima's concessions history, Forum network developed first, and was then extended to 22@ district to allow the development of the DHC network on this second concession. However, as the network layout had to snake through the districts to preserve archaeological areas (generating more pressure drops though the network pipes) and as Forum plant is located relatively far away from 22@ district (increasing both pressure and thermal losses), **Tanger plant was commissioned to complement the production from Forum in the 22@ district**. This second plant also provides **more flexibility to accommodate the urban development dynamics** (the Western part of the area having developed more than expected compared to the Central part). Today, the Central area is being reactivated and represents an important development potential for Districlima.

On a more technical side, the Forum plant is used as base load (more efficient equipment which allow to maximise the RES share), while Tanger plant is rather used for peaks. For DC, the **Forum plant produces 65 to 70% of the cold in summer time, and 100% in winter time (and it produces almost 100% of the heat all year long as seen before).**

For DC, **absorption heat pumps** (Broad in the table above) **in the Forum plant are used in summer time** (about 4 months), when the demand is stable (better efficiency, with a COP of about 1.3). They are used as first priority (fed by the excess heat coming from Tersa) and operate at full load. They are complemented by electrical chillers from both plants.

In winter, cold is provided by electrical chillers from the Forum plant with better COP (especially with the cold sea water used to evacuate calories, which enables to reach a COP of 7 on McQuay chillers e.g., and avoids installing cooling towers) and **better flexibility** when compared to absorption heat pumps. Therefore, the Forum plant is equipped with a **sea water collection station of 5,000 m^3/h**. The system is completed with a **cold-water storage tank of 5,000 m^3**. Under the current technical and economic conditions, Districlima estimates that sea water in Barcelona is too warm to be used directly for free-cooling.

In addition, **an advanced ice storage system of large capacity (120 MW)** has been installed in the Tanger plant **in order to meet peak demand**. This large storage system is made of a 40 m pool divided in 3 parts and plate heat exchangers ensuring the interface with the DC network. **The storage is filled with Friotherm compression chillers (delivering compressed water at -7°C) at night to benefit from lower electricity prices**. In summer time, the loading/unloading frequency of the storage is daily, while it is monthly in winter.

Figure 71: Broad absorption heat pump (left picture) and steam-water exchangers (right) in Forum plant (source: Districlima)

B Economic considerations

As previously mentioned, Districlima did not benefit from any subsidy. However, **the key element of its business model is that the DHC network is fed in a very significant part (91% for heating, 6% for cooling, or 37% in total) by the excess steam provided by Tersa waste treatment plant**. The CAPEX related to this excess steam is very limited since the waste treatment plant is already amortized with the revenues of its main activity (waste treatment) and since it is **located less than 50 m away from Forum plant** (short feeder). The related OPEX for Districlima are also limited: the operation and maintenance of the required equipment (feeder and heat exchangers) is standard, and **the cost of the imported heat is competitive** since selling direct heat to the DHC network helps the waste treatment plant to reach the targeted ratio of energy recovery set by the national policy (derived from the 2008 European Directive on waste treatment).

Therefore, the excess heat imported from Tersa is used as much as possible to generate heating as well as cooling through absorption heat pumps.

For cooling, despite their much lower COP when compared to the electric chillers (as discussed above), **the low cost of the excess heat makes the absorption pumps equally competitive**. However, as these electrical chillers are much more flexible (absorption heat pumps need 1 week for start-up and constant load), these machines might take a higher share in the DC energy mix in the future (still maintaining the 0 CO_2 emission thanks to green certificates for electricity).

Finally, as discussed above, economic optimization is also developed thanks to the flexibility provided by the ice storage pool, **the storage being loaded at night with electrical chillers when the electricity cost is lower** (Districlima's electricity purchase agreement contains 6 different time zones).

C Contractual and organisational aspects

Third-party access to DHC networks is not regulated in Spain. The long-term **contract between Districlima and Tersa** has been negotiated on a voluntary basis between both parties. As presented in Section IV A, Tersa provided 63 GWh of heat to Districlima in 2019. The plant, which treats about 350,000 tons of waste yearly, also generates about 190 GWh of electricity from steam turbines.

The key points of this agreement are:

- Tersa delivers steam at **160°C and 8 bar**, through a 300 mm diameter pipe
- The maximum capacity is **20 MWth** (corresponding to 30 t/hr of steam)
- The minimum capacity is 5 MWh over 5 hours
- There is no "take-or-pay" clause (if the heat is not used by Districlima, Tersa can turbinate the steam for power generation)

D Cooperative approaches and role of digital solutions

As the **world leader in DC** networks management, Engie, the current network operator, has established many business and RDI partnerships and built up a significant experience in DC. Its cooperation with the **City Council**, as explained above, is also fluent and fruitful.

In addition, digital solutions have been developed for a long time in the Engie Group for the management of its various DHC networks. Dedicated tools have been developed internally, like "Nemo", which allows to optimize the management of the different production facilities (energy mix constraints, fuel contract requirements, equipment availability and constraints) according to a multiple-objective trade-off (energy, cost…). It is a powerful tool based on self-learning models that build up by **integrating numerous data** collected over the years.

V Synergies with Other Urban Infrastructure and Local Value Creation

Districlima's DHC system was conceived by the City Council as a means to value cross-sector synergies, in this case between **waste management, urban development and heating and cooling**, with the ultimate goal of decarbonising the local economy through an innovative and sustainable solution.

The mandatory installation of **service galleries** in new buildings for the DHC pipes as well as IT and electricity cables, required by the City Council in the 22@ district, allows to reduce costs at both construction and operational phases, reducing DHC connection and O&M (Operation and Maintenance) costs.

Figure 72: DHC pipes in multi-service public galleries (right), and in the public thoroughfare (left)

With regard to **local value creation**, the reduction of CO_2 emissions brought by Districlima in 2019 is estimated at 29,792 ton eq. Other economic benefits such as the reduction in the energy bill, the creation of local jobs, the return on investment for the public stakeholders, the reduction of the urban heat island effects, or the additional revenues in connected service buildings thanks to the space freed up (e.g. new rooftops in hotels), have not been quantified.

VI Consumer Empowerment

Districlima's clients can consult their consumption and invoices on their client area on the operator's website. Even if invoices are based on consumption measured at the supply point, typically at building level, Districlima also helps its clients to deal with cost allocation (where needed) through **sub-metering**, which is based on actual energy consumed.

The operator is an active contributor to **creating awareness on the benefits of DHC** across consumers. It has published a Guideline to final-users presenting the grid and its services, and collaborates on a regular basis with the City Council on this issue (e.g., through annual open doors days to all citizens, or visits of engineering students).

VII Prospects

Districlima DHC system has been **growing since its creation**, and all new investments in production and distribution capacity are being done in accordance with the growth of the demand. Any increase of the installed capacity follows an efficiency criterion in order to not only increase the installed power but the overall DHC network efficiency.

VIII Conclusion and Key Success Factors

Districlima Barcelona DHC is a flagship example on how **energy planning** can be effectively integrated in urban projects, and has played a pioneering role in showcasing the benefits of **efficient DHC** in Spain. It was the first large DHC system in the country, and remains the largest.

The key success factors to integrate low-carbon energy sources identified in this case study are the following:

i. **A pioneering role of the City, integrating energy planning into their urban planning activities to reach its climate goals**. The City of Barcelona was the first in Spain to plan a DHC system, and it did it in the frame of its energy transition strategy, integrating environmental criteria in the development of the new Forum and 22@ districts through an in-depth planning phase. By doing so, the City prepared the grounds for a DHC system valuing synergies between urban planning, energy infrastructure (heating and cooling) and waste management, becoming a key agent of change towards climate change adaptation and mitigation.

ii. **The development of an efficient public-private partnership**. As DHC was a new solution requiring a high level of investments and operational resources, and containing a certain level of commercial risk, Barcelona planned the project within a PPP logic, through a long-term concession requiring no subsidy. Through the retained governance, the City keeps a steering role on the network's development. A public tendering allowed them to select its private partners. Engie, the selected operator, brought its DHC expertise and international experience, and has been successfully delivering since 2004.

iii. **Applying the energy-efficiency-first principle at district level, and imposing the most energy efficient solution** to the buildings. The City Council established an obligation to connect to the DHC grid if it is the most efficient energy solution, and also requires new buildings to integrate service galleries to host utility infrastructure, including DHC, resulting in lower connection and O&M DHC costs. The overall efficiency of the system was also supported by a national policy (derived from a European Directive) that incentivises the waste incineration company (Tersa) to sell part of the available steam to the DHC grid (instead of maximising the electricity production).

iv. Indeed, the **optimised technology and energy mix, combining local energy resources and storage, and continuously seeking operational optimisation**, is an essential reason for the success of Districlima Barcelona. Thanks to the significant amount of waste heat available at Tersa (used for both heating and cooling) and to the purchase of green certificates for electricity (also used for cooling), Districlima energy mix is extremely decarbonized and allows to avoid 29,792 tons of CO2 each year. The optimised and flexible heating and cooling production and distribution makes the DHC network competitive and profitable without any subsidy. The quality of the service is very high, the **heating and cooling prices are competitive** against the alternative and its environmental performance is sought by real estate promoters to obtain green labels and comply with urban planning requirements.

v. **The use of digital solutions** also contributes to an enhanced network performance. For instance, the automatic adjustment at the building substations to optimize the delta T of the customers increases the efficiency, and the network has automatic leakage detection sensors to avoid losses.

vi. **The smooth cooperation between the local actors, partly facilitated by the utility's governance.** The municipality, DHC operator, waste treatment plant operator and the clients share a long-term view on the network's development and associated services. The public-private shareholder structure of Districlima, including the key operational actors, facilitates the alignment of interests. These actors also coordinate their efforts in explaining the benefits of the DHC solution, **creating awareness** about DHC, which is still an emerging technology in Spain.

vii. Finally, it is worth also mentioning **the dynamic urban development context of Barcelona, as well as the high price of the m²**. Dense urban environments and space limitations facilitate the business case for DHC, and DC is particularly interesting in the case of the Forum and 22@ districts, with numerous hotels and office buildings having a high cooling demand. Besides, Barcelona is a growing and attractive city, experiencing numerous urban development operations, providing new opportunities for the grid's extension.

4.6 GERMANY: Recovering industrial waste heat for DH in HafenCity (Hamburg)

A previous JRC report on Efficient DHC systems presented Eastern HafenCity's DH system. This case study shows how the energy sourcing strategy of the grid has evolved since 2016 to integrate a new industrial waste heat source that would have been otherwise wasted, improving the system's environmental and financial performance.

Growing DH market 14%

Renewable Energy Sources + Waste Heat/Cold Sources → 90% of RES share

Biogas | Industrial heat | Thermal storage

HafenCity East DH (Hamburg)

Private governance

1 845 000 inhabitants

DH market share	100 % of the area covered
CO_2 emissions	< 40 kg/MWh
Installed capacity	28.3 MWth 1.5 MWe
Energy production	24 GWh/y
Supply/return temperature	70 to 90°C / 50°C

Key Success Factors

- National commitment to become climate neutral by 2050, alongside investment subsidies for DHC operators and waste heat suppliers
- Local commitment from the City of Hamburg to support DH market share increase and decarbonisation
- Comprehensive urban planning, integrating environmental performance and energy efficiency requirements to the new buildings
- Strict environmental requirements set on the supply side, corresponding in practice to an obligation to connect to DH, but leaving an opt-out option and incentives for continuous improvements
- The modular and decentralised architecture of the DH system, enabling to seize opportunities as the networks develops (in this case, industrial waste heat integration)
- The fruitful cooperation between the industrial partner (waste heat provider) and the DH operator

I National Context[70]

Germany committed in 2016 to become climate neutral by 2050 at the latest and released at the end of 2019 a "Climate Protection Programme - 2030" with ambitious intermediary targets for 2030. At the heart of this programme is a new national CO_2 pricing system for the transport and heating sectors which should come into effect in 2021. Further measures intend to make DHC grids more efficient and contribute to convert them to renewable energies and waste heat (excess heat).

The integration of renewable energies into heating systems will play a major role for achieving the ambitious national climate targets, as shown in many studies and research activities which have been calling for a "Wärmewende"[71]. However, **only 10% of the total heat consumed in residential buildings is supplied by district heating in Germany** and although 70% of district heating systems are supplied with CHP plants, 85% of these plants are still burning fossil fuels (coal or gas). As a consequence, even if the potential of more integration of renewables into DHC systems is huge, it should go along with a general development of DHC systems to have a significant impact on the path to climate neutrality.

In the past 5 years, the development of district heating has remained quite stable. Both in existing buildings and in new constructions, the decline of oil and gas systems has benefited the installation of modern heat pumps and other individual heating systems rather than DH. One explanation to this status-quo, is the fact that **the heating market is completely liberalised** in Germany. As a consequence, if a company (in almost all cases, the local utility company or "Stadtwerke") wants to develop and market a DH system, it has to make high initial investments and bear the demand risk, since consumers are, in general, free to choose their source of heat. The amount of investment and associated risks represent thus a high barrier and most local utilities do not have the financial and personal resources to overcome it. Furthermore, there is no strategic "Heating plan" at the national level, and only a few at local level. In most regions and cities, heating

[70] Details on the national DHC context are provided in **ANNEX 4**, including key figures, actors, and regulatory and policy aspects

[71] Heat Transition

is still considered as a topic for building constructors and owners only, and not as a strategic topic for the energy transition[72].

An incentive to develop more sustainable DHC networks can be found in the new comprehensive "Building Energy Act" which has replaced several former laws in November 2020. The main objective of this regulation is to **encourage more sustainable heating solutions,** to forbid inefficient and polluting ones (such as oil-fired boilers as from 2026) and, as far as DHC is concerned, to foster the use of renewable and sustainable sources of energy. **In 2019, only 15% of the heat consumed by DHC customers was produced from renewable sources and waste heat** (86% of the renewables being biomass).

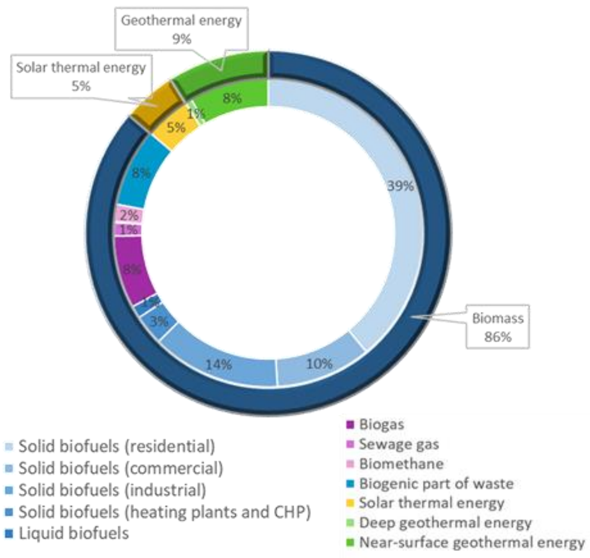


Figure 73: Heating consumption from renewable sources (source: Tilia from German Ministry of Economy data, February 2020)

With the enforcement of this law, new DHC systems have to meet one of the following characteristics in order to supply newly constructed buildings:

- Use heat or cold produced *mainly*[73] from renewable energies;
- Use more than 50 % of waste heat (excess heat);
- Use more than 50 % of heat/cold from CHP plants;
- Use more than 50 % of heat/cold produced by combining the above measures.

This should lead to positive effects in the building sector. A combination of these sustainable district heating grids with smart control and heat storage systems could enable a secure, largely fossil-free heat supply. To this end, an expanded renewable energies **funding programme** will provide additional incentives for the transformation of existing heating and cooling grids. This will come on top of:

- existing national funding schemes (e.g. Wärmenetze 4.0, subsidies for CHP and DHC …) targeting the development and implementation of new DHC systems, as well as the associated public communication;
- regional programmes aiming at the transformation and modernisation of areas with an economic system strongly dependant on coal74.

However, numerous observers claim these measures will not be sufficient to reach the ambitious goals set for 2030 and 2050. Aside technology-specific incentives, a more ambitious political framework would be needed: comprehensive urban heating plans at local and regional levels, higher prices for fossil fuels and CO_2 so that renewable DHC systems can compete with conventional ones, changes in the electricity tax system especially for heat pumps, new regulation in the housing rental market, etc.

[72] A detailed description of the DHC market in Germany and its main players was provided in the 2016 JRC report mentioned above

[73] At the moment, there is no precise figure defining the "mainly" and debates among practitioners are running.

[74] https://www.bmwi.de/Redaktion/DE/Downloads/E/eckpunkte-strukturwandel.pdf?__blob=publicationFile

II Local Context

A City context: place of DHC in urban regulations and other local policies

With a population of 1.84 million inhabitants, the city of **Hamburg** is the second-largest city in Germany and 7th largest in the European Union. It is located in the North of Germany, close to the North Sea, at the mouth of river Elbe.

The City of Hamburg updated its **climate masterplan** in 2019. In this revised document, it acknowledges the most significant parameter in Hamburg's responsibility for reaching the 2030 CO_2 reduction targets is *the expansion and qualitative improvement of district heating supplies with the aim of complete decarbonisation in the medium term*[75]. The target is to **increase the share of DH to 35% by 2030** (from ca. 20% today) with an emission factor of 175 g/kWh, thus saving 300,000 tons of CO_2 per year compared to 2017. As part of its strategy to increase the level of RES in DH, and following the results of a referendum held in 2013, in 2019 the City of Hamburg bought back from a private operator the central district heating system including the grid and the "Thiefstack" and "Wedel" coal plants, the city's two major generation facilities.

The HafenCity Project[76]

HafenCity is **one of Europe's biggest inner-city urban development projects**. It consists in converting a former harbour and industrial 157 ha area situated in the centre of Hamburg into a modern city district which includes residential buildings, offices and businesses. A local company was created in 1997 to develop and manage the project. In total, more than 2.4 million square meters of gross floor area are to be built with 7,500 residential units for more than 15,000 residents. At the end of 2018, approximately 3,000 residential units were built. The programme is due to end before 2030.

As regards DH, HafenCity is split between the western part connected to an older cogeneration-based district heating grid and the eastern part where a new modular and decentralized DH grid is being developed. The latter is owned and operated by enercity Contracting Nord GmbH (hereinafter enercity Contracting). This case study focusses on **eastern HafenCity.**

B Local heating and cooling markets

Demand and supply

The City of Hamburg has an average heat demand of approximately ca. **3,000 heating degree days** (HDD) which is slightly lower than Europe's average demand (3,050 HDD). For Hamburg, the trend is a decreasing demand between 2010 and 2019 from about 3,700 to 2,700 HDD.

As regards supply, **DH grids had a steady share of 20 to 21% of total supply** between 2011 and 2017. During the same period, the share of CHP in DH heat generation varied between 55 and 60%, whereas the share of RES grew from 14 to 19%.

For HafenCity, the very high standards of energy efficiency in buildings imposed by the **HafenCity Ecolabel** imply a lower primary energy use than the German building code requirements (GEG - Gebäude Energieeffizienz Gesetz). Up to now, around half of the HafenCity buildings are certified or pre-certified with this label.

The enercity Contracting network is currently expanding to Rothenburgsort, an adjoining district of eastern HafenCity.

[75] Drucksahe 21/19200 - Erste Fortschreibung des Hamburger Klimaplans und Gesetz
[76] https://www.hafencity.com/

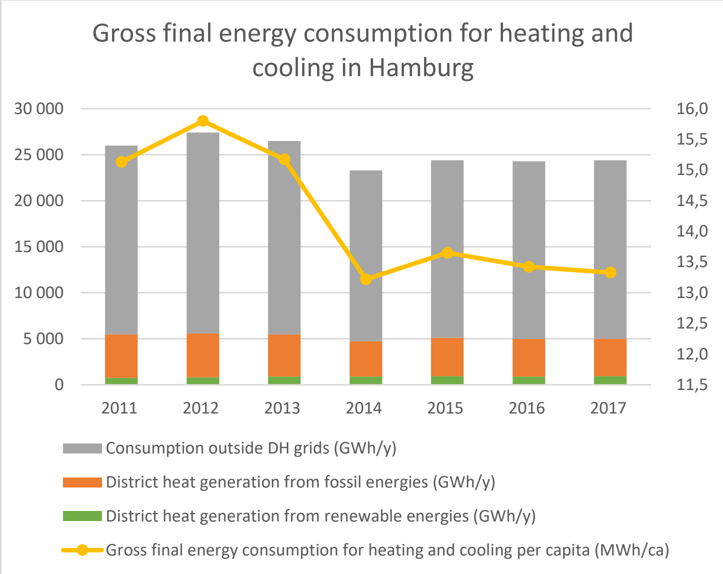


Figure 74: Breakdown of gross final energy consumption for heating and cooling in Hamburg (source : Statistisches Amt für Hamburg und Schleswig-Holstein)

Price competitiveness of different solutions, incl. DHC

In eastern HafenCity, there are two options for heat supply: connection to the DH grid or individual heating with emissions lower than 89 gCO_2/MWh (see details in the following section). This environmental constraint imposed to all heating solutions makes **DH usually the most economical option**. As a matter of fact, up to now, only one building chose not to connect to the grid.

Concerning Rothenburgsort, the constraints imposed to new buildings are not as strong as in HafenCity, though the new "Building Energy Act" gives DH a better chance to be competitive against individual solutions. enercity Contracting plans the first connections to their DH in this area in 2021.

III Presentation of the DH System

The district of HafenCity is a very good example of **sustainable urban development**. Instead of extending Hamburg in the periphery lands, the old port area of HafenCity is being converted into a modern city district. The comprehensive Masterplan for this major inner-city development was approved in 2003 and included high environmental standards, which also affect the heat supply of new buildings.

Key facts and figures (2019)

DH market share	100 % of the area covered
RES share	about 90 %
CO_2 emissions (heating)	less than 40 kg/MWh
Installed capacity	28,3 MW_{th} 1,5 MW_e
Energy production	DH: 24 GWh
Km network (double-pipe)	About 6 km (only eastern HafenCity)
Supply/return temperature	70-90/50 °C

The contract for the construction and operation of the **private low-temperature DH grid** in eastern HafenCity was awarded through a **public procurement** process organized by the city of Hamburg. Originally, the **tender** included very high environmental standards, notably a maximum CO_2 emissions of 125 g/kWh. The tender was awarded in 2009 to the public-private company enercity Contracting, which proposed at the time a heat generation with an enhanced environmental performance - namely 89 gCO_2/kWh - achieved through a production mix using **almost exclusively renewable energies** (biofuels) and to be developed through a modular approach to follow the arrival of new buildings in the district.

Depending on the energy demand, energy plants are being built step by step. The last one, named “Peute”, was designed to integrate waste heat from the Aurubis[77] copper smelter industry into the energy mix. This **modular approach to heat supply** enables the DH system to optimally adapt to structural developments, and has thus made it possible to integrate alternative technologies and energy sources.

In 2019, the DH operator finalised the connection of the Aurubis’ industry, which supplies today most of the heat demand (67%) with **almost CO_2-free industrial waste heat** that would be lost otherwise. As a result, **the maximum CO_2 emission for the DH in eastern HafenCity was reduced from 89 gCO2/kWh to 70 gCO_2/kWh.**

The DH network operates at a temperature between 70°C and 90°C (depending on the outside temperature) and presents a **90% renewable ratio**. The renewable ratio and the associated CO_2 emissions are expected to stabilize by the end of waste heat integration process (2028) at 88% and 35 kg CO_2/kWh.

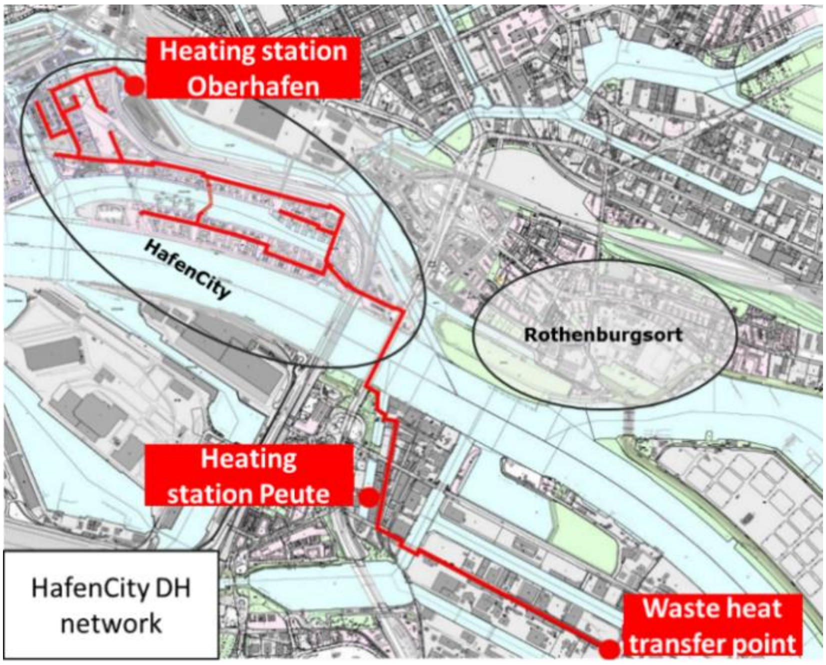


Figure 75: Eastern HafenCity DH network (source: enercity Contracting)

The **eastern HafenCity DH system** produces today about 24 GWh/y with a CO_2 emission ratio lower than 40 kg CO_2/kWh[78] thanks to the **mix** below:

- 18 MW waste heat (excess heat from cupper industry)
- 8 MW natural gas fired boiler in the “Oberhafen” energy plant
- 1.7 MW_{th}/1.5 MW_{el} gas fired CHP (biomethane) in the Oberhafen plant
- 0.04 MW_{th}/0.02 MW_{el} gas fired CHP (natural gas) in the Oberhafen plant
- 18 MW natural gas fired boiler for peak load and back-up in the Peute plant
- 30 MWh of heat storage capacity in the Peute plant

District cooling is planned for 2022 based on waste heat sources (cf. Section VIII).

[77] https://www.aurubis.com/en
[78] Methodology: AGFW-Arbeitsblatt FW 309-6, Link

IV Business Model

A Governance

Since 2004, HafenCity Hamburg GmbH, 100% owned by the City of Hamburg, manages the development of the HafenCity project.

enercity Contracting Nord GmbH is a subsidiary of enercity Contacting GmbH, itself being a subsidiary of enercity AG, originally founded and still mainly owned by the City of Hannover.

enercity Contracting Nord GmbH operates several DH systems in the northern part of Germany. It provides several energy services (including energy efficiency consulting, conception, planning, construction, operations and maintenance of DH grids) to investors, urban planners and residents.

In eastern HafenCity, it **owns and manages the whole DH system** including the grid, heat generation and customer care.

The utility is in charge of the **construction and operation** of the district heating grid in eastern HafenCity. The first building was connected to this DH system in 2013. The contract will end in about 20 years, more precisely ten years after the last planned building is connected to the network.

B Strategy and Offer

Inside eastern HafenCity, the network is developed as the district grows. In 2016, a second phase of development was planning a biomass plant to cover the new heating needs. However, another solution was found and now supplies the growing DH with industrial waste heat, proving the **adaptability of DH to continuously integrate local energy sources**. The operator considers the DH solution as a success story, as it keeps extending and real-estate promoters continue to connect.

Since 2019, enercity Contracting has been building the main pipeline to connect its network to the neighbouring district Rothenburgsort. The first customers in this area should be connected in 2021.

Currently, the utility has no direct access to the end-users and does not manage their meters, but only deals with the building owners, who are its clients.

At the moment, the main heat resource is the waste heat from Aurubis which supplies nearly 70% of the demand. The associated contract duration is 20 years and started in 2018.

C Financial model

Tariff structure

The tariff structure has two components, which in general contribute equally to the final price of heat:

- A fixed component ("Grundpreis"): covering capital and operating fixed costs (maintenance, administration, etc.). The customer is billed based on maximum capacity (MW).
- A variable component ("Arbeitspreis"): unit price per MWh consumed. The customer is billed based on individual (measured) consumption.

In 2019 the "Grundpreis" was 44.04 EUR/kW and the "Arbeitspreis" was 4.89 centEUR/kWh. In 2019, a typical customer with a contracted capacity of 0.5 MW and a demand of 650 MWh per year payed about 54,000 EUR. Those prices are reviewed every year according to the contracted price revision formula.

Connection fee

A connection fee is paid for new connections. Usually the price is defined depending on the connected load.

The duration of the contracts with the clients is usually 10 years, with a possible 5-year extension of term.

Connection specifications

Even if the city of Hamburg issued an "almost" **obligation to connect to the DH grid** (given the maximum CO_2 emission requirement) for residential buildings in the entire area of eastern HafenCity, it is not the case for Rothenburgsort district that will be connected in 2021. There, enercity Contracting commercials inform future potential customers who will choose between the DH and other alternatives.

It is possible to disconnect from the DH grid. During the term of the contract, a client may terminate the contract if a mutual agreement is found between the parties.

Financial results

In the previously-mentioned JRC report published in 2016, the operator pinpointed the deterioration in financial results due to a delayed and disseminated real estate development.

The integration of waste heat as main heat source has certainly changed the financial balance of the project, significantly improving it after receiving public grants, as well as its ecological performance. It is however important to highlight that **this project could only become financially viable thanks to investment subsidies, as the project has particularly high investment costs.**

The financing plan of the waste heat supply project is as follows:

- 34 MEUR invested by enercity Contracting;
- 20 MEUR invested by Aurubis (waste heat supplier);
- Investment subsidies from KfW[79] and ERDF[80] covered about 30 to 40% of the total amount.

The DH operator's investments to integrate the waste heat into the heat supply of eastern HafenCity and to expand the network to Rothenburgsort concern:

- The pipeline between eastern HafenCity and factory premises of Aurubis;
- The pipeline to Rothenburgsort;
- The Peute energy plant.

KfW provided funding for the construction of the pipelines and adaption of the technology at Aurubis' plant. European structural funds (ERDF) were used to finance the Peute energy plant. Eligible costs engaged in the construction of the Peute plant are covered up to approximately 40%, the subsidy being capped to a maximum amount of approximately 2.9 MEUR.

[79] Kreditanstalt für Wiederaufbau
[80] European Regional Development Fund

V Integrating RES and Waste Heat

A Technical considerations

HafenCity is designed as a new urban district for the city centre of Hamburg, both in terms of urban planning and architecture. HafenCity site was once largely occupied by single-storey sheds and only a few existing buildings could be preserved or were worth preserving. Hence, the district currently consists almost exclusively of **new and highly efficient buildings, using low-temperature heating equipment**. With approximately 50% flats and 50% offices, the typical annual energy consumption in eastern HafenCity is estimated between **50 kWh/m2/y and 90 kWh/m²/y.**

In this new urban area, district heating already supplies 2,500 dwelling equivalents (31 buildings) and **expects 9,000 dwelling equivalents in 2030**.

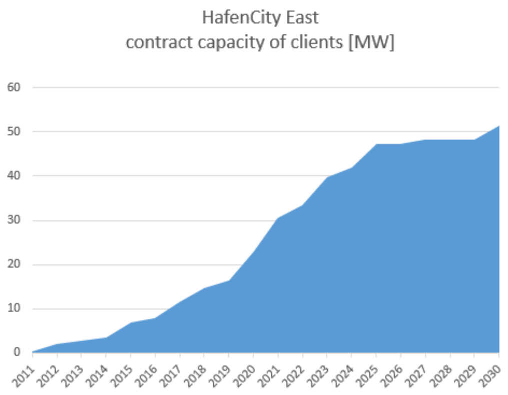


Figure 76: HafenCity contract capacity evolution (source: enercity Contracting)

With growing demand, the operator needs new production units to comply with evolving environmental requirements and technical constraints.

In order to supply **70 GWh per year in 2030**, the DH operator had planned the construction of the production facilities in 2 phases, to meet the expected rise in energy demand:

- In November 2014, the Oberhafen plant was commissioned. It contains a biomethane-fuelled CHP unit of 1.5 MW_{el} and 1.6 MW_{th}. The biomethane comes from enercity Contracting's own production in the region (Schleswig-Holstein). In addition to the CHP unit, there is an 8 MW_{th} heat-only boiler (HOB) generation plant fuelled with natural gas, to cover peak load.
- A second and a third energy plants were originally planned in 2018 and 2024. They were expected to host three biomass HOB fuelled by sustainable woodchips and a heat pump of 3 MW_{th}. However, as **industrial waste heat was found nearby** the network before their implementation, this source replaced the originally planned facilities.

Indeed, Aurubis appeared as the perfect opportunity to supply the eastern HafenCity DH system with industrial waste heat. **A joint feasibility study** was realised by enercity Contracting, the industrial partner and two project promoters (Tilia and the electricity distributor Hamburg energy) showing that **more CO_2 could be saved through waste heat,** among other positive economic and environmental benefits.

In October 2018, 18 MW of waste heat from the copper smelter industry Aurubis was connected to the DH grid by means of a 3.7 km pipeline and the Peute energy plant. For the moment, heat is recovered from the production of sulfuric acid, from the sulphur contained in the copper concentrates. The **160 GWh/year** of heat produced by this exothermal reaction is adapted and used in eastern HafenCity and Rothenburgsort for DH.

Figure 77: Connection of eastern HafenCity DH with Aurubis waste heat (source: Aurubis)

In the final stage, the 160 GWh industrial waste heat will **avoid the emission of 20,000 tons of CO_2 per year**.

- 10,000 tons of CO_2 by Aurubis (replacement of natural gas used to produce steam on the Aurubis plant premises);
- 10,000 tons of CO_2 by enercity Contracting, which will be supplying the two districts of eastern HafenCity and Rothenburgsort with this waste heat.

In 2019, **Aurubis provided 67% of the 24 GWh heat production** with industrial waste heat. Today a large part of the heat requirements are hence covered by almost CO_2-free industrial waste heat (only 0.4 g CO_2/kWh due to the electricity use for pumping) that **otherwise would have been wasted**.

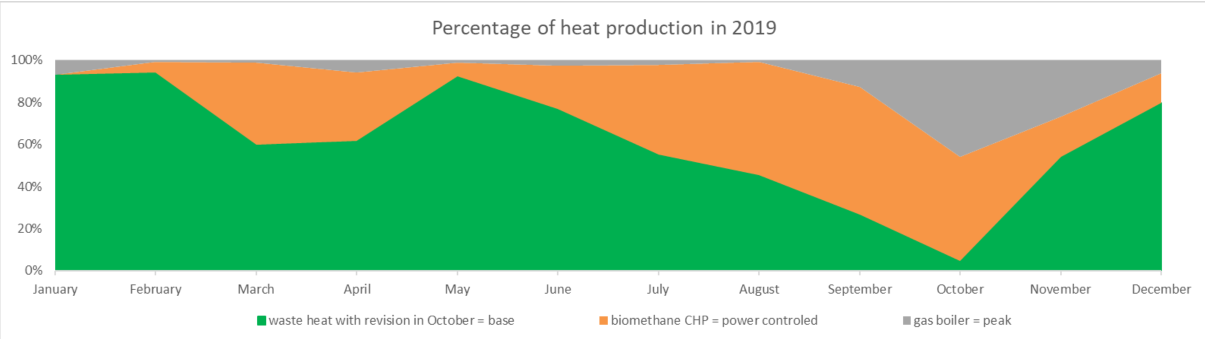


Figure 78: Percentage of heat production in 2019 (source: enercity Contracting)

Interruptions in the supply of industrial waste heat due to construction works were expected during the construction phase (2018 – 2020). Therefore, the current figures in Figure 78 are not yet representative for the ratio of waste heat, biomethane and natural gas.

In the event of planned or unplanned breakdowns, the Peute plant together with the Oberhafen plant **ensure the supply of heat to the customers**. Indeed, with the help of **30 MWh of heat storage** and the additional 18 MWth of gas fired (LNG or Liquefied Natural Gas) boiler for peak-load and back-up production, both installed in the Peute plant in 2020, the strong fluctuations in waste heat caused by industrial production hazards are compensated.

The Peute plant not only secures the heat but **also presents an interest for the industrial heat supplier to cool its process**. The return water from the customers at 60 °C is sent back to Aurubis where it is heated up to 90 °C again thanks to plate heat exchangers with a total capacity of 25 MW.

Aurubis has the technical potential to extract 500 GWh of heat, three times the current heat volume. Hence, Aurubis could be interested in selling it to other neighbouring DHC grids. enercity Contracting has anticipated future needs and built the pipeline over the Elbe larger than necessary for its own needs (capacity of 60 MW). In case of a cooperation between Aurubis and another neighbouring DH operator, enercity Contracting will be a cooperation partner, enabling the distribution of Aurubis waste heat over the Elbe through their heat pipes.

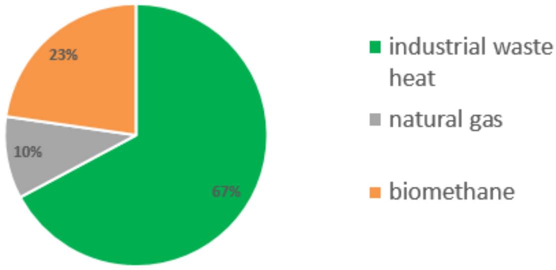


Figure 79: Heat production mix in 2019 in eastern HafenCity

Currently, eastern HafenCity heat losses are about 13%. With the increase of clients in the next years the heat losses are expected to decrease. The average DH density is expected to increase and reach **9 GWh/km in 2030** (from ca. 4 GWh/km today).

B Economic considerations

The national and local contexts explained above encouraged the operator to find renewable solutions for its new DH grid in eastern HafenCity.

For the CHP operation, the **wholesale electricity price is a significant factor**. In most cases the operator gets a fixed tariff for the electricity produced. In addition, it can sell its electricity production on the wholesale market, increasing the incomes from electricity production.

As the CHP is **power controlled,** it is possible to optimize the electricity output of the system and therefore the revenues related to electricity production.

As explained before, all customers pay a heating price depending on the heat consumption and capacity. Indexing has been agreed in the contracts depending on primary energies, wages and manufactured products. In Germany the Statistische Bundesamt (Federal Statistical Office) publishes each year the valid indexes of the year.

C Contractual and organisational aspects

There is no obligation to allow third-parties to sell heat through eastern HafenCity DH. Currently, the DH operator buys heat from Aurubis and sells it directly to its customers.

When using industrial waste heat, many boundary conditions and requirements of the actors from industry and the energy sector must be taken into account. On the one hand, **the priority is the undisturbed production operation of the industrial site**. On the other hand, **security of supply for the heating customers has to be guaranteed**. Such a project can only succeed through intensive and trusting cooperation between the 2 partners.

D Cooperative approaches

The partnership between the DH operator and Aurubis, called "Industriewärme", is a **unique project in Germany both in terms of size and complexity.**

For the network between Aurubis and eastern HafenCity, highly experienced civil engineers were needed. As the pipeline crosses a large bridge over the Elbe and waterways, the project involved technical partners to emerge.

VI Consumer Empowerment

Since enercity Contracting has no direct access to end-users yet, it has not developed any consumer empowerment programme. However, the utility favours direct personal contact with each of its customers and advises them if needed.

VII Synergies with Other Urban Infrastructure and Local Value Creation

The main synergy valued in this DH grid concerns the **partnership with Aurubis**. Further synergies are expected to be developed, notably synergies between heating and cooling, and with neighbouring DHC networks (cf. Section VIII).

Moreover, as pinpointed in Section II.B, HafenCity GmbH has developed an Ecolabel that implies a reduction of primary energy use compared to the German **building** code requirements. Buildings in this district integrate low-temperature heating equipment (including heat emitters), compatible with the DH network.

VIII Prospects

As stated before, enercity Contracting will finalize the connection with **Rothenburgsort district** in 2021. It will lead to new consumers and connections in the next few years and the ability to further valorise waste heat recovered on the Aurubis site.

In the near future (2022), the utility will also provide **district cooling** from the industrial waste heat to business customers. The waste heat used for cooling will be cheaper in summer than during the winter period. **Absorption** refrigeration will be used for cooling with waste heat. Customers will be able to choose between two options:

- Either the DH operator supplies the cold directly, or
- Customers buy waste heat from the DH operator and implement the refrigeration system themselves.

As **Hydrogen** can be produced by renewable electricity and help dealing with fluctuations in production from RES (solar, wind…), the operator is looking at it as a future new source that could replace natural gas. A project in Hamburg already uses a mixture of 30% of hydrogen and 70% of natural gas. A first test operation is being led by enercity Contracting on the subject[81].

Finally, a new eco-district called **Grasbrook**[82] is being built in the southern part of HafenCity, seeking climate neutrality and integrating highly innovative and efficient utility services, including DHC. It will be a new mixed-used district built in a former harbour area,

[81] mySMARTLife – HORIZON2020 European project – Am Schilfpark area (Link)
[82] https://www.grasbrook.de/en/

where **old buildings will be demolished to build new and efficient residential buildings and offices** between 2024 and 2040 (6,000 residents and 16,000 jobs). At the time of writing this report, energy planning is ongoing (conceptual design expected by 2021). Preliminary results show an estimated demand for buildings of around 40 kWh/m^2/y (primary energy), to be supplied through a **new low-temperature DHC network** (supply at 40°C, return at 30°C or lower) that will value local low-temperature energy sources such as geothermal energy and ambient energy from wastewater using heat pumps. During summer, the **cooling demand is expected to be covered using industrial waste heat from Aurubis**, through absorption machine. Seasonal heat storage will be used to the maximum extent possible, to be loaded in the summer season by utilising industrial waste heat and unloaded in winter season to heat the buildings in the Grasbrook district.

IX Conclusion and Key Success Factors

The eastern HafenCity DH system is a remarkable example of an **efficient and modular approach to district energy**, integrating a high share of **industrial waste heat**. This excess heat potential would otherwise have remained untapped. The key success factors identified in the case study are summarised below:

i. **National commitment to become climate neutral** by 2050. Germany set ambitious targets with clear intermediate steps as reducing by 55% the CO_2 emission by 2030. A **new national CO_2 pricing system** for the transport and heating sectors and **national subsidies** to incentivize more sustainable heating solutions are part of the national effort to reach those targets, improving the business case for sustainable DHC, including the one analysed in this case study.

ii. **Direct financial support through investment grants.** The waste heat recovery project would not have been financially viable without the national and EU investment grants received.

iii. **Local commitment from the City of Hamburg**. In the 2019 version of its Climate Masterplan, the City targets a DH share growth from 20% of the total heating demand in 2019 to 35% in 2030. As project promoter of eastern HafenCity, it has also set an ambitious environmental target, which was improved by the DH solution retained (current maximum emission factor of 70 gCO_2/kWh).

iv. **Comprehensive urban planning, integrating energy efficiency requirements to the new buildings.** Hamburg has set high environmental standards to all new buildings in the eastern HafenCity district. This can be illustrated through the creation of the HafenCity Ecolabel, required in many tenders for new constructions, and the use of low-temperature heating systems in buildings.

v. Together with the above requirements on the demand side, **strict environmental requirements are set on the supply side, corresponding in practice to an obligation to connect to DH** in eastern HafenCity. All buildings need to respect the low emission factor target set for the DH grid. DH is favoured by **economies of scale**, and thus has in general lower costs and ultimately lower prices for final users than the alternatives.

vi. **The modular and decentralised architecture of the DH system** enables a smooth planning and allows seizing opportunities for integrating low carbon energy sources while improving the financial performance of the grid, as the project was eligible for investments grants. The Aurubis waste heat project, which had not been foreseen when the grid was designed, is a good example of the flexibility of that architecture. The development of this waste heat recovery project has also enabled new synergies with neighbouring districts and infrastructure, providing new levers for energy optimisation.

vii. Finally, the **cooperation between the industrial partner Aurubis and private operator** enercity Contracting has been essential for developing the waste heat recovery project. Both parties have aligned their interests, ultimately also benefiting the final consumers.

4.7 LITHUANIA: Vilnius, the energy transition of a major DH system within a highly regulated market

Established DH market 56%	Renewable Energy Sources + Waste Heat/Cold Sources	55% of RES share
	Biomass; *In 2021* Waste-to-energy	

Vilnius DH	
Public governance	
587 000 inhabitants	
DH market share	80%
CO_2 emissions	140 kg/MWh
Installed capacity	1,887 MWth
Energy production	2,752 GWh/y
Supply/return temperature	70-115/40-60 °C

Key Success Factors

- The historical commitment of the Municipality with the DH grid
- The efficient mobilisation of European and national subsidies
- Competitive prices thanks to the integration of local renewable energy and waste heat sources
- Competitive prices thanks to a close control of the national regulator and to the auctions market set for the heat supply
- Technical expertise to integrate external heat sources
- Continuous improvement of the efficiency and environmental impact of the network by developing innovative solutions
- Implementation of relevant synergies with other urban infrastructure

I National Context[83]

Lithuania has a **long tradition in district heating** and DH networks are well developed in the country, with a total installed capacity of 8,645 MWth and more than 357 DH systems mainly owned by municipalities. DH is today the most common option for heat supply, with a very high market share in the heating sector reaching around 57% throughout the country and around **76% in the main cities**. DC is not yet developed in Lithuania but projects are expected to emerge to meet the annual cooling demand estimated at 2-3 TWh. For the moment, local compressor chillers ensure the cooling production.

The trend is positive for DH in Lithuania since not only new customers are being connected to DH systems, but also those who previously disconnected are coming back. Such consumer behaviour is influenced by reduced heat prices mainly explained by:

- the replacement of expensive natural gas by cheaper local biomass,
- and the renovation of old network facilities that improved their energy efficiency.

Since 2012, the heat price has been divided by more than two (see Figure 80).

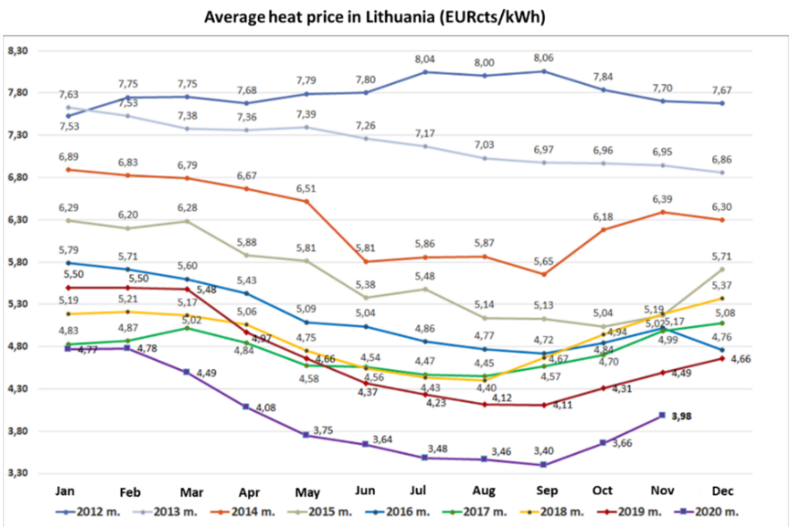


Figure 80: Average heat price in Lithuania from 2012 to August 2020 (source: Lithuanian District Heating Association "LSTA")

[83] Details on the national DHC context are provided in **ANNEX 5**, including key figures, actors, and regulatory and policy aspects

The Lithuanian DH market is **strongly regulated** by the State through the National Energy Regulatory Council (named VERT[84] in Lithuanian). The national energy strategy is updated frequently and the version adopted in 2018 sets the following goals: **DH supply from RES has to reach 70% by 2020** (current projections estimate that it will be reached by the end of the year), 90% by 2030 and 100% by 2050.

The heating sector is managed by the 60 municipalities that make up the country with the objective of supplying the consumers at the lowest cost whilst minimizing the negative impact on the environment. **The heat supply is a monopoly** for each municipality on its territory, regulated by VERT for DH networks above 10 GWh/year, or locally regulated (by municipalities themselves) for networks below 10 GWh/year.

While heat supply is a monopoly, the **heat production is organized through monthly auctions** where independent producers and public companies compete against each other. A maximum auction heat price is calculated every month by the company in charge of the heat distribution according to VERT's methodology and the actual fuel price at the considered time. Today, there are **44 independent heat producers** registered in Lithuania which represent 31% of the total heat delivered to the DH networks.

Although Lithuania focuses more on the production of green electricity because of its very unfavourable power balance (Lithuania has the lowest internal power production rate of the EU), several incentives have enabled to set a very competitive price of DH. For example, a **reduced VAT rate** of 9% (instead of 21%) is applied to households for heat and hot water supplied from DH networks and a compensation of payments exists for low-income families to tackle energy poverty.

Moreover, the support from **EU structural funds** (around 240 MEUR subsidies between 2007-2013 and 2014-2020) as well as **Special Programme for Climate Change** (distributing loans and investment subsidies) made a positive impact for **accelerating biomass projects' implementation as well as modernization and expansion of DH networks**. As a result, the heat losses in the district heating networks decreased from 16,6% (2012) to 15,3 % (2017) and **the share of RES (mainly biomass) in the overall fuel structure of district heating increased from 24% (2011) to 70% (2017)** as shown in Figure 81. In 2017, the share of heat from natural gas was less than 30% in the fuel balance (while it was the main fuel until 2013).

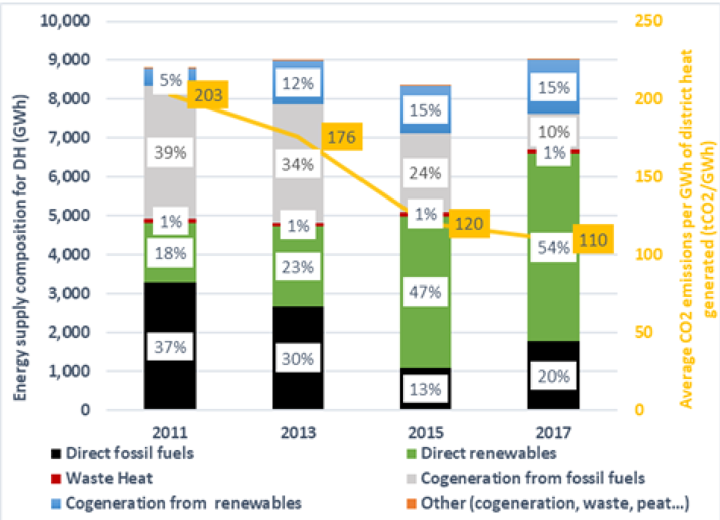


Figure 81: Energy mix and average CO2 emissions of DH supply (own graph, from EuroHeat&Power country report 2019)

Moving to cheap and mostly local biomass not only reduced heat prices but also brought significant benefits to the country's economy, increased energy security of supply, and contributed to climate change adaptation measures.

[84] https://www.vert.lt/

II Local Context

A City context: the capital of the country hosting the biggest DH network

Vilnius is the biggest city in Lithuania with a population reaching about 550,000 citizens, slowly growing since 2010. Regarding district heating, **Vilnius represents more than 30% of the DH sales in the country**. Although the density is relatively low because of the many green spaces composing the city (1,392 inhabitants per km^2), it has **an efficient DH system supplying 80% of the heat consumers** in the city (more than 200,000 households).

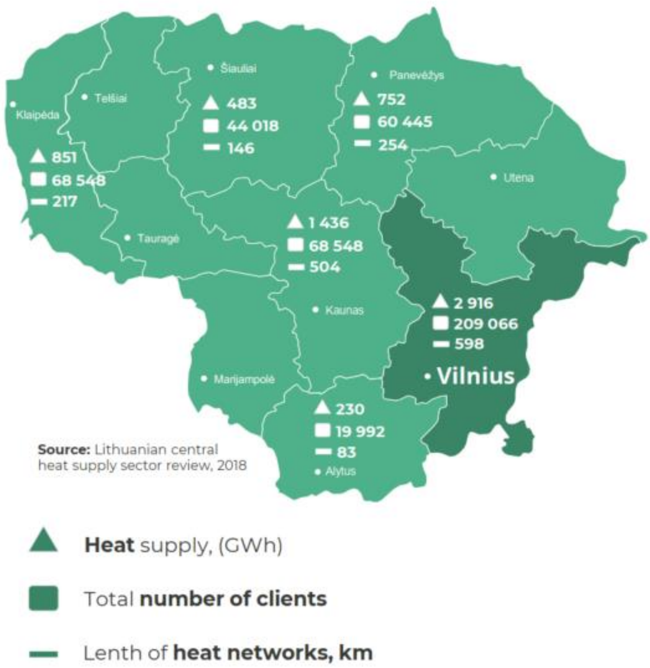


Figure 82: Vilnius DH figures compared to the rest of the country (source: LSTA)

Most buildings are relatively recent as displayed in Figure 83. Only 5% have been renovated. The City Council has approved a programme for energy efficiency until 2023. As of October 2020, there are 272 renovated buildings and 201 undergo renovation. The average annual consumption of the new buildings is about 60-90 kWh/m².

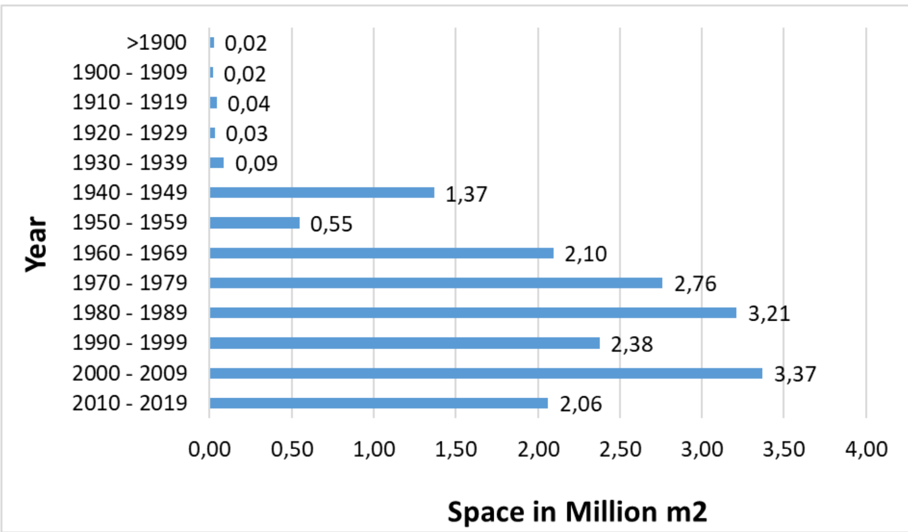


Figure 83: Distribution of Vilnius buildings according to their age (source: Vilnius Municipality)

Since 2017, following the end of the previous 15-year concession for DH (cf. Section IV.A), **the dominant market player is Vilnius Šilumos Tinklai (VST), owned by Vilnius Municipality**, who operates the DH system as a public limited liability company. Vilnius is in advance concerning the national objectives for climate change since the part of **renewable energy in DH supply is expected to reach 90% in the coming years** thanks to new biomass and waste-to-energy units.

On top of its responsibility to transpose the national plan for energy transition into its territory, **Vilnius Municipality is in charge of the heat planning** and in particular the zoning. The municipality divides the city in two types of zones:

- "DH zones": In some particular areas (mostly in the high-density areas), it is recommended for heat consumers to connect to DH, which means that they have to apply for terms of connection to DH (but they remain completely free to choose an alternative solution). The heat consumers have also the possibility to use other RES, the most common individual RES solution being geothermal systems with heat pumps.
- "Competition zones": In the other areas, consumers can directly choose DH (if feasible), RES or any other alternative (usually gas).

B Local heating market

In 2019, the DH heat sales amounted to 2,371 GWh, slightly lower than in 2018 (see Figure 84). The main clients are the **residential buildings which represent 70%** of the DH sales. Private companies represent 16% of the sales, the remaining 14% corresponding to public companies.

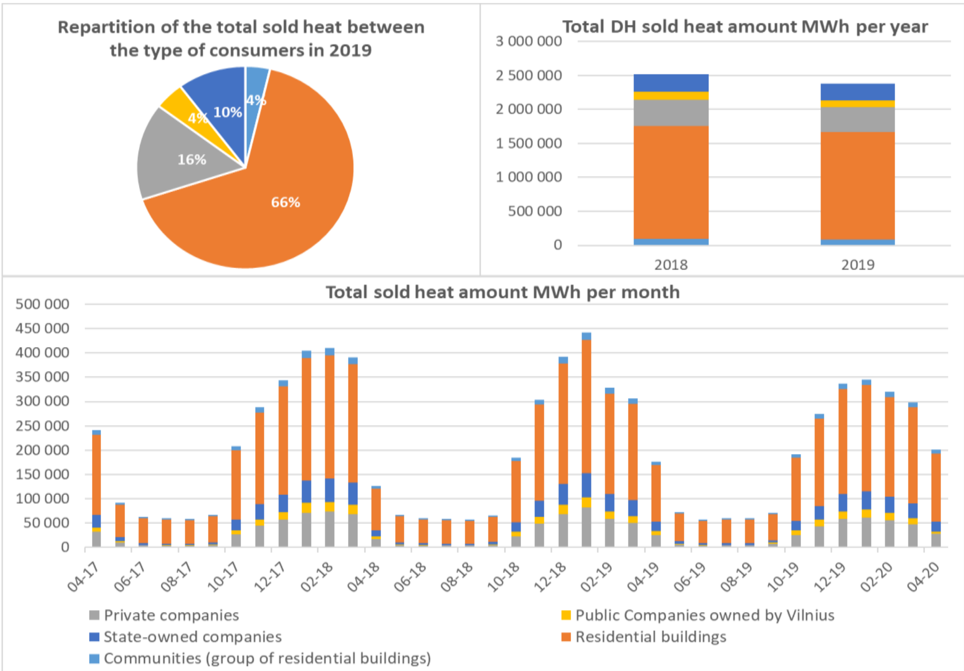


Figure 84: Evolution of the sold heat amount and repartition between the different clients (own graph, from VST data)

Thanks to the low prices of biofuels and the investments realized, **DH is very competitive compared to the other alternatives**, and even against natural gas in the "competition zones".

Compared to other Lithuanian cities, the heat price in Vilnius is on the lowest side (see Figure 85). This is an essential parameter of the network as the heating bill is a key factor influencing Lithuanians' purchasing power and can represent more than 12% of the income for low-income households.

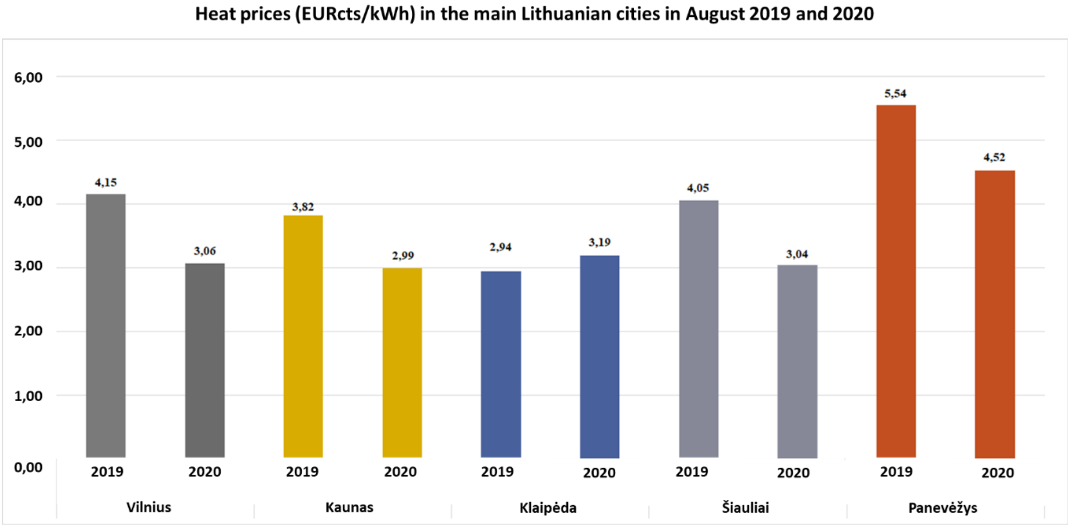


Figure 85: Heat prices in the main Lithuanian cities in August 2019 and 2020 (source: LSTA)

III Presentation of the DH System

Vilnius DH network was created in 1950, and currently serves **7,200 buildings and more than 200,000 customers** for a heating space of 10 million m^2.

180 km of the network (i.e. 25%) have been renovated and the average age of the pipes is about 32 years.

The main network's estimated peak **heat demand is about 1,080 MWth** (-23°C° on the coldest day). The installed heat capacity is about 1,707 MWth including 268 MWth from renewable sources (including the independent producers) and the installed electricity capacity is about 29 MWel including 17 MWel from renewable sources.

Vilnius DH network is composed of several DH systems:

Key facts and figures

DH market share	80 %
RES share	54.5 %
CO_2 emissions (heating)	140 kg/MWh
Installed capacity	1,707 MWth
Energy production (heating)	2,752 GWh/y
Km network (double-pipe)	740 km
Supply/return temperature	70-115/40-60 °C

- The main DH system corresponding to a maximal heat demand of 1,080 MW;
- The DH system Naujoji Vilnia with a heat demand of 28 MW;
- 3 small DH systems with a total heat demand of 5.7 MW;
- 32 very small DH systems corresponding to a heat demand of 2.3 MW.

The 35 small and very small DH systems are supplied with natural gas.

Naujoji Vilnia DH system

This system is supplied by one boiler house ("RK – 2") composed by:

- 2 biomass boilers (2*6 MWth, one as buffer);
- 2 flue gas condensers (2*1.5 MWth);
- 2 gas boilers (30 MWth each) for back up.

A new biofuel CHP plant shall be installed in the near future with a capacity of 2.6 MWe and 6 MWth.

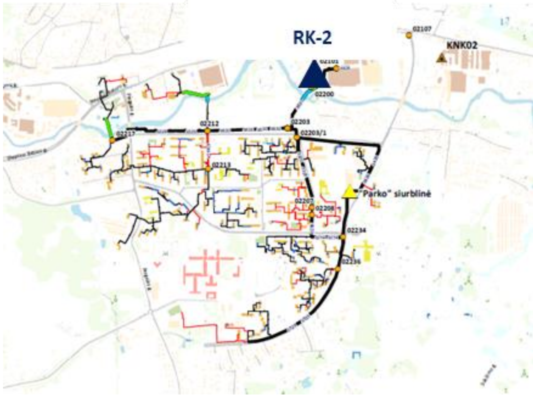


Figure 86: Map of the network and location of the main production unit (source: VST)

The main DH system

7 independent heat producers (owned by private companies) are connected to this network using biomass-powered hot water boilers with an installed capacity of ca. 185 MWth. They provide about 40% of the annual heat production on the DH network.

A 1094 MWth CHP unit ("CHP – 2") owned and operated by VST is connected to the network and ensures the majority of the heat production through:

- One biomass-powered steam boiler of 60 MWth and 16.8 MWe. This boiler is used in priority (winter and summer), and completed with a flue gas condenser of 19.4 MWth;
- 7 natural gas-powered water boilers (824.4 MWth). One flue condenser of 10 MWth completes this installation;
- Several natural gas steam boilers (180 MWth and 12 MWe).

Finally, two natural gas boilers are used for back up and peak:

- The natural gas-powered boiler house number 8 ("RK-8") (495 MWth);
- The natural gas-powered boiler house number 7 ("RK-7") (30 MWth).

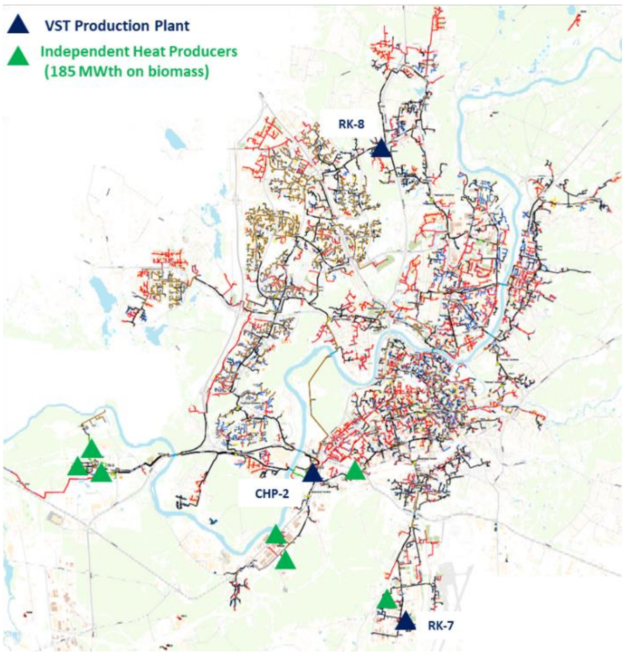


Figure 87: Map of the main network and location of the main production units (source: VST)

As displayed in Figure 87, the production units are mainly located south of the network, relatively far from the dense urban area where customers are located (which degrades their competitiveness as discussed in Sections V A and C).

The energy production mix of Vilnius DH in 2019 is displayed in Table 2. Thanks to the decrease of biomass fuel price compared to gas (which fosters this energy for both VST and the independent heat producers), **the part of RES in the energy production mix is currently higher than 50%.**

Table 2: Energy production mix in 2019

	Production mix in 2019	
	MWh	%
Natural gas	1,241,788	45.1%
Biofuels	1,498,529	54.5%
Oil	9,362	0.3%
Diesel	1,877	0.1%
Total	2,751,556	100%

This rate will continue to increase since a new CHP plant owned and operated by a state-owned company (Ignitis group) will be commissioned in the coming years. With a total installed capacity of 227 MWth and 88 MWe, it will become the main independent heat producer supplying heat to Vilnius DH network. It will have two production units:

- one **municipal waste incineration** plant with a thermal capacity of 53 MWth and an electrical capacity of 18 MWe (already operating in testing environment and expected to be commissioned in 2021),
- one **biomass** plant with a thermal capacity of 174 MWth and an electrical capacity of 70 MWe.

Furthermore, the network has a **high reliability** since the number of technical interruptions during the heating seasons are between 28 and 39 since 2016, which is relatively low for a 740 km network.

IV Business Model

A Governance

Vilnius DH network is managed by the Municipality of Vilnius, through the company **Vilniaus Šilumos Tinklai** (VST, meaning "Vilnius District Heating") which owns and operates the network. **The municipality owns 99.4% of the company**. The company is an independent legal entity, and its governance is organised through a board made of 5 members: 3 independent members and 2 representatives of the Municipality.

VST's main activity is to operate the DH network, with the particularity that heat production is open to competition in the country (meaning that third-party suppliers can access the DH network) as explained earlier. The majority of VST's revenues come from:

- heating and hot water production, distribution and sales,
- electricity production (from CHP plants),
- and other activities generating limited revenues (energy services).

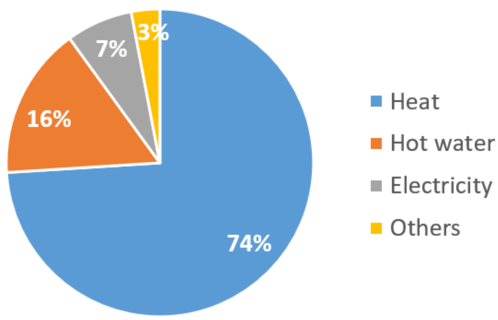


Figure 88: Share of VST revenues (own graph, from VST data)

The business model of the company has experienced major changes for the last decades. In 1996, heating activities were separated from electricity and gas activities (initially gathered under a **national company** after the country independence in 1990) in order to be managed locally by municipalities with their own staff. After 2000, a concession wave reached Lithuania, and Vilnius DH network was managed as a **concession** (operated by

Veolia) for 15 years. At the end of the contract, in 2017, Vilnius Municipality (like the other municipalities in the country) decided not to renew the concession and retrieved the operatorship and associated staff (600 people) of the DH network, creating a **municipal operator.**

Because of a lack of efficiency blamed on the operators during the concession wave, Lithuania has now set a **significant regulatory framework** for DH activities in the country. DH companies operate under economic rules, but **cost optimization is very closely scrutinized to ensure that any additional profits return to the customers**. If the company generates an IRR[85] above the regulated WACC[86] (about 3% currently), the additional profits shall be returned. In exchange, the regulator allows to recover financial losses made over one period within the next period.

B Strategy and Offer

Started in 1950, Vilnius DH network has a **long development history** and supply today more than 80% of the customers for heating in the municipality. The development plan is therefore well controlled, focusing on new urban areas as they develop.

The main challenge for the system will be to **anticipate and accommodate the slight but continuous decrease of heat consumption in the Municipality** (see Figure 89) caused by increasing energy efficiency in buildings and expected to be accelerated by the Renovation Wave initiated in 2020 by the European Commission.

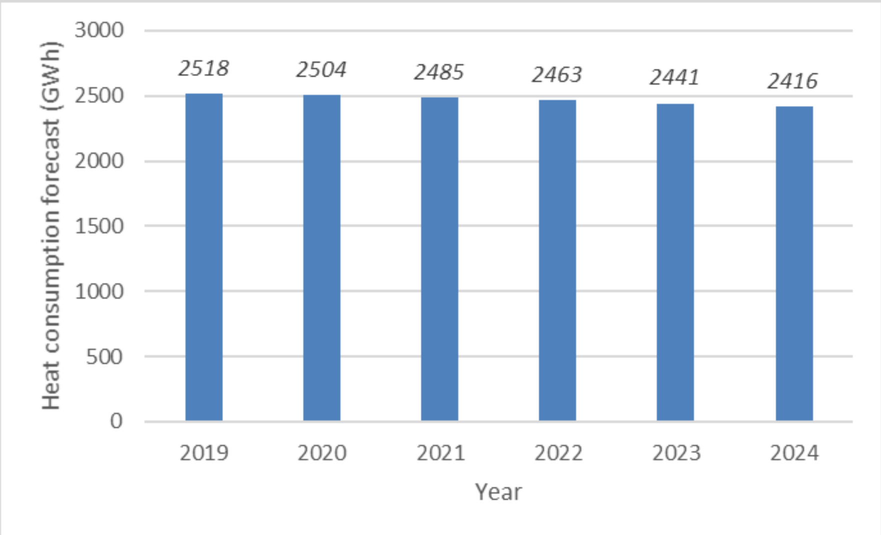


Figure 89: Heat consumption forecast for Vilnius DH (source: VST)

In order to connect to the DH network, a client must ask for the **terms of connection** where VST assesses the feasibility of the connection. VST is entitled to reject the application of a client. The feasibility of the connection is based on several parameters, like power density per km, required investments and payoff, losses on the line… **The key parameter is the amount of heat losses incurred by the connection as a percentage from the total supply**, which is compared to a historical benchmark (on a 3-year average).

- If this percentage calculated for the new client is below the historical average, the terms of connection are issued.
- If it is above but not more than 2 times, the client is required to compensate financially the heat losses above the average for the next 30 years.

[85] Internal Return Rate
[86] Weighted Average Cost of Capital

- If it is more than 2 times above the historical average, the client's application is rejected (and they can choose alternative solutions such as gas or renewable energies).

Before rejecting an application, additional analyses are made on the potential of the considered area (possible new buildings which could take a share of the losses on the line) **and on technologies** (recently, terms of connection have been issued for new low temperature DH networks which reduce losses on the line).

On their side, **the clients are entitled to disconnect from the network at any time**. This is however rare since DH is a competitive solution in Vilnius and clients are overall satisfied with the service (see Section VI).

The principles of pricing in the heating sector are defined in the **Law on Heat Economy** of the Republic of Lithuania. Heating and domestic hot water prices are regulated by VERT (see Section I) based on the supplier's past costs incurred for the service. VERT defines pricing methodologies and controls their application.

An energy purchase and sale agreement is concluded with any person who applies for DH services. The prices and conditions of goods and services set in this contract must be the same for all consumers of the same category, except in cases established by law (when preferential conditions may be applied to certain categories of consumers).

Contracts are concluded with customers for the provision of hot water and heating services. There are two ways to supply domestic hot water:

1. When VST supplies domestic hot water as a complete product (VST purchases cold water from Vilnius water supply company).
2. When VST supplies the energy for water heating (the customer purchases cold water by themselves).

Different prices for heat and for domestic hot water are offered and reflect their respective associated past costs according to the VERT methodology (more details in Section IV C).

The substation infrastructures can be owned by the customer (in this case, the limit of property is usually the outer wall of the supplied building) or co-owned by the DH operator and the customer.

All buildings supplied with heat and domestic hot water from VST DH network have meters, 83% of them being equipped with remote reading. Customers are **invoiced monthly**.

Some new residential buildings have individual heat sub-meters, but the majority of the connected buildings have not. In this latter case, the heat consumption is distributed according to the meter of the whole building and to the selected method chosen by the residents.

All flats have hot water meters (about 70% being **smart meters** with remote reading option).

C Financial model

The **tariff structure** for heating consists of a variable, a fixed and an additional part, all expressed in €/MWh (the fixed part covering personal, depreciation, maintenance and other general costs). The domestic hot water prices consist of a single term expressed in €/m^3. This structure is the same for residential clients and for tertiary and industrial clients, except that the VAT rate differs (reduced rate for residential clients).

Table 3: Tariff structure (from VST data)

Residential clients	Tariffs observed in October 2020	
	Excluding VAT	Including 9% VAT
Heating prices	31.2 €/MWh	34.0 €/MWh
Fixed component	*9.4 €/MWh*	*10.2 €/MWh*
Variable component	*21.3 €/MWh*	*23.2 €/MWh*
Additional component	*0.5 €/MWh*	*0.6 €/MWh*
Domestic hot water prices		
When hot water is supplied as a complete product	*34.0 €/m^3*	*37.1 €/m^3*
Tertiary and industrial clients	**Tariffs observed in October 2020**	
	Excluding VAT	Including 21% VAT
Heating prices	31.2 €/MWh	37.8 €/MWh
Fixed component	*9.4 €/MWh*	*11.4€/MWh*
Variable component	*21.3 €/MWh*	*25.8 €/MWh*
Additional component	*0.5 €/MWh*	*0.6 €/MWh*
Domestic hot water prices		
When hot water is supplied as a complete product	*34.0 €/m^3*	*41.1 €/m^3*

In Lithuania, **the basic heat price is set for three to five years, but some components of the tariff are updated every month or year according to the regulator's methodology**:

- The variable component, which includes fuel costs, is recalculated each month by taking into account the real **fuel costs** from the operator's own production facilities and from the monthly **auctions** (see Section V C below). There is a 2-month lag between the projected price and the actual price of the auctions. Adjustments are made at the end of the year and are subject to the Regulator's approval.
- A second variable component (included in the main variable part in the table above) is also revised yearly by the Regulator in order to adjust the **actual energy mix** observed through the year.
- The fixed component, which includes depreciation and amortisation, staff cost, operation and maintenance, etc. is also revised yearly by the Regulator based on VERT methodology which takes into account **actual past costs**.

As detailed in the previous Section, the terms of connection define the application of a **connection fee** or not:

- If the new client is below the threshold defined on heat losses, the connection is made at the expense of VST.
- If the new client is above, the client is required to compensate the heat losses surplus for 30 years.

To validate the monthly and yearly tariff adjustments, the Regulator can ask the DH operator any question and any supporting documents over any periods. If the goal of this close regulation is to ensure the best optimized price for the customer, the analysis and discussions required to validate the tariffs usually take a long time and may in some cases delay the application of new tariffs or the development of new projects.

In addition, as discussed earlier, the lack of efficiency during the concession wave has made the Regulator very strict in the recognition of expenses. DH operators have pointed out these issues and discussions are being held with VERT in order to **set up a more efficient and more realistic regulation process**.

For VST, the DH business itself is not profitable. This is mostly explained by the fact that **all the expenses are not covered by the DH tariff** to the end-users (e.g. staff costs have a ceiling set by the regulator). Therefore, this lack of profitability has to be compensated by other unregulated businesses like electricity sales, real estate and others. In total, VST generated a yearly revenue of 131 MEUR in 2019.

V Integrating RES and Waste Heat

A Technical considerations

As discussed earlier, Vilnius DH network has **already reached 54.5% of renewable and waste energy sources in its production mix** thanks to the implementation of biomass boilers and flue gas condensers. This rate is expected to reach **more than 90% in the coming years** with the commissioning of the new CHP plant fuelled by biomass and waste incineration (see Section III).

The corresponding production units are spread in various locations across the network, some being owned and operated by VST, others by independent heat producers. **If the temperature regimes of these production facilities do not raise any major issue** (today they all include boilers operating at high temperature), **their respective location and availability for heat production must be perfectly anticipated and handled by the DH network operator** in order to ensure smooth operations on the network and avoid hydraulic issues.

Figure 90: Control room of Vilnius DH network (source: VST)

This raises a particular point of attention in the Lithuanian context as **the access to DH networks is open to any independent heat producers.** While this enables to maximize the integration of local renewable or waste heat sources and to increase competition to optimize the tariffs to the end-users, it **must be carefully framed in order to avoid technical failures on the DH network and heat supply shortages**.

In this view, the right of independent heat producers to use DH networks is enshrined in the Compendium of Conditions for Use of Heat Transmission Networks, which was approved by the State Price and Energy Control Commission in 2015. This Compendium describes in detail the procedure for connection of heat production facilities of independent producers to the district heating networks (see Section V C).

B Economic considerations

Fuel costs

As depicted by Table 4, **the primary energy cost of renewable fuels is now cheaper than fossil fuels**, which of course makes the integration of renewable energies in the production mix very interesting for both the DH operator and the end-users.

According to Lithuanian law, VST has to purchase its fuels for heat production (gas or biomass) through the **Lithuanian commodity exchange** for at least 50% of the fuel needs. The rest (maximum 50% of the fuel needs) can be purchased to other suppliers through dedicated contracts (e.g., long-term contracts), but the corresponding price should not be more than 5% higher than those on the commodity exchange, or the surplus will not be covered by the tariffs to the end-users (i.e. it will be a direct loss for the DH operator).

Table 4: Average fuel cost

Average fuel cost	Prices observed in 2020 by VST
Renewable fuels	
Wood chips	*11.2 €/MWh*
Wood pellets	*29.0 €/MWh*
Straw	*10.4 €/MWh*
Peat	*9.5 €/MWh*
Biogas	*9.4 €/MWh*
Fossil fuels	
Natural gas	*14.1 €/MWh*
Heavy oil	*41.5 €/MWh*
Diesel	*48.4 €/MWh*
Coal	*14.5 €/MWh*

Auctions scheme

The Lithuanian regulation requests the **DH operators to update every month** their heat demand forecast. On this basis, operators estimate:

- The competitive **capacity**, i.e. the capacity that is opened to the auctions scheme. For DH system in Lithuania, the competitive capacity represents **70% of the heat demand**.
- The peak capacity, i.e. the capacity to answer peak demands. This capacity is reserved to the DH operator own facilities. For Vilnius DH system, the peak capacity represents 30% of the heat demand.
- The reserve capacity, i.e. the capacity for back-up. This capacity is reserved to the DH operator own facilities as well. For Vilnius DH system, the reserve capacity represents 50% of the heat demand.

Therefore, 70% of the heat demand supplied by VST is open to competition through a **monthly auctions scheme driven by the lowest prices available**. In Vilnius, VST and its own heat production facilities competes with 7 independent heat producers as discussed earlier (which will be 8 soon with the commissioning of the new CHP plant).

To ensure the fairest prices to the end-users, VST calculates every month the **ceiling heat price for auction** according to the estimated fuel prices by VERT and the estimated heat production costs (according to VERT methodology). Independent producers can bid only at the maximum price or below it.

Due to the location of its production facilities (which are closer to the network than the ones of the independent producers, mostly located in the South of the city), **VST has a clear competitive advantage, as the independent producers have to cover in their**

heat price the costs incurred by their connection to the DH network (pipeline and substation).

In addition, **in summer, when the heat demand is lower, the major producers (VST in front) offer a significant discount on the heat price ceiling** in order to be able to run their CHP plant and maximise their power generation. Therefore, the smallest independent producers usually do not participate to auctions in summer, as the price ceiling is too low and the competition too high. Instead, they take advantage of this to carry out their maintenance operations.

The auctions mechanism in Lithuania is seen by VST as a good mechanism to ensure the end-users the fairest price possible and to maintain the DH network's competitiveness against alternative heating solutions.

As a heat production facilities operator, the risk of competition for VST is minimized by the peak and reserve capacities (not opened to auctions) and by the competitive advantage brought by the size and location of their plants (closer to the demand). **The main risk for the DH operator is that independent heat producers do not calculate properly their volumes of produced heat, so that VST has to compensate with gas, inferring a decrease of the renewable share and an extra cost for the end-users.**

Subsidies

Investment subsidies from EU funds helped financing network renovation, biomass and CHP plants, as well as other equipment increasing the system's efficiency (such as absorption heat pumps). These subsidies usually reached around 40% of the project investments.

VST has recently been awarded new EU financial support for one additional biomass CHP plant where the total investment is 11.1 MEUR and the subsidy is 4.9 MEUR.

C Contractual and organisational aspects

As stated earlier, a potential independent heat producer shall submit an **application to the DH system operator for connection to the district heating network**. The procedure, described in detail in the Compendium of Conditions for Use of Heat Transmission Networks, is as follows:

1. Publication of information enabling a potential independent heat producer to choose the location of its activities.
2. Issuance of conditions for connection to the DH network (heat supply temperature, pressure, connection location, connection technology…).
3. Conclusion of a preliminary heat purchase and sale agreement.
4. Submission of the assurance of the fulfilment of the conditions of the planned connection to the DH network (minimum power, availability, operatorship of the heat exchanger…).
5. Technical inspection of the heat production facilities registered in the State Register.
6. Creation of reliable and safe operating conditions for the heat production facilities and start-up-adjustment works. Recognition of the heat production facilities as fit for use in accordance with the procedure established by legal act.
7. Signature of a heat purchase and sale agreement **for at least 1 year**, allowing the independent heat producer to participate to the auctions for the DH network.

To date, no application from independent heat producers has been rejected by VST.

As mentioned earlier, **all costs related to the connection of an independent heat producer to the network shall be borne by the independent producer itself.** As a result, independent producers build, own and operate their own heat exchangers, according to the technical specifications delivered by the DH operator.

Moreover, if VST identifies a need to upgrade its own network (extension, pipes diameter increase…) when assessing the feasibility of a connection from an independent producer, the incurred cost shall be borne by the independent producer as well. This is also regulated and has to be validated by VERT.

Therefore, an independent heat producer needs to carefully integrate all these costs to make sure that its offer will be competitive in the auctions market.

D Cooperative approaches and role of digital solutions

VST has developed several partnerships with **technology providers**. These partners have brought a wider knowledge on new technologies and helped to identify related key issues. At the moment, VST is actively searching new technology solutions in renewable energy development, energy efficiency improvement and district cooling development.

Figure 91: Future priorities identified by VST for Vilnius DH network (source: VST)

Digital solutions have been implemented with smart meters to strengthen operations, detect leakages, ease billing and increase customer empowerment (see next Section).

VI Consumer Empowerment

An automated **customer survey** is conducted after each customer contact by writing, by phone or during a visit. The results are monitored and analysed daily. The average of the 2019 survey evaluations is high and reaches 8.2 points out of 10. A company perception survey is also planned for 2020, which will include service issues.

In addition, to increase the efficiency of the network's operations and to involve even more its clients, VST is developing **smart metering** and has installed heat and hot water meters for almost all its clients:

- 7,125 heat meters with remote data reading at the substations of the buildings,
- and 265,971 hot water meters in apartments (including 187,771 meters with remote data reading).

The data collected from heat meters are used for billing and to manage the operations on the network. Moreover, the analysis allows the detection of leaky heat exchangers at building substations level.

VII Synergies with Other Urban Infrastructure and Local Value Creation

Several projects with other urban infrastructures are currently being evaluated. For example, the excess heat recovery from a **wastewater treatment plant** using heat pumps is being studied.

VST also studies the possibility to provide **flexibility to the electricity distribution grid**. This is expected to be a growing market in Lithuania since there is a significant plan to develop intermittent renewable energies in the country in order to increase the internal power production rate.

Figure 92: Wastewater treatment plant in Vilnius (source: Vilniaus vandenys)

VIII Prospects

In addition to the new CHP plant operated by Vilnius Municipality, there are several ongoing innovative projects.

Development of low temperature district heating pilots

2 pilot projects are being developed (60 MW and 10 MW demand) with the creation of low temperature (**65°C**) networks which will be connected to the main DH system.

A low temperature DH network area will allow **more efficient integration of renewable energy sources and waste energy sources** into the system. As a result, this will increase the number and diversity of independent heat producers and increase the reliability of heat supply.

Additional heat producers are expected to emerge in a 10-year perspective. For example, supermarkets and data centres could supply waste heat to the networks thanks to heat pumps. The expected capacity of waste heat sources could reach 50-60 MW in 10 years. Solar thermal collectors with a capacity of 20-30 MW should also appear on the roofs of residential houses and other buildings and provide heat to the networks.

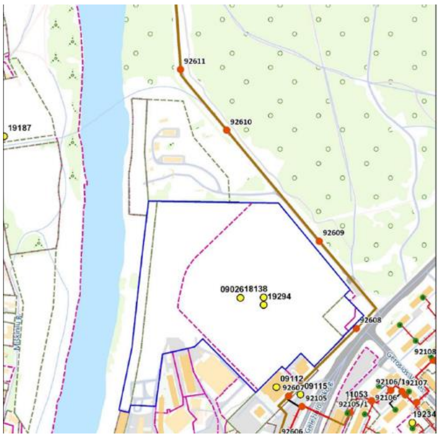


Figure 93: Plan of the low temperature DH pilot in Gelezinio Vilko (source: VST)

Heat recovery from flue gas through absorption heat pumps

The company is planning to install two industrial absorption heat pumps with nominal capacity of 8.5 MW. The purpose of the project is to increase the efficiency of the biomass steam boiler "CHP-2" and to reduce the consumption of fossil fuels for heat production.

It is estimated that the absorption heat pump evaporator will recover from combustion products at least 8.5 MW of nominal heat power and 17,250 MWh/year of heat. 3,747 tons of CO_2 emissions are expected to be saved.

This kind of project will be one of the first in Lithuania.

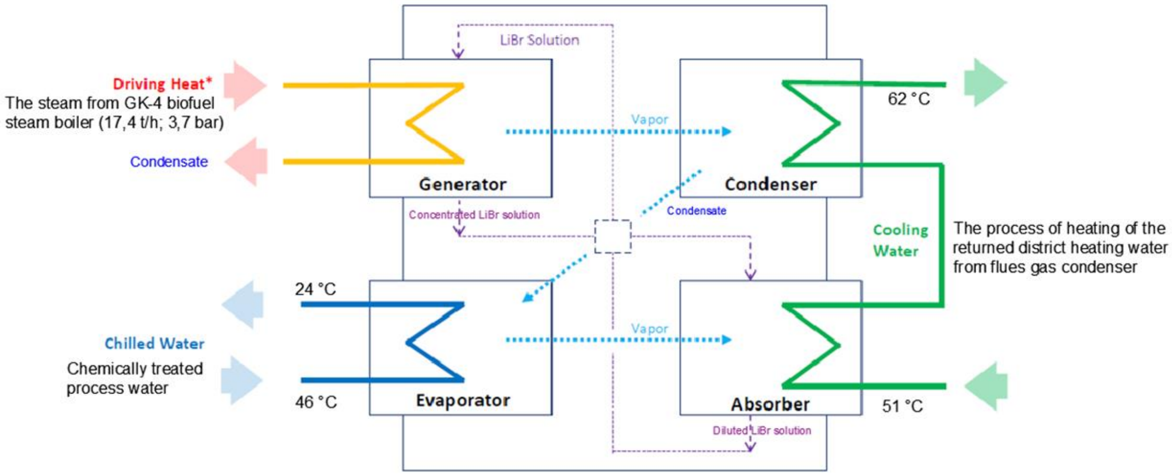


Figure 94: Principle of the project of heat recovery from flue gas (source: VST)

Installation of a solar power plant and heat pumps for heat and electricity production

VST also plans to develop a ground-mounted solar power plant with an installed capacity of 500 kWp and 2 heat pumps with a nominal heat capacity of up to 700 kW to produce heat and electricity.

Figure 95: Presentation of the solar power plant project

DC development

Regarding DC development, VST plans to launch a preliminary pilot project in 2021. One expert has been hired to tackle this subject.

IX Conclusion and Key Success Factors

Vilnius' DH system is an example of a **major and relatively old network which has been successfully renovated by integrating renewable energy sources, in a country that has set strong DH regulations**. The key success factors identified in the case study are summarised below:

i. **The historical commitment of the Municipality with the DH grid**. Even if the governance scheme has changed over time (experiencing the concession mode for some time before going back to direct public operatorship), the Municipality and its teams have a long-term operational experience with the network, and have been using it as a powerful tool to reach its ambitious energy transition goals.

ii. **The efficient mobilisation of European and national subsidies**. Thanks to a strong will to adapt, VST has been able to obtain significant subsidies in order to modernise the network, increase its efficiency, and build new production facilities to integrate a high share of renewable and waste energy sources (up to 90% in 2021).

iii. **Competitive prices thanks to the integration of local renewable energy and waste heat sources.** The significant use of low-price biomass and waste-to-energy (from 2021) sources makes the DH system competitive to alternative solutions (mostly gas), and pushes the operator to increase even more the share of these clean energies. This fuel switch (from gas to biomass and waste-to-energy) has allowed to divide the heat price by 2 in less than 10 years and has made Vilnius DH network the first option for heating in the city (80% market share).

iv. **Competitive prices thanks to a close control of the national regulator and to the auctions market set for the heat supply.** The national regulator has set detailed rules and a methodology to maximise the operational excellence (e.g., competitive heat supply) and to ensure that all the related benefits go to the final users. This, however, is managed through a relatively tight and heavy process which threatens sometimes the profitability and reactivity of the DH operator.

v. **Technical expertise to integrate external heat sources.** The integration of heat from independent producers in the DH network requires operational skills, proper anticipation and smooth communication. These skills have been developed through operational experience gained over time and thanks to a detailed operational framework defined by the National Regulator.

vi. **Innovation**. VST keeps trying to improve the efficiency and environmental impact of its network by developing innovative solutions, such as low-temperature networks, heat recovery from flue gas via absorption heat pumps, and even power production from solar photovoltaic to develop sector coupling opportunities.

vii. **Implementation of relevant synergies**. VST is evaluating the opportunity for excess heat recovery from a wastewater treatment plant using heat pumps. The company is also studying the possibility to provide flexibility to the electricity distribution grid.

4.8 ITALY: Milan DHC network, a continuously developing system making the most of the waste energy sources available

Emerging DH market 3%

Renewable Energy Sources + **Waste Heat/Cold Sources**: Geothermal energy; Industrial heat; Waste-to-energy — **68% of RES share**

Milan DHC

PPP governance

1 400 000 inhabitants

DH market share	10 %
CO_2 emissions	110 kg/MWh
Installed capacity	DH: 901 MW DC: 7,5 MW
Energy production	DH: 1 226 GWh/y DC: 6 GWh/y
Supply/return temperature	90-115/60-65 °C

Key Success Factors

- Consistent integration of energy strategy in urban planning, recognizing the role of DHC in achieving climate targets
- Prioritising the positive environmental and social impacts of a significant integration of renewable energy and excess heat sources
- Using the integration of local renewable energy and excess heat sources as a lever to increase the prices competitivness
- Implementation of relevant cross-sectorial synergies
- Support from the Municipality (awareness raising, promotion of integrated approaches, ownership)
- Building a culture of innovation to continuously improve performance
- Introducing a district cooling offer; expected to be a key axe of future DHC development
- Reliable and local service, appreciated by consumers

I National Context[87]

The Italian heating and cooling markets are dominated by **individual solutions**, mainly based on natural gas and electricity, respectively. District heating is relatively new and in 2019 represented **2,3% of the national thermal demand[88].** However, since 2000, DH is rapidly growing especially in the North of the country, even though this trend has been slowing down during the last years. DC developments are recent and mainly linked to existing DH systems. DC networks represent a total installed capacity of 204 MW (2017).

The Italian National Energy and Climate Plan drafted in 2018 by the Ministry of Economic Development targets in 2050 a 33% GHG emission reduction compared to 2005 and a 21.6% RES share in the final energy consumption. Even though no specific objective is set for the development of DHC, the Government has recognised recently, and for the first time, the potential of DHC grids to contribute to its climate objectives. The Italian Government has indeed integrated DHC in the National Plan for 2019-2021.

DHC companies operate in **a competitive market** with limited regulation at national level. For example, it is not possible to enforce the connection to a DH grid and therefore DH activities take place in a highly competitive environment where the choice of heat supplier is principally based on prices.

Since 2017, following the transposition of the European Energy Efficiency Directive into national legislation, a **DHC regulation** scheme is being developed by the Italian Regulatory Authority for Energy, Networks and Environment (**ARERA**)[89], focused on quality standards (technical and contractual guidelines) and market transparency (commercial processes). However, the Italian legislation has still a limited role in the DHC market and the data analysis does not show a significant growth of DHC since the transposition of the Directive.

[87] Details on the national DHC context are provided in **ANNEX 6**, including key figures, actors, and regulatory and policy aspects

[88] 2020 study from Politecnico di Milano and Politecnico di Torino

[89] Italian Legislative Decree No. 102 of 4 July 2014, transposing the Energy Efficiency Directive 2012/27/EU into national law, allocated the ARERA specific functions as regards district heating and cooling. Within this context, the Authority exercises control, inspection and sanctioning functions as provided for by the law establishing its jurisdiction, and exercises sanctioning powers under Article 16 of Italian Legislative Decree No. 102/2014.

Moreover, there are **not many national incentives** to DHC. A **reduced VAT** is applied to heat sales to residential consumers supplied with RES or CHP and a **tax credit** is granted for DHC systems using geothermal or biomass energy sources (Laws of 23 December 1998 and 22 December 2008).

Figure 96: Geographical distribution of DHC systems (AIRU, 2019)

However, there are **no specific investment grants for DH**, despite the long payback time of these systems. In addition, some DH support has been significantly reduced, which could prevent new DHC projects from being developed. For instance, the support of DHC projects through the issue of **white certificates**[90] (corresponding to the primary energy saved through the projects), that could be traded on the market, has been reduced during the last years because of a change in the support scheme.

Italy has more than **300 DH systems**, mainly located in the Northern regions (cf. Figure 96). Most of these systems were **originally publicly owned**. However, the newly developed systems are mostly privately owned and managed by heat supply companies. The 3 large systems supplying Turin, Brescia and Milan are managed under public-private partnerships (concessions).

In 2018, 148 companies were registered as DHC operators. The 34 largest operators, including a few big multi-utility groups such as A2A (the DH market leader, operating Brescia and Milan's grid), IREN, HERA or EGEA, serve over 75% of users, corresponding to more than 85% of the thermal energy supplied.

The **energy mix** of the Italian DH systems is based on **renewable sources and waste heat for 24%** of the energy supply composition for DH (2017)**.**

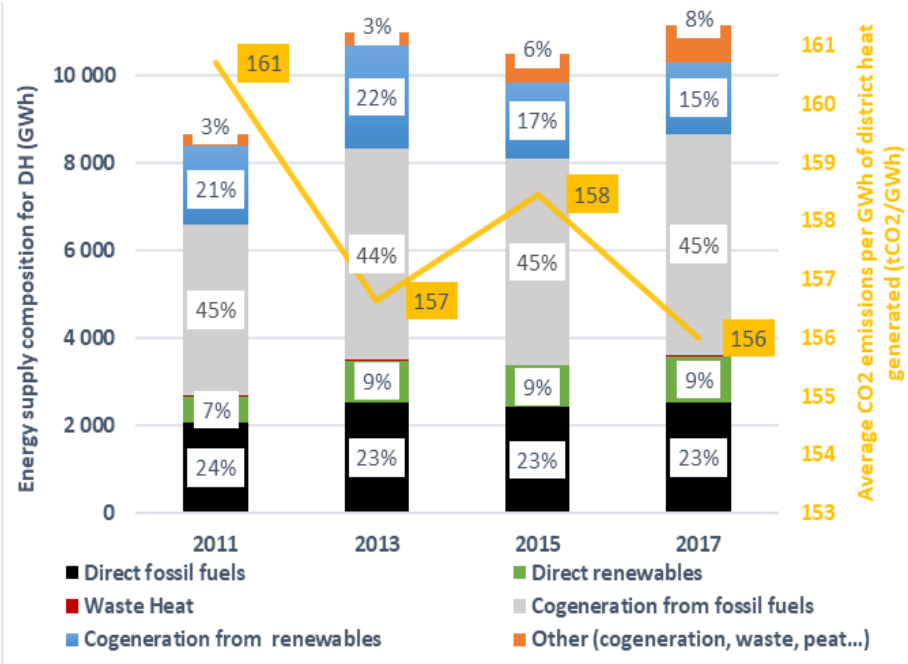


Figure 97: Energy supply composition for DH (own graph, from EuroHeat&Power country report 2019)

In Italy DH is sometimes wrongly perceived by some people as a rather old technology. There is a great potential for improving the **awareness** about the benefits of deploying efficient DHC systems. The Italian District Heating Association (AIRU[91]) is one of the key actors working on it.

[90] The scheme was introduced in 2005, requiring distributors of electricity and gas with more than 50,000 to deliver a certain number of white certificates per year, through the implementation of energy efficiency projects or purchasing these certificates bilaterally or in a trading market. The scheme is managed and developed by GSE SpA (*Gestore dei Servizi Energetici*, owned by the Ministry of Economy) and the market is operated by GME SpA (*Gestore Mercatto Elettrico*), a branch of GSE SpA.

[91] http://www.airu.it/

II Local Context

A City context: one of the country's biggest cities benefitting from a significant urban synergies

With 1.4 million inhabitants and a density of about 7600 inhabitants/km², **Milan is one of the biggest and high-density populated cities in Italy**, which makes it particularly suitable for DHC (Milan's DH grid could potentially cover almost completely the heat demand of the city). This trend is expected to grow as the reference demographic scenario plans to reach 1.5 million inhabitants by 2030.

More than 67% of the city consists of built areas, mostly concentrated in the centre of Milan as depicted on Figure 98. This represents a significant amount of possible customers for residential, tertiary and possibly industrial use, as well as possible excess heat sources from industries. Indeed, **half of the end-use energy consumption of the city comes from residential, tertiary and industrial heat** (12 TWh in 2013), this consumption being mostly covered by natural gas.

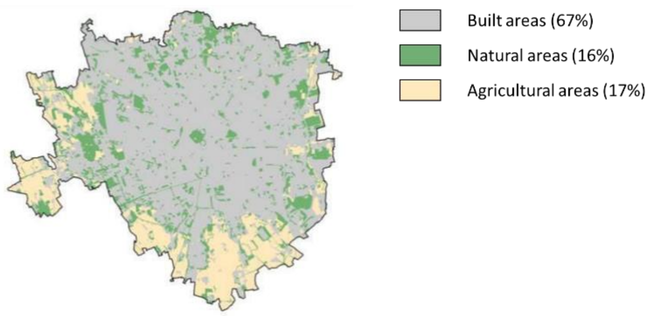


Figure 98: Land use in Milan (source: Territorial Government Plan, 2019)

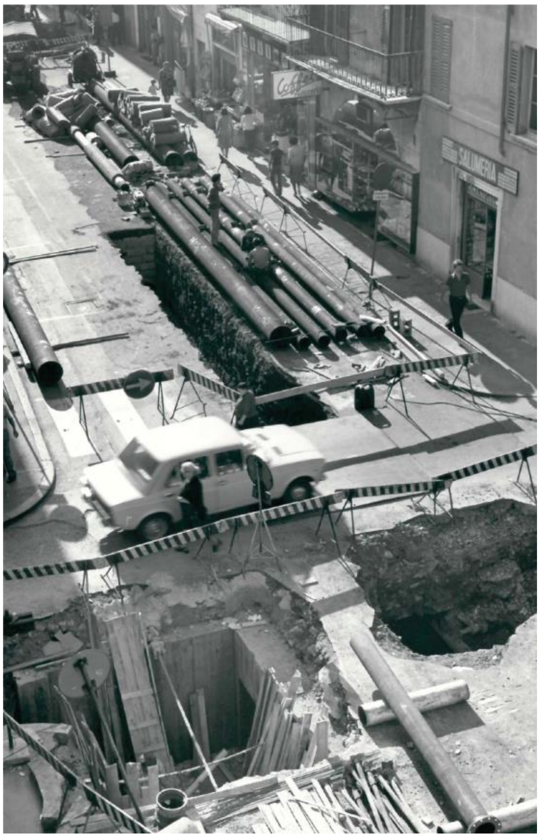


Figure 99: Civil works in a street of Milan for DH network construction

In order to carry out its energy transition, **the city of Milan has adopted in 2018 a strategic plan for sustainable energy called PAES** (Action Plan for Sustainable Energy in English). The action plan tackles issues related to energy efficiency, transport, public lighting, renewable energy production and waste.

The measures promoted by the Municipal administration to achieve the CO_2 reduction objective include the development of DHC, as an efficient heating source that, especially in conjunction with the energy production systems powered from renewable sources, minimizes the air pollution generated by heating services to private and public buildings. Therefore, the PAES action plan includes actions to support the development of DHC in the city: feasibility studies to assess the connection to an existing DHC network for high-consumption industries, technical and financial audits to increase transparency, training and promotion of DHC.

As discussed in section IV A, **the development of Milan DHC has been supported by the Municipality since its creation in the 1990s**. In addition to being one of the main shareholders of the operating company, the city of Milan has promoted the DHC system, and fostered an integrated approach for DHC energy supply and waste management. The DH construction works have been developed over years as shown in Figure 99 and Figure 100.

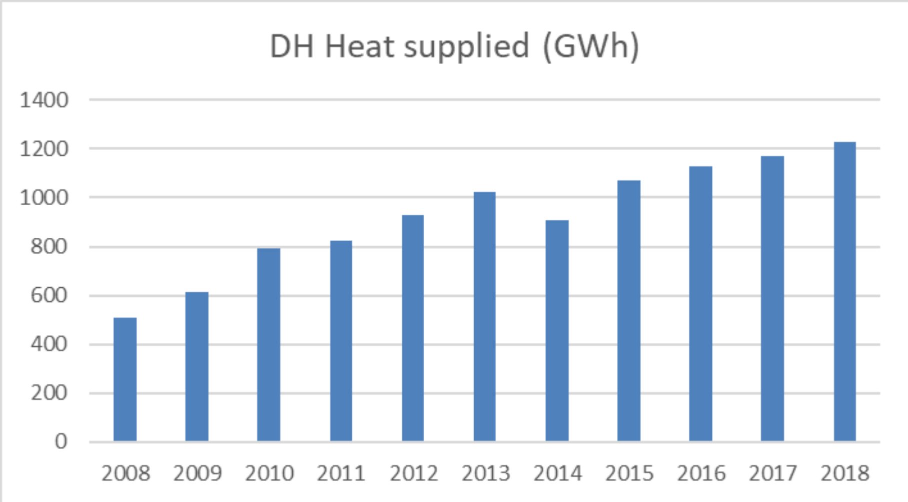


Figure 100: Evolution of the heat supplied by Milan DHC network (source: A2A)

B Local heating and cooling markets

Milan has an annual heating **demand** of ca. **2,200 heating degree-days**. As mentioned earlier, the overall heat requirement of the city is estimated at around 12,000 GWh/year, about **10% being covered by district heating**. Furthermore, the DHC operator has assessed the potential that could be technically supplied by DH and found approximately 6,100 GWh/year, corresponding to ca. 60 % of Milan's total heat demand. Therefore, **the current DH system covers less than 1/5 of this potential**, which leaves room for further developments.

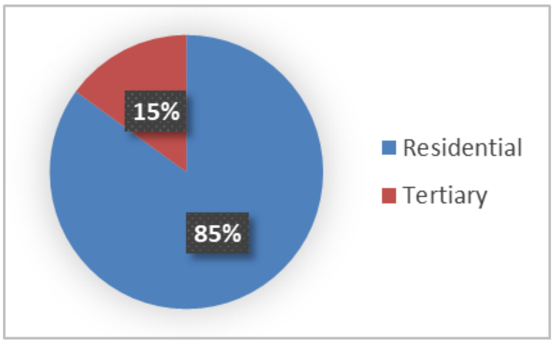


Figure 101: Share of clients' typologies for heating sales (source: A2A)

With 78% of residential buildings dating from before 1970, the typical annual DH energy consumption for connected buildings is about 102 kWh/m^2. For new buildings, this figure is about 86 kWh/m^2.

Consumers are free to choose their heating solution from those available in the market (DH, gas boilers, biomass boilers, heat pumps, electric heating, etc.). Among others, one of the most common **alternatives to DH** is **natural gas**.

In Italy, within this competitive market, current support measures are oriented towards individual solutions like condensation boilers, pellet stoves, individual air-heat pumps, etc., while DH does not benefit from any particular support.

However, **Milan DHC being fed by a significant share of renewable energy and waste heat sources, which are competitive compared to fossil sources, the DH prices applied in the city are attractive** and provide grounds for commercial success.

Regarding **cooling** supply, the DC network supplied about 6 GWh in 2019, mostly to tertiary clients (80% of the sales), but also to residential clients (the remaining 20%) in new districts. Cooling sales are limited to the summer season. Similar to heating, this trend is increasing and presents a high development potential in Milan (10 GWh sales forecasted for 2024).

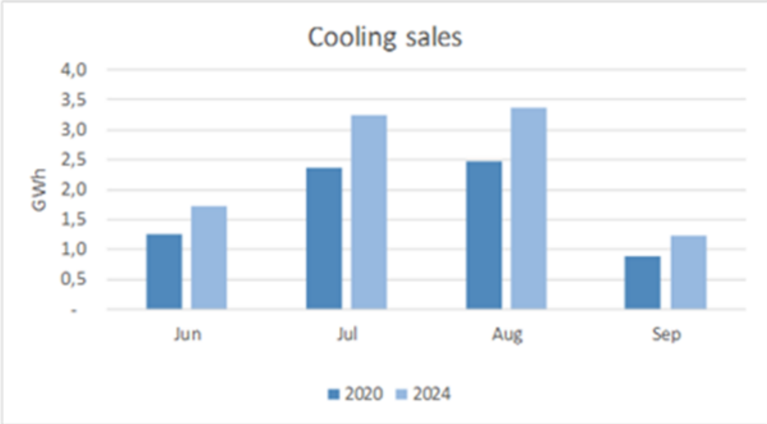


Figure 102: Monthly cooling sales from DC in 2020 and forecast for 2024 (source: A2A)

III Presentation of the DHC System

Classified as an **"Efficient District Heating"**, Milan DH complies with the European Energy Efficiency Directive and the Italian Decree Dlgs 102/2014. It supplies 3 main geographical areas of Milan through 3 networks which are not interconnected, as shown in Figure 103 below.

Milan DH system uses a **wide mix of technologies** among which renewable energy and waste energy play a significant role. In 2018, the heat was produced:

- In majority by renewable & waste heat source (68%);
- By CHP plants 5%;
- And by natural gas boilers for peak (27%).

Key facts and figures

DH market share	10 %
RES share	68 %
CO_2 emissions (heating) - average	110 kg/MWh
Installed capacity	DH: 901 MW DC: 7.5 MW
Energy production	DH: 1,226 GWh/y DC: 6 GWh/y
Km network (double-pipe)	DH: 317 km DC: 7 km
Supply/return temperature	90-115/60-65 °C

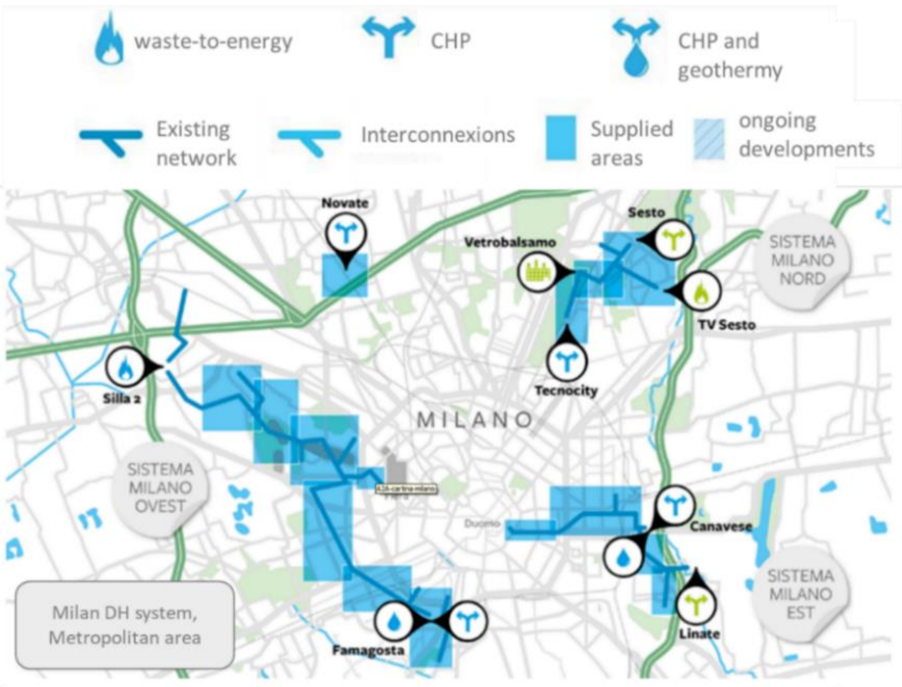


Figure 103: Milan district heating network (source: A2A)

Each geographical area features specific technologies:

- **Milan West** sector is mainly supplied by the "Silla" **Waste-to-Energy** Plant (WtE), owned and operated by A2A group.
  - The plant produces 375 GWh of heat and 345 GWh of electricity per year from residual waste.
  - Additionally, for peak demand, heat comes from natural gas boilers as shown in the bar graph below.
- **Milan East** is supplied by the "Canavese" DH **geothermal** plant (owned and operated by A2A) and by the "Linate" Plant (third party).
  - Canavese Plant produces heating from geothermal energy and heat pumps (14%), high-efficiency cogeneration engines fuelled with natural gas (22%), natural gas boilers (25%) for integration and peak demand, and high efficiency electric boilers for instantaneous "smart" peak (as from Magnitude project discussed later), and for future synergies on sector integration.
  - Linate Plant provides heat from natural gas CHP and gas boilers (39%).
- **Milan North** heat supply mainly comes from **excess heat** from third party plants:
  - The Edison power plant (64%), where heat that otherwise would be lost, coming from the discharge of the electricity production system (a Combined Cycle Gas Turbine-CCGT), is recovered for the DH network (see "Sesto" on the map above).
  - The CORE WtE plant (21%), which manages residual waste of several municipalities around Milan (located in the area "Sesto" - "TV Sesto" on the map above).
  - Vetrobalsamo Spa, recovering waste heat from a glass factory making special bottles (6%).
  - Additional heat is produced by a CHP plant and natural gas boilers (9%).

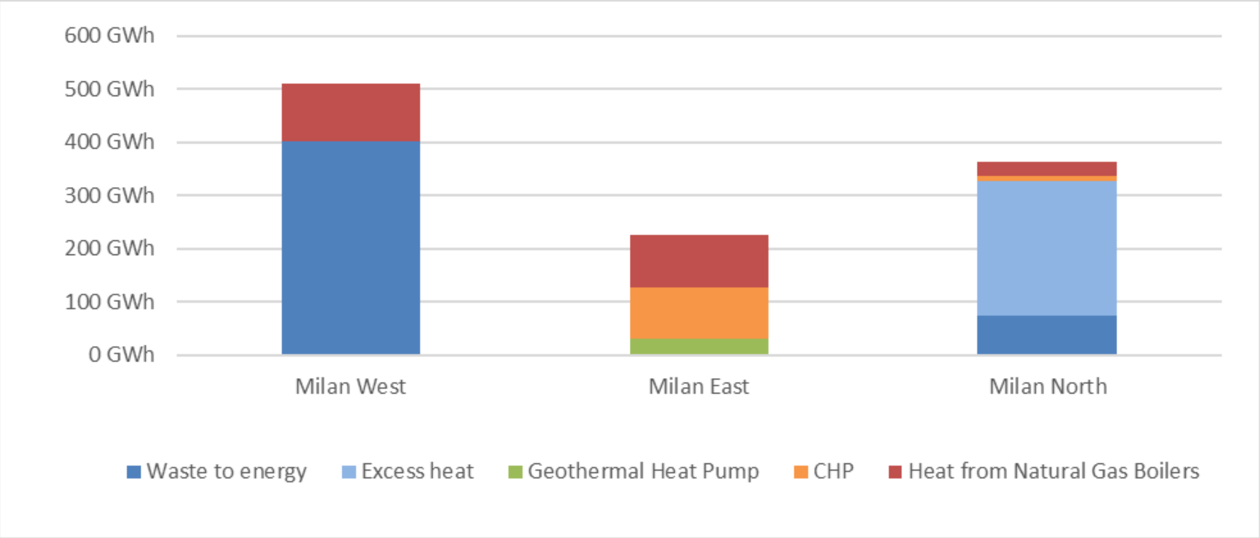


Figure 104: Annual production profile per technology and sector (source: A2A)

A2A also operates a **district cooling system** in Milan North. It supplies cooling to the University of Bicocca, the Arcimboldi theatre and some private customers. In total, the DC network represents 7 km length of double pipe and 6 GWh/y, generated by a 7.5 MW **electric chiller** (3 units + 1 under construction) and cooling towers.

IV Business Model

A Governance

Milan DHC networks are owned and operated by A2A Calore & Servizi SRL. The company is 100 % owned by the **A2A Group**[92], which is listed on the Italian stock exchange. The Group is **the largest Italian multi-utility** and operates in the production, distribution and sale of electricity and gas, district heating, environmental services and activities related to the integrated water cycle. Its main business units are presented in Figure 105 below. The large scope of the company's activities allows to find **efficient internal and external synergies**, as it is the case here for DHC with waste-to-energy operation (internal) or with the import of excess heat from related industries (external).

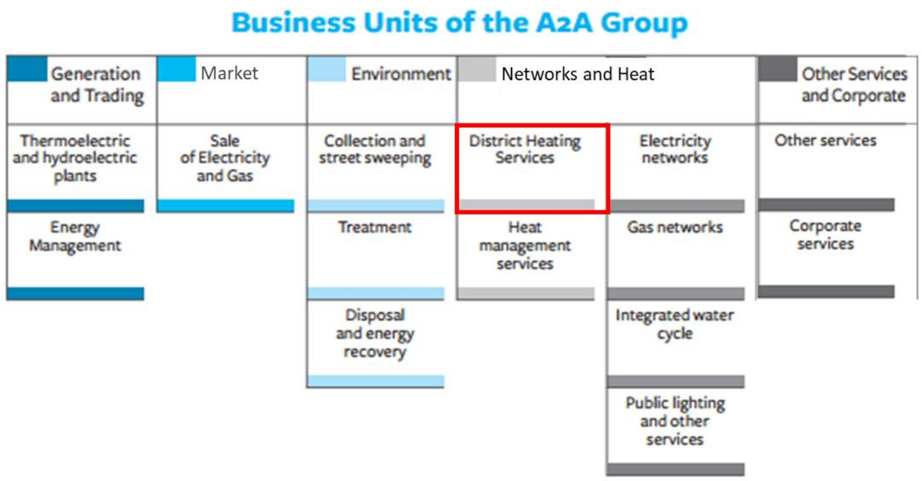


Figure 105: Business units of A2A Group, A2A Calore & Servizi highlighted in red (source: A2A)

Originally 100% public with two separate entities (A2A Milan and A2A Brescia), the company opened its capital to private investors about 20 years ago and merged the two entities 10 years later (2008). Today, the Group is **50 % owned by the Municipalities of Brescia and Milan** (in equal parts), as presented in the shareholding structure below. Market shareholders consist of institutional (about 37%) and retail (about 11%) investors.

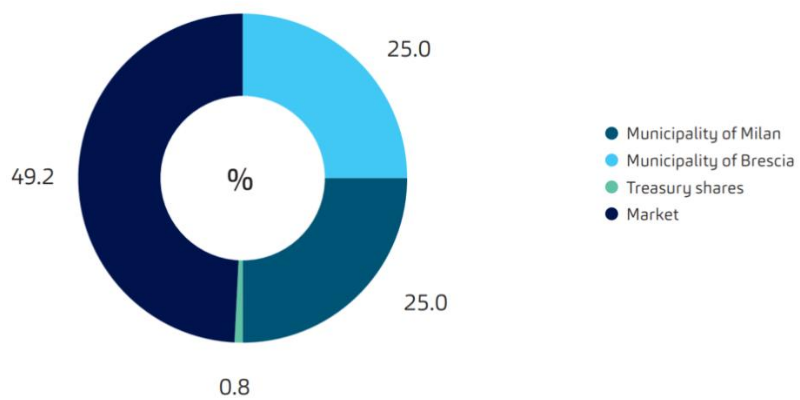


Figure 106: Shareholding structure of A2A 2015 (source: A2A)

The Group's **board of directors** oversees its activities and represents its stakeholders. It is composed of 12 board members who are elected for a 3-years period. Each daughter company has also its own board of directors.

[92] https://www.a2a.eu/

A2A is the DH leader in Italy. The **DHC strategy of A2A** is focused on improving the efficiency and carbon footprint of the grids and to continue providing high quality service.

B Strategy and Offer

The development of Milan DHC network started from the completion of peripheral connections between the different heating plants and from **the integration into the city from the outskirts to the centre**. In this view, the connection to the network of the most emblematic buildings of downtown Milan (such as the "Scala" Theater, the Historical Gallery, Marino Palace and the Court Palace) highlights the commercial success of the operation. Through this centripetal extension path, Milan DHC reaches the newest transformation areas, but also the existing residential districts like Gallaratese (West Milan).

Thanks to its environmental performance, **the DHC network clearly integrates and supports the strategy of Milan as a sustainable smart city**. As an example, the DHC network has recently reached a new smart district of the city: UpTown. This new district promotes the sustainability from different points of view: it improves the air quality thanks to its 25 hectares of green areas, and it is also a carbon-free district. Thanks to the district heating network of Milan West, UpTown can offer an active contribution to the environment, compensating for the CO_2 emissions of the city.

Figure 107: Palazzo Marino, connected to District Heating

A2A Calore & Servizi (ACS) provides **heat and domestic hot water, as well as cooling** for tertiary and residential clients. The DHC infrastructures in public property (network) are designed, built, operated and owned by ACS. The substations can be either owned and operated by ACS, or built by ACS and owned and operated by the client. In the latter case, ACS offers a guarantee on the substation equipment.

The clients can disconnect whenever they want with no penalty.

Overall, **clients are satisfied** with the quality of the DHC service and the consumption-based price: 96% of interviewed clients recommend Milan DHC services to other users. ACS performs surveys on a regular basis to assess its customers' satisfaction through dedicated internal resources. A website is available for all stakeholders (gathering DHC main data, such as network length, number and volume of connected building, environmental protection data…) and a phone number is provided to customers for questions, information and for any emergencies. In addition, ACS publishes every year a Sustainability Report, publicly available on the internet, where a lot of information about the environmental benefits of DHC can be found.

Thanks to its local management, high reliability confirmed over the years, competence and good assistance provided by ACS in the city as well as the continuous improvements of the system efficiency, **citizens in Milan seem to have a good perception of DHC**. Qualitative surveys show that customers consider that DHC has a lower environmental impact than traditional plants. It is also considered as an innovative and safe service that requires an easier maintenance than traditional systems.

C Financial model

The A2A Group has a **strong financial position**, and its DHC business is profitable and keeps growing. In 2019, the Group's EBITDA[93] reached 1,234 MEUR, which represents an increase of 21 % over the past 5 years. Its financial information is accessible on its website.

[93] Earnings Before Interest, Taxes, Depreciation and Amortization

The **revenues** of the DHC company are mainly generated by the sales of heat, cold and electricity. **Invoicing** takes place every month and prices are updated on an annual basis, using indexes published by the National Institute of Statistics, ISTAT.

Specific **DH prices**[94] (not regulated in Italy) are established for 2 groups of clients: residential buildings and tertiary buildings. **For residential clients, a trinomial formula is proposed** and made of:

	Prices observed in 2020 (excl. VAT)	
	Min	Max
Variable component: unit price per MWh consumed in the building or apartment		
Clients with subscribed capacity below 35 kW	*70 €/MWh*	*78 €/MWh*
Clients with subscribed capacity above 35 kW	*42 €/MWh*	*50 €/MWh*
First fixed component: calculated as a function of subscribed power in kW		
Clients with subscribed capacity below 399 kW	*50 €/kW*	
Clients with subscribed capacity below 999 kW	*45 €/kW*	
Clients with subscribed capacity above 1000 kW	*40 €/kW*	
Second fixed component		
Clients with subscribed capacity below 35 kW	*22 €/yr*	
Clients with subscribed capacity below 399 kW	*122 €/yr*	
Clients with subscribed capacity below 999 kW	*2280 €/yr*	
Clients with subscribed capacity above 1000 kW	*7172 €/yr*	

For tertiary clients, a binomial formula is proposed and made of:

	Prices observed in 2020 (excl. VAT)	
	Min	Max
Variable component: unit price per MWh consumed in the building or apartment		
Clients with subscribed capacity below 700 kW	*58 €/MWh*	*66 €/MWh*
Clients with subscribed capacity above 700 kW	*55 €/MWh*	*63 €/MWh*
Fixed component: calculated as a function of subscribed power in kW		
Clients with subscribed capacity below 700 kW	*10 €/kW*	
Clients with subscribed capacity above 700 kW	*12 €/kW*	

Thanks to the recovery of waste heat and its biogenic part by ACS' DH network, most of DH customers benefit from a **tax-credit** according to Italian law (this does not apply to the smaller network of Milan East that is not connected to any waste-to-energy plant).

DC prices are negotiated on a case-by-case basis.

Connection fees are also negotiated on a case-by-case basis according to the distance of the network and ACS' commercial strategy.

Individual metering is widespread at building level. In some cases, sub-meters are installed in each apartment. All the installed meters are **smart-meters**, capable of recording the consumption data as well as sending these data via m-bus to the billing system once a day (or even more frequently if desired).

V Integrating RES and Waste Heat

[94] Prices observed over the 4 semesters of 2019 (available on: https://www.a2acaloreservizi.eu/home/cms/a2a_caloreservizi/area_clienti/prezzi)

A Technical considerations

At present time, the three DHC networks are not connected and thus have their own production units for normal conditions as well as for peak load and backup situations. The network is **operated under a relatively low temperature regime**, varying throughout the year from 90°C to 115°C for supply, and from 60°C to 65°C for return. **Heat loss in 2019 reached about 10% with no particular fluid leakage** (network made of pre-insulated pipes).

Milan DH network prioritizes heat sources as follows:

1) **Heat recovery from residual waste in waste-to-energy plant**: the waste plant is running anyway for waste incineration (that would be landfilled otherwise) and power production, therefore the recovery of surplus heat, otherwise wasted, increases the efficiency of the whole energy system through a circular economy approach. The recovery of heat from this waste treatment plant to supply the DH network makes it a sustainable and integrated system.
2) **Waste heat from power plants discharge**, valuing synergies with power production infrastructure.
3) **Low temperature heat recovery with temperature level increase through heat pumps:** this maximises the recovery of various local heat sources, such as shallow geothermal, wastewater from sewage plants, etc.
4) **High-efficiency combined heat and power** also allows to reduce the use of fossil fuels thanks to the combined production of electricity and heat and to its high efficiency yield.
5) **Gas boilers** are typically used during integration and peak demand.

To face peak load demand, ACS has also implemented **heat storages** (9 accumulators ranging from 200 to 2,000 m^3 and spread over 4 different plants) and started studies and developments to implement new ones to increase the amount of stored heat. They should enable to decrease the direct heat production during peak load demand by storing heat, ("**peak shaving**" of the loads), and thus improving at the same time the recovery of excess heat while reducing the use of fossil fuels.

Figure 108: Canavese Plant (source: achivio fotografico A2A)

CO_2 emissions associated to the heat supply of Milan DHC network are around **110 kg_{CO2}/MWh of heat**. This low CO_2 emission level, together with the circular management of residual waste through the waste-to-energy plant, create strong synergies able to avoid more than 400,000 tons of CO_2 on a yearly basis. **Since 2010, the share of fossil fuels decreased by 33.5% for the combined DHC systems of Milan and Bergamo.**

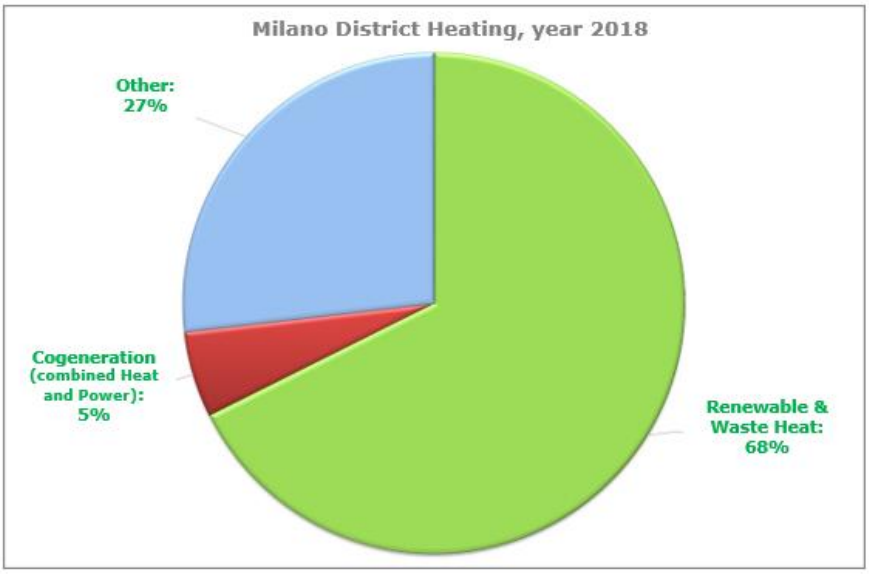


Figure 109: Heat production mix in 2018 on Milan DHC: from the 68% of renewable and waste heat, 44% comes from waste to energy, 21% from excess heat, and 3% from geothermal energy (source: A2A)

In the near future, several alternatives could be taken into account to further improve the DHC system, like heat recovery from industrial excess heat and other waste heat sources, heat recovery from power plants, additional geothermal sources, cogeneration solutions, etc. **Several projects are already under feasibility study**:

- Heat recovery from wastewater treatment plant.
- Surplus heat from third party DHC network (under negotiation).
- Pilot project of heat recovery on existing geothermal wells used for groundwater control: construction of a "neutral" network (where the temperature of the network is equal to the temperature of the soil) and substations with heat pumps.
- Pilot project of heat recovery from electric transformer heat losses.
- Heat recovery from other existing plants (under study).

B Economic considerations

In Italy, there is no specific incentive-scheme for District Heating at the moment. As a consequence, there is no mechanism to take into account the environmental benefits brought by the DHC system (reduction of both CO_2 emissions and local air pollutants like dust and NO_x) in the final price to customers.

To propose the lowest price to final consumers and ensure the network profitability, **ACS' objective is to increase the share of renewable and waste energy sources, as it is actually more competitive than fossil fuels (gas)**. Implementing **heat storage facilities** has also helped managing peak load and thus decreasing the use of fossil fuels.

In Milan DH, **waste heat comes firstly from Silla waste-to-energy plant, operated by A2A**. As this plant is a steam turbine unit, the heat bled from this site is almost completely recovered (instead of being wasted otherwise), which improves significantly the economic competitiveness of the operation.

ACS is also recovering **excess heat from industrial processes** (e.g., Vetrobalsamo glass factory) **and from power production plants** (e.g., Edison CCGT plant). Usually, the costs for network adaptation are covered by ACS while the costs for industrial process adaptation are covered by the third-party heat supplier. The excess heat price is mainly indexed on gas prices.

C Contractual and organisational aspects

Regarding heat produced by ACS, **the energy purchase agreements are significantly eased by the strength of a major multi-utility company such as A2A Group**. In the case of Milan DH network, this energy either comes from:

- Excess heat from Silla waste-to-energy plant, which is operated by A2A group. In this case, the heat purchase agreement is an internal agreement negotiated between the different A2A companies.
- Geothermal heat, which is basically free, except for the costs coming from the electricity required to run the corresponding heat pumps. This electricity is either directly provided by the CHP plant on site, or purchased through annual agreement provided by the local electricity operator (owned by A2A Group).
- Natural gas to run CHP and boilers is purchased through annual agreement provided by the local gas operator (owned by A2A Group).
- In addition, the electricity produced by CHP plants generates extra revenues. This electricity is sold on the electricity market (no feed-in tariff).

Regarding heat imported from **third-party suppliers** (such as Vetrobalsamo glass factory or Edison CCGT power plant), such agreements are not regulated in Italy. They are therefore negotiated by both parties (ACS as the DH operator and third-party as external heat supplier) on a voluntary basis and cover various topics (organisation, technical requirements, price structure, penalties, responsibilities…). These contracts are usually long-term contracts, ranging between 10 to 20 years typically.

In the case of Milan DH network, heat from third-parties is supplied to ACS through heat exchangers that are operated by the third-parties and located on their sites.

D Cooperative approaches and role of digital solutions

ACS is developing several projects to implement digital solutions for DH. For instance, the company is developing:

- A platform for Predictive Maintenance,
- A Platform for Predictive Thermal Loads,
- Thermal images by drones for leakages' detection.

ACS is involved in several partnerships and participates in some EU Projects for research and development. The company has, for instance, initiated the following projects and actions:

— **"MAGNITUDE[95]"**, to develop business and market mechanisms, as well as supporting coordination tools to provide flexibility to the European electricity system, by enhancing synergies between electricity, heating, cooling and gas systems.

— **"REWARD HEAT[96]"**, to combine renewable technologies for a renewable district heating and/or cooling system.

— TEMPerature Optimisation for Low Temperature District Heating **"TEMPO[97]"**, to explore low temperature systems.

VI Consumer Empowerment

ACS is **customer-oriented**: customers are the final users of the services and shall be well served. Serving customers is very important for ACS, hence various dedicated resources

[95] https://www.magnitude-project.eu/
[96] https://www.rewardheat.eu/en/
[97] https://www.tempo-dhc.eu/

and tools are in place (e.g. website, contact phone, DHC information, etc.), and overall clients are satisfied, as indicated in Section IV.B.

Furthermore, an on-going pilot project is being developed at small scale to supply consumers with **real-time data** of consumption and performances of their DH substation. This new service would be provided through a smartphone application.

Finally, ACS also informs the customers **through the Municipality and its Local Council**. Therefore, ACS continuously informs about the DH network developments and takes into account comments from citizen representatives. The company representatives also meet periodically with **consumer associations** in order to inform them about new projects and trigger upstream related discussions.

VII Synergies with Other Urban Infrastructure and Local Value Creation

ACS collaborates with urban developers, to improve the heating systems of the **urban areas under construction** in the city. Some new districts have been already connected to district heating (UpTown Project, Merezzate Project), some others are identified and studied for potential developments (Seimilano Project, L'Innesto Project and other C40 Reinventing Cities Projects[98]).

Milan DHC has also developed **synergies with other local infrastructures** on the production side. For instance, and as discussed earlier, the new "neutral" district heating project in Via Balilla (under design) will use the underground water already pumped out by wells for groundwater control, and will extract heat from it to supply the DH grid.

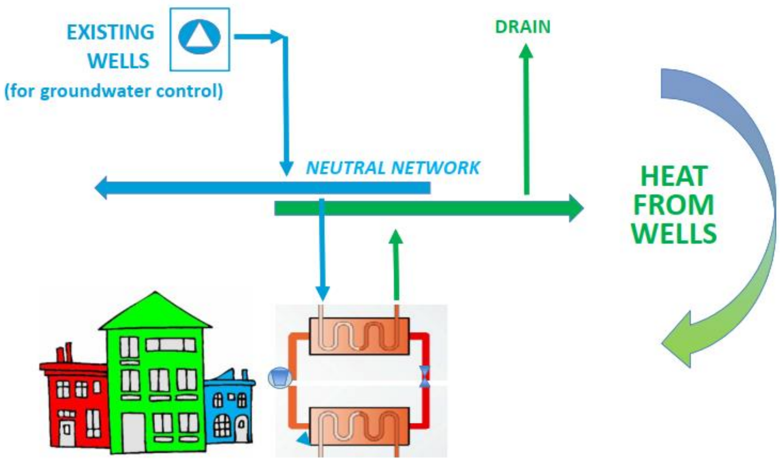


Figure 110: Via Balilla project: demo case (source: A2A)

By means of different projects and different technologies (some of them already realized, some others under design), A2A DHC system in Milan is able to recover geothermal energy, to transform DH into **DC** (by means of absorption systems), to integrate solar thermal, and to develop innovative projects (such as heat recovery from urban wastewater).

In this way, DHC in Milan is further **oriented to a synergy-approach, recovering all the existing heat sources on the territory, transforming waste heat into useful heat**: this approach will enforce the circular-economy of the urban energy system and will improve the environmental footprint of the city.

VIII Conclusion and Key Success Factors

Milan's DHC is a flagship example of an **efficient and integrated approach to energy use and waste management**. The City has developed this integrated approach in order

[98] https://www.c40reinventingcities.org/en/sites/winning-projects/

to improve the energy efficiency and the environmental footprint of its territory, using DHC as a key driver.

The DHC system is further developing, supporting the City to reach the local, national and European environmental and energy targets.

The key success factors identified in the case study are summarised below:

i. **Consistent integration of energy strategy in urban planning.** The city of Milan adopted in 2018 a strategic plan for sustainable energy called PAES that recognizes DHC as a key lever to decarbonize the city. As part of this plan, the integration of DHC in the energy strategy of new districts has been systematically studied. Several recent examples of new residential and commercial buildings that chose to connect to the DHC network, aiming at implementing a zero-energy and carbon-free approach, show how DHC can be a key driver to create high-value and environmentally-friendly districts

ii. **Positive impacts of a significant integration of renewable energy and excess heat sources**. While Milan DHC is the second biggest DHC in Italy (with 1.2 TWh of heat sales and 317 km of network), A2A group managed to integrate local renewable energy and excess heat sources, which amount to 68% today, much above the national average of 24%. Combined with the use of CHP plants, the use of these clean energy sources in the DHC network allows to increase the sustainability of the energy system, to improve local air quality and to reduce greenhouse gas emissions.

iii. **Competitive prices thanks to local renewable energy and excess heat sources.** The significant use of low price or free renewable and excess energy sources makes the DHC system competitive to alternative solutions (based on gas or electricity), and pushes the DHC operator to increase even more the share of these clean energies.

iv. **Implementation of relevant cross-sectorial synergies**. The broad scope of A2A activities enables to find efficient synergies, with the target to further improve the energy system of the City and to integrate all energy sources already available on the territory, avoiding to waste energy and maximizing synergies within different sectors.

v. **Support from the Municipality**. Milan is one of the biggest and densest cities in Italy, which makes it particularly suitable for DHC. The development of Milan DHC has been supported by the Municipality since its creation: in addition to being one of the main shareholders of the operating DHC company, the City of Milan has promoted the DHC system for its inhabitants and fostered an integrated approach for DHC energy supply and waste management.

vi. **Culture of innovation.** ACS keeps trying to improve the efficiency of Milan DHC network by developing innovative solutions tackling various issues and opportunities. The main projects being studied or developed today include interconnection with a third-party network, construction of a “neutral” network supplied by geothermal wells, heat recovery from wastewater treatment plant, heat recovery from electric transformer heat losses, and in general heat recovery from existing sources. In addition, the flexibility brought by the multiple heat storage facilities has helped to manage peak load and thus to decrease the use of fossil fuels. New storage facilities are emerging to develop even more this flexibility.

vii. **Cooling offer. ACS also proposes an offer for cooling, which is expected to be a key** axis of development in the near-future, mainly for tertiary clients. New cooling generation systems based on geothermal energy and absorption machines are being studied.

viii. **Reliable and local service**. Thanks to the continuous improvement of the energy infrastructure (upgrading to the best available technologies), local management (focus on quality of services and on environmental performances), good reliability, ease of maintenance (no chimney to build and to clean in buildings), competitiveness of prices and competences provided by ACS, the population in Milan seems to have a good perception of DHC.

5. Cross-case study analysis: key success factors and replicability

5.1 Main benefits of integrating RES and waste energy sources in DHC systems

The in-depth case study analyses undertaken have allowed to illustrate through concrete examples in different countries and contexts how **DHC systems facilitate the integration of renewable and waste (excess) energy sources in urban environments**. According to the technical specifications of the DHC networks and the potentials found in the area in terms of low-carbon fuels, these systems can mobilize a broad spectrum of energy sources, each of them having their own technical and operational properties, and thus contribute to developing **low-carbon and resilient local energy systems**.

As pictured by the different case studies presented in the previous sections, the main benefits of integrating low-carbon energy sources in DHC systems are of different nature:

- **Environmental:** The first obvious benefit is the **decarbonisation** of the H&C production, as these systems usually present an alternative to individual or collective solutions fuelled by oil, gas or electricity (still mostly of fossil origin), or the integration of low-carbon energy sources is part of a strategy to decarbonize an existing DHC network fuelled by fossil energies. Besides, it also leads to the improvement of the **air quality**, as chimneys are either located at the heat plant out of the city centre (and subject to environmental regulations) or even not used at all. The increase of RES and waste energy sources in the heating and cooling sector through the integration of these sources in DHC systems is one of the key objectives from the revised Renewable Energy Directive of the European Commission (articles 23 and 24) in line with the 2015 Paris Agreement.
- **Economic:** The second type of benefits, which constitutes a game-changer in most of the countries as technologies and energy market prices evolve, is the **competitiveness** of these solutions. The development of new equipment (e.g., efficient heat pumps able to reach high/low temperature regimes), the building-up of the learning curve (e.g., to lower the risk of geothermal projects), the implementation of cost-efficient synergies (e.g., excess heat recovery or integration of intermittent renewable electricity) has allowed to implement competitive solutions which eventually benefit to the clients through lower and more stable prices. In addition, the primary energy sources used in these solutions are usually very competitive (or even free in the case of geothermal or solar thermal energy) and **less exposed to price fluctuations** than fossil fuels.
- **Societal:** DHC systems fuelled by RES or waste energy sources also bring direct societal benefits, e.g. through the reduction of the energy bill (improving energy **affordability**, and therefore tackling energy poverty) or the mobilization of local energy sources which (unlike imported fossil fuels) enables to develop local synergies and fosters **circular economy** as well as local employment, improving the overall attractiveness of the supplied area. In addition, **community initiatives** and other forms of social innovation can also foster consumer participation in the energy sector, ultimately influencing benefit.
- **Technical:** Finally, these systems constitute a mix of technical and operational optimizations. They can accommodate a **wide range of capacities** (from several hundreds of kW for decentralised heat pumps fed by low-temperature excess heat to tens of MW for deep geothermal or biomass facilities), they match perfectly with low-temperature networks (which are **more efficient** than high-temperature ones since heat losses are reduced), and they allow to **increase flexibility** through various opportunities (diversified and complementary energy mix, mid-temperature water loop supplying decentralised heat pumps, thermal storage, CHP and other sector integration equipment, dynamic optimisation of the operation…).

The identified Key Success Factors enabling to reach these benefits are described and discussed in the following sections.

5.2 Key Success Factors identified in the case studies

The 8 case study analyses presented in Section 4, and the complementary interviews with the DHC operator in Gothenburg (Sweden), have identified **10 Key Success Factors** (KSF) leading to an efficient integration of RES and waste energy sources in DHC systems. These KSF are listed below and developed in Section 5.4, while Section 5.2 indicates the case studies where the KSF resulted critical to its success.

	Key Success Factors	Description
1	**National policies: supportive framework for efficient DHC[99]**	The national energy policy and regulatory environment provide adequate ground and incentives for the integration of RES and/or waste energy sources in DHC systems (e.g. by setting ambitious CO_2 and RES targets, organizing third-party access to promote the use of RES and/or waste energy, etc.). *Case studies: Taarnby, Jaegerspris, Paris-Saclay, Vilnius, Gothenburg*
2	**Direct and indirect financial support to new investments**	When market prices do not reflect the socio-economic benefits of decarbonised DHC systems, financial support may be needed. The business case for efficient DHC projects becomes then viable thanks to direct financial support (e.g. national or EU investment subsidies) and/or indirect financial support (e.g. fiscal incentives, including environmental taxes) conditioned by the level of integration of RES and/or waste energy sources. Research, Development and Innovation (RDI) to support new DHC developments is also financially supported. *Case studies: Direct support in Paris-Saclay, Mieres, HafenCity, and Vilnius. Indirect support in Taarnby, Jaegerspris, Paris-Saclay and Gothenburg*
3	**Local governance and commitment of the various stakeholders**	Public authorities at regional and/or local level, end-users (consumers), the DHC operator and other local actors cooperate in an efficient manner to achieve a good quality service and a sustainable and cost-efficient heat and cold supply. *Case studies: All*
4	**Energy planning as an integral part of urban planning**	Local authorities promote efficient DHC as part of their energy supply and climate strategy and integrate heat planning (and cooling if relevant) in their urban development projects (e.g. undertaking a long-term cost-benefit analysis for heat planning, establishing DH zones or specific environmental requirements for buildings, etc.). Synergies at district and municipal levels are valued. *Case studies: Taarnby, Jaegerspris, Paris-Saclay, Barcelona, HafenCity, Milan*
5	**Energy infrastructure in buildings at the heart of the local energy system**	Building regulation and urban planning are developed in a way that fosters the integration of efficient DHC networks in the new and refurbished building stock (e.g. promotion of collective solutions, low-temperature heat emitters, demand side management). *Case studies: Paris-Saclay, Barcelona, HafenCity, Milan*
6	**Compatibility and competitiveness of local RES and waste heat/cold sources**	The potential of the different local RES and waste energy sources is mapped and their respective technical compatibility with the DHC network (capacity, temperature levels, production profile…) is properly assessed. Comprehensive economic evaluation is also carried out to support the prioritisation of these sources and ensure the implementation of a competitive DHC system against the alternative H&C solutions available in the market. *Case studies: All cases*

[99] In the sense of Article 2(41) of the Energy Efficiency Directive of the European Commission ("district heating systems using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat")

7	**Power-to-Heat solutions valuing renewable electricity and low-temperature sources**	DHC systems can be key flexible consumers for intermittent renewable electricity, supporting the stability of the electrical grid and benefitting from low-price surplus electricity. This is achieved through the implementation of PtH solutions using renewable electricity, such as electrical boilers and large heat pumps coupled with thermal storage. These PtH solutions also enable the integration of low-temperature energy sources. *Case studies: Taarnby, Jaegerspris*
8	**Sector integration**	Synergies with other networks (electricity, gas, water), urban infrastructures (e.g. wastewater treatment plant, data centre, etc.) and local industries are developed and create value for the community through increased efficiency (e.g. waste heat recovery) and flexibility (e.g. balancing services). *Case studies: Taarnby, Jaegerspris, Mieres, Barcelona, HafenCity, Milan, Gothenbourg*
9	**District cooling**	District cooling provides DHC systems a clear competitive and operational advantage and enables their integration in urban energy systems in the long term. It also allows to develop clear synergies with district heating and possibilities to decarbonize cooling supply, enabling the integration of ambient energy and waste cold sources (free cooling) otherwise not used. *Case studies: Taarnby, Paris Saclay, Barcelona*
10	**Adaptability and continuous optimisation**	Flexible strategies allow a better integration of the various RES and waste energy sources available and a better integration of the different buildings prospected through time. This can be achieved through modular architecture of the DHC network or heat cascading e.g. *Case studies: All*

5.3 Impact of the key success factors in the integration of RES and waste energy sources

The **level of influence of the KSF on the integration of RES and waste energy sources** in the analysed case studies has been assessed and is presented in Table 5 below, where "+++" represents the strongest influence.

This table shows that most of the identified KSF influenced the decarbonisation of each of the networks investigated. However, their impact varies across the case studies, and 2 groups of factors stand out.

- Firstly, the key role of a **strong and inclusive local governance** (KSF 3), together with a **thorough energy planning** ensuring the price **competitiveness of DHC** against its alternatives (KSF 6) in the frame of a **flexible strategy enabling to continuously optimise the energy supply** (KSF 10) identified across all case studies suggests this could constitute a common pillar for successful decarbonisation strategies in H&C.
- Secondly, **comprehensive and coherent approaches across sectors following an "energy-efficiency-first" principle** appear also as a powerful way to decarbonise H&C through DHC. This can be done by connecting urban planning to energy infrastructure through enhanced energy planning (KSF 4), integrating also the **DHC-buildings nexus** (KSF 5), and valuing **synergies with other urban and energy infrastructure** (KSF 8).

When valuing those synergies between DHC and other infrastructure, two rather emergent trends appear, which are expected to play a more important role in the future. In particular, **district cooling** (KSF 9) has proved to be a strong lever to increase DHC system efficiency while decarbonising the increasing cooling demand and bringing further socio-economic benefits. The introduction of Power-to-Heat solutions coupled with thermal storage to enable **smart sector integration** (KSF 7) allows the integration of intermittent renewable electricity and low-temperature sources through electric heat pumps (e.g. geothermal and ambient energy, waste heat from wastewater treatment plants or data centres, etc.), and presents a strong potential to further decarbonise H&C through DHC, especially in the view of growing RES shares in electricity production.

It is interesting to note as well that **support at national** level to DHC systems based on RES and waste energy sources (KSF 1) had in general a strong influence on the studied networks, but did not prevent those developed under less supportive environments (e.g. Southern Europe) to succeed. In those cases, the lack of national support was compensated by the strong support found at local level (KSF 3) and the competitiveness of the DHC offer developed (KSF 6).

Finally, most of the networks studied benefitted from direct or indirect **financial support** (KSF 2) to secure their investments, leading to a decarbonised DHC supply. These support schemes normally come along national policy measures and strategies (KSF 1). EU structural funds (ERDF) can play a key role when the national framework does not provide the grounds to make the project financially viable (e.g. Mieres).

Case studies	Influence of KSF on the success in integrating RES and waste energy sources									
	KSF1	KSF2	KSF3	KSF4	KSF5	KSF6	KSF7	KSF8	KSF9	KSF10
	National policies: supportive framework for efficient DHC	Direct and indirect financial support	Local governance and commitment of the various stakeholders	Energy planning as an integral part of urban planning	Energy infrastructure in buildings at the heart of the local energy system	Compatibility and competitiveness of local RES and waste heat/cold sources	Integration of Power-to-Heat solutions	Sector integration	District cooling	Adaptability and continuous optimisation
DK - Taarnby	+++	+++	+++	+	++	+++	++	+++	+++	++
DK - Jaegerspris	+++	+++	+++	+	++	+++	++	++		+++
FR - Paris Saclay	++	+++	++	+++	+++	+++	+	+	+++	++
ES - Mieres		+++	++	+	++	+++	+	++		++
ES - Barcelona			++	+++	+++	+++	+	+++	+++	++
DE - Hafencity (Hamburg)	+	+++	++	+++	+++	+++		++		+++
LT - Vilnius	++	+++	++	+		+++		+		+++
IT - Milan			++	+++	++	+++	+	+++	+	++
SE - Gothenburg	+++	+++	+++	+	+	+++	+	+++	+	+++

Legend	
	Low influence
+	Moderate influence
++	Significant influence
+++	Strong influence

Table 5 Level of influence of KSF on the integration of low-carbon energy sources

5.4 Detailed analysis of the Key Success Factors and replicability

This section provides an analysis of the KSF identified in this study for the integration of RES and waste energy sources in DHC systems. **It is aimed at providing policy makers, project promoters, DHC operators and other stakeholders with a set of recommendations based on best practices and lessons learnt from some of the best-functioning sustainable DHC systems in the EU**. For each of these KSF, the following items are detailed:

- General description
- Target audience
- Impact on the DHC project life cycle
- Key facts and examples from case studies
- Potential drivers and barriers
- Replicability
- Impact on the integration of renewable and waste heat/cold sources in DHC

KSF 1: National policies: supportive framework for efficient DHC

The national energy policy and regulatory environment provide **adequate ground and incentives** for the integration of RES and/or waste energy sources in DHC systems (e.g. by setting ambitious CO_2 and RES targets across all sectors, organizing third-party access (TPA) to promote the use of RES and/or waste energy, etc.).

Target audience	Impact on DHC project life cycle
• Policy makers • National and regional authorities • Regulators	• Initial feasibility of the project • Contracting with clients • Long-term economic equilibrium

Key facts and examples from case studies

- Setting ambitious **national CO_2 targets across all sectors**, expressing RES share targets in terms of primary and final energy consumption, and recognizing the **key role of efficient DHC systems in the decarbonization of the heating and cooling sector** (and in the integration of intermittent renewable electricity as discussed in KSF 7) is essential to drive the integration of RES and waste energy sources in heating and cooling. If some countries have set clear **national objectives and strategies for the development of DHC and the increase of their RES and waste energy share** in heating (e.g. France, Sweden), the role of DHC systems in decarbonization is still underestimated in some emerging DHC markets, partly due to low (though growing) political and public awareness on their benefits.

- Some EU countries are already very advanced in the implementation of integrated energy approaches addressing energy efficiency, RES supply and sector integration, and **place DHC grids at the heart of smart and efficient multi-energy systems** (discussed in KSF 5 to 10). In Denmark, this approach is supported (amongst other measures) through mainstreamed long-term H&C planning in cities using a transparent and nation-wide shared methodology, taking into account socio-economic externalities, and driving investments towards smart sector integration.

- While the efficiency of the overall DHC regulation depends on many country-specific parameters, tax arbitrage between the different energy sources and carriers as well as direct and indirect financial support schemes are key levers to enhance the competitiveness of solutions based on RES and waste energies (discussed in KSF 2).

- It is also interesting to highlight the fact that organizing the **access of third-party heat suppliers** to DH networks has proven to be effective in Lithuania in order to maximize the integration of the RES and waste energy sources available locally, and to achieve the most competitive costs and prices to end-users through monthly heat auctions.

- The role of national authorities is also crucial to increase **public awareness** and to **protect and inform the consumers**, especially in less mature markets. In some countries like Sweden or Denmark, a national benchmark allows all consumers to compare their tariffs in DH and other utility services to those in other cities, which fosters performance improvement. Studies and best practices shared at the European level as well as European Directives implementing reporting methods to monitor DHC activities in Member States are also key to **increase the knowledge needed to develop relevant public policies**.

Potential drivers	Potential barriers
• Guidelines made at the European level • National political willingness / H&C targets • Pressure from citizens and organisations to speed up the energy transition	• Little awareness on DHC benefits • Lobbying from existing alternative solutions • Heavy procedures required by some regulated activities (e.g. monthly heat auctions for TPA)

Replicability

- This KSF is by nature directly dependent on the national political context. However, the **European Union** has a key role to play to share best practices and provide guidelines to the Member States in order to support the common goal of heating and cooling decarbonization.

- The **integrated approach** (described above and in KSF 8) and the **level of regulation** (e.g. through mandatory heat planning and zoning, third-party access rules, or price regulation) is also strongly connected to various national features (homogeneity and transparency of the practices in heating and cooling supply, ownership structure of DHC networks, organization and structure of the competition…) and therefore cannot be replicated straightforwardly from one country to another.

Impact on the integration of renewables and waste heat/cold sources in DHC

- National objectives for decarbonization through DHC systems set clear guidelines that are even exceeded locally sometimes, like **Vilnius Municipality** which will reach the target of having **90% of the DH supply from RES almost 10 years before the national target set for 2030**.
- Integrated approaches allow to consider the integration of RES and waste energy sources within the wider framework of energy efficiency and energy systems' flexibility: **DHC operators are then not only pure energy suppliers, but also active players in energy efficiency and flexible consumers that can provide also balancing services**, like the DH grid of Jaegerspris.
- In Vilnius, third-party access has significantly supported the DHC network **fuel switch** from gas and heating oil to biomass and waste-to-energy, and thus participated in the **decrease of DHC prices**.
- Increased public awareness allows to **support the end-users to make the right choices**, by considering the true (long-term) cost of the different solutions, together with their environmental impact and quality of service.

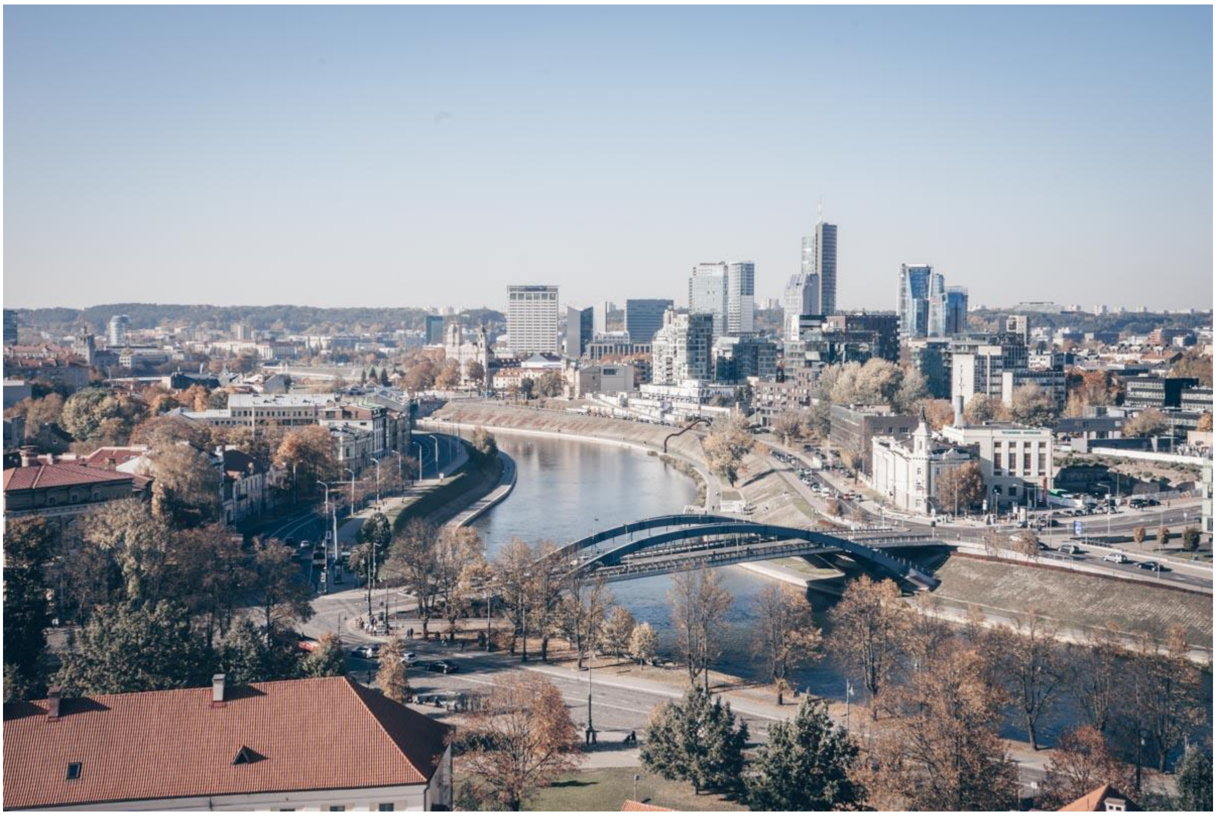


Figure 111: City of Vilnius, Lithuania (source: www.nomadepicureans.com)

<table>
<tr><th colspan="2">KSF 2: Direct and indirect financial support to new investments</th></tr>
<tr><td colspan="2">When market prices do not reflect the socio-economic benefits of decarbonised DHC systems, financial support may be needed. The business case for efficient DHC projects becomes then viable thanks to direct financial support (e.g. national or EU investment subsidies) and/or indirect financial support (e.g. fiscal incentives, including environmental taxes) conditioned by the level of integration of RES and/or waste energy sources. Research, Development and Innovation (RDI) to support new DHC developments is also financially supported.</td></tr>
<tr><th>Target audience</th><th>Impact on DHC project life cycle</th></tr>
<tr><td>• Policy makers
• National and regional authorities
• Other funding entities at all levels</td><td>• Initial feasibility of the project
• Contracting with clients
• Long-term economic equilibrium</td></tr>
<tr><th colspan="2">Key facts and examples from case studies</th></tr>
<tr><td colspan="2">• Indirect support schemes are diverse, and come along with national climate and energy strategies (KSF 1). CO_2 taxes on fossil fuel consumption and taxes on non-recovered waste heat is a widely-used lever to enhance the competitiveness of RES and waste energy-based solutions. Denmark has recently eliminated the electricity tax for heat produced from heat pumps, recognizing the role of DHC systems in smart integration of renewable electricity and improving the business case for further DHC electrification. Reduced VAT for end-users supplied by RES or waste energy (for all heating technologies, like in Italy, or only for DHC, like in France) is also found in several EU countries.

• When indirect support schemes do not exist or are not sufficient to make the integration of low-carbon energy sources through DHC financially viable, direct support schemes may be needed. These are usually provided through national funding programmes (e.g. kfW[100] in Germany or ADEME[101] in France) or EU structural funds (like in the case of Mieres or Vilnius). They usually consist of investment subsidies applicable to the production facilities (including those at the waste heat producers’ sites), as well as network infrastructure and substations in some countries. They can also be revenue support schemes (feed-in or premium tariffs) in the case of RES-based CHP, or technical assistance to prepare the investments (e.g. energy planning and feasibility studies). This funding should be coherent with other energy efficiency and renewable energies support schemes (KSF1), jointly driving investments towards reducing energy demand and increasing the share of RES & waste heat/cold sources in the supply.

• Funding RDI projects and initiatives is also key to continue improving the efficiency of DHC systems and their capacity to integrate local and low-carbon energy sources. The scope of such initiatives can be of different nature, combining technical, policy and regulations, and social innovation (such as energy communities and further consumer participation).

• The status of waste energy recovery varies significantly across the EU and efforts remain to be made to homogenize the support of this huge potential for heating and cooling decarbonization and recognise its value. In some countries, the share of waste energy in DHC systems is not taken into account for the grant of investment subsidies (either for production on the supplier side or for network development on the DHC operator side) or for the application of reduced VAT for end-users.</td></tr>
<tr><th>Potential drivers</th><th>Potential barriers</th></tr>
<tr><td>• Guidelines made at the European level
• EU and national political willingness (KSF 1)
• Recognition of DHC networks as key systems to decarbonize the heating and cooling sector (KSF 1).</td><td>• Lobbying from existing alternative solutions or relevant stakeholders (e.g. waste management operators exposed to higher taxes)
• Public rejection of increased environmental taxes
• Capacity of the public authorities to set the appropriate level of support according to projects’ characteristics</td></tr>
</table>

[100] German State-owned development bank (Credit Institute for Reconstruction)
[101] French agency for environment and energy management

Replicability

- Support schemes cannot be directly replicated from one country to another since they fall within country-specific regulatory frameworks and markets. However, **general principles and common best-practices** on direct and indirect schemes can be used as a baseline (e.g. guidelines on priority low-carbon sources for DHC by ADEME in France).
- As already underlined, the support to **waste energy sources** is very heterogeneous today across Europe and constitute a large potential for improvement.

Impact on the integration of renewables and waste heat/cold sources in DHC

- In many countries, direct support schemes are still necessary to **unlock the investments in RES production facilities which are particularly CAPEX-intensive** (e.g. geothermal energy, biomass, solar thermal). In some others however, indirect support schemes (high CO_2 and environmental taxes in particular) are already sufficient to develop projects with no investment subsidies, e.g. in Denmark (highly regulated model) and Sweden (completely liberalised market).
- Indirect support schemes usually play a significant role in the business plan of efficient DHC systems, and should be **established on the long-term to ensure stability of the project economic equilibrium and thus the stability of prices to end-users**.
- Despite an overall delay with respect to RES, **waste energy** sources are being successfully integrated in more and more DHC networks (under development in Paris-Saclay or Vilnius e.g.) thanks to their **competitiveness enhanced if tax incentives exist**. According to their technical settings, these projects may also require direct financial support, like the integration of industrial waste heat in HafenCity’s DH network, which would have not been viable without the significant investment subsidies received (around 40% for both the DH operator and industrial partner).

Figure 112: Hafencity in Hamburg, Germany (source: www.ndr.de)

<table>
<tr><th colspan="2">KSF 3: Local governance and commitment of the various stakeholders</th></tr>
<tr><td colspan="2">Public authorities at regional and/or local level, end-users (consumers), the DHC operator and other local actors cooperate in an efficient manner to achieve a good quality service and a sustainable and cost-efficient heat and cold supply.</td></tr>
<tr><th>Target audience</th><th>Impact on DHC project life cycle</th></tr>
<tr><td>• Regional and local authorities
• Energy and urban development agencies
• DHC operators
• End-users and their representatives
• Any other stakeholders possible (e.g. third-party energy suppliers)</td><td>• Initial feasibility and design of the project
• Long-term management</td></tr>
<tr><th colspan="2">Key facts and examples from case studies</th></tr>
</table>

- Whereas only 26% of European cities have a climate action plan or an energy transition strategy[102], all the cities analysed had one, with actions related to DHC. **Municipalities have a central and key role** in the development of efficient DHC on their respective territory:
  - By recognizing efficient DHC networks as powerful tools to achieve their climate targets and setting associated **action plans** to foster their development.
  - By **initiating and steering the development of the DHC networks** on their territory. From the very beginning of the project, Municipalities must have a clear and relevant vision of these projects and their different short-term (construction) and long-term (operation) issues. The support from high-quality and experienced consulting teams is often very valuable to jointly put the project on the right track, like in Paris Saclay. These new forms of private-public cooperation also enable all utilities and communities, independently of their size, to develop world-class projects (e.g. Taarnby, Jaegerspris).
  - By **actively participating in their technical and economic monitoring, or even in their operatorship**. According to the national regulation, this can be done through total or partial ownership of the DHC infrastructures or project company (which can also provide guarantees for loans).
  - By directly or indirectly (e.g. through the DHC operator) supporting **prices control and transparency** to ensure benefits are shared with end-users, as well as supporting **information and concertation with citizens** (on civil work, planned and unplanned shutdowns...).
  - By **coordinating energy planning and urban planning** (see KSF 4).
  - By **connecting public buildings** (which often represent a significant amount of heat/cold sales) to the DHC network in the early phase of the project to help 'de-risking' the project (like in Mieres or Jaegerspris).

- Alongside Municipalities, **DHC operators** bring up-to-date knowledge as well as additional human and material resources to build (most of the time) and operate the network. Close collaboration between Municipalities and DHC operators is required to ensure a common understanding of the objectives and the achievement of these.

- The involvement of **other stakeholders** like third-party energy suppliers or regional energy institutes (e.g. the waste incineration plant and the energy institutes of Spain and Catalonia entering the ownership structure of the DHC project in Barcelona) contributes to a smooth development and operation of the DHC network.

- In addition, **new participative methods integrating end-users through energy communities** are emerging. In Jaegerspris for instance, consumers are gathered in a citizen energy community: they are at the same time the clients and the only shareholders of the DH network, and share the objective of ensuring long-term, resilient heat supply at the lowest cost possible (along with a high share of RES). In Sweden, the Price Dialogue scheme encourages DHC operators to invite customer representatives to discuss development plans, evolution of prices, new services... ultimately enhancing customers' empowerment.

[102] 2020 SWECO, Urban Insights, *Planning for Climate Adaptation Key actions for resilient and adaptive cities of the future* (link to report)

Potential drivers	Potential barriers
• Increased Municipalities awareness of their own role • Local Climate / Energy Transition Action Plans, addressing all sectors including H&C • Development of comprehensive assessments of the externalities of DHC projects and sharing them with the stakeholders involved • Emerging participative methods involving end-users (energy communities)	• Limited political will to undertake a local energy transition • Limited human resources of Municipalities and empowerment of their teams • Need of change of the operators' state of mind in this relatively new paradigm (higher cooperation)

Replicability

- This KSF relies mostly on best-practices and should be **replicable** in any country, at least for the general principles for each key actor mentioned above. However, its exact deployment is related to some extent to national DHC regulation and specific local contexts.

Impact on the integration of renewables and waste heat/cold sources in DHC

- As stated above, better involvement and coordination of the different stakeholders (municipalities, DHC operators, possible partners, end-users...) facilitate to define and reach common objectives. In terms of integration of RES and waste energy sources, the **active steering** of Municipalities (to reach their **climate targets**) and the participation of end-users and/or energy institutes e.g. (to improve and/or maintain the **attractiveness of their living area**) are key.

- The establishment of operational and cooperative **climate action plans** by the communities, addressing all sectors including H&C, has proved to be a powerful political tool to foster decarbonisation.

Figure 113: Solar field and city of Jægerspris (source: Jægerspris Kraftvarme)

KSF 4: Energy planning as an integral part of urban planning

Local authorities promote efficient DHC as part of their energy supply and climate strategy and integrate **heat planning** (and cooling if relevant) in their urban development projects (e.g. undertaking a long-term cost-benefit analysis for heat planning, establishing DH zones or specific environmental requirements for buildings, etc.). Synergies at district and municipal levels are valued.

Target audience	Impact on DHC project life cycle
• Regional and local authorities • Energy and urban development authorities	• Initial feasibility and design of the project • Long-term development

Key facts and examples from case studies

- As discussed in KSF 3, Municipalities have a key role to play in the development of efficient DHC systems on their territory. According to their legal competencies, Municipalities and other regional/local authorities are the guarantors of a **consistent and efficient coordination of energy planning and urban planning**.

- Firstly, this encompasses a **comprehensive assessment of the optimized scenario** to develop efficient energy solutions designed for the considered urban plan in a tailor-made approach, assessing in detail available local resources to compare possible solutions integrating environmental and cost criteria in the long-term. The objectives of this assessment can be set upon **national or local guidelines**, like the hierarchisation of RES and waste energy sources set by ADEME in France (favouring waste energy sources and leaving biomass as the last option possible).

- The role of local authorities is particularly key for:
  - **planning and facilitating the construction of DHC production plants and networks** (e.g. Taarnby), which is specially challenging in dense urban areas,
  - **anticipating possible synergies** with other urban infrastructures (also discussed in KSF 8),
  - **initiating and supporting the link between DHC operators and other stakeholders** like real estate developers (particularly import to initiate Barcelona's project e.g.).

- Finally, local legislation/regulation might be implemented to foster the development of efficient DHC networks and/or consider their technical requirements in the construction or refurbishment of efficient buildings. This can be done through **zoning** measures, establishing areas with favoured or mandatory connection to DHC networks, or maximum CO_2 emissions for heating (like in HafenCity), or by **integrating environmental, energy and cost efficiency criteria** (on which efficient DHC networks usually bring relevant solutions) **in urban development codes** like in Paris-Saclay and Barcelona.

Potential drivers	Potential barriers
• Guidelines made at the European level • Funding programmes (KSF 2) or urban procedures based on energy planning studies • Increased awareness at local authorities level of the mutual impacts of DHC and urban development, as well as the related benefits for the energy transition	• Little awareness on DHC benefits • Limited human resources of Municipalities and empowerment of their teams • Building codes encouraging alternative H&C solutions

Replicability

- This KSF is **mostly replicable,** as local authorities usually benefit from the legal competencies evoked here. However, human and material resources to apply these best-practices vary from one country to another, and even within the same country. In addition, national regulations do not necessarily offer the same range of levers (e.g. zoning is not allowed in all countries).

Impact on the integration of renewables and waste heat/cold sources in DHC

- Consistent and close coordination of energy and urban planning allows to **anticipate and thus maximise the concretization of the different opportunities** that may arise in the long-run for the integration of RES and waste energy sources in urban energy systems (also discussed in KSF 8).

- The **organised fuel switch from oil and gas to DH** can significantly increase the share of RES, as seen in Mieres, Taarnby or Jaegerspris, supported in some cases with subsidies. In Denmark, for example, it is expected that most areas currently supplied by natural gas will switch to DH (for the densest urban areas) or individual heat pumps by 2030.

KSF 5: Energy infrastructure in buildings at the heart of the local energy system

Building regulation and urban planning are developed in a way that fosters the integration of efficient DHC networks in the new and refurbished building stock (e.g. promotion of collective solutions, low-temperature heat emitters, demand side management).

Target audience	Impact on DHC project life cycle
• Policy makers at all levels • Housing and urban development agencies • Real estate developers • DHC operators	• Initial project design • Whole project life cycle

Key facts and examples from case studies

- Located at the end of the chain, buildings and associated equipment are key parts of DHC systems. In particular, **heat emitters technology** (cast iron radiators, steel panel ones, radiant floor...) and their configuration as well as the **level of insulation** directly impact the design of DHC networks by setting their operating temperature regimes. As a result, new or refurbished districts made of modern buildings where low-temperature heat emitters are commonly found now favour the **direct integration of low-temperature RES** (e.g. solar thermal, geothermal energy or ambient energy) and **waste energy sources** (e.g. underground railway, data centres).

- In addition, as the load profile of each customer impacts the DHC network's operation, means to **shape the load curve** should be anticipated when designing and operating buildings. Reducing peak demand could thus be achieved through **smart demand side management** (e.g. taking into account the real-time and forecasted availability at the production site, or the prices on energy spot markets when relevant), energy management services like in Gothenburg or in the Danish cases (to reduce return temperatures in particular), or implementation of thermal storage facilities.

- Therefore, it is crucial to have a **consistent and coordinated urban planning and energy planning** (KSF 4), including building codes (KSF 1), addressing building energy infrastructure.

- Indeed, building codes are key tools to encourage and facilitate the development of DHC connections when these solutions are proved to be the most cost-efficient for the end-users. **Unfortunately, today most EU building codes neither deal with this building-DHC nexus nor integrate the positive environmental impact of efficient DHC networks in buildings' energy supply requirements** (e.g. the Primary Energy Factor[103] associated to DHC systems is not set according to their share of RES or waste energy in most European countries, and in some countries it is even set at a higher level than fossil-based solutions).

- Specific tariff incentives from the DHC operators can also be implemented to enhance the overall efficiency of the system: **bonus/malus mechanisms based on the return temperatures** (like in the Danish cases analysed and Gothenburg) help to minimize these temperatures in DH or maximize them in DC, and **seasonal tariffs** (like in Paris-Saclay or Taarnby) positively impact the load profile over the year for some clients (e.g. industries).

Potential drivers	Potential barriers
• Early integration of energy strategy in urban development planning (KSF 1 and 4) • Market development of the corresponding heating equipment and energy services • Consumers empowerment and incentives to participate in the system's energy efficiency • Integration of supply-side measures in building refurbishment programmes	• Building codes encouraging alternative H&C solutions • Limited understanding of DHC opportunities and technical constraints by policy makers and local authorities • Low fossil fuel prices (alternative solutions) • Lobbying from existing alternative solutions

[103] Primary Energy Factor is the ratio of primary energy input to delivered energy input

Replicability

- This KSF relies mostly on best-practices and should be **easily replicable** in any country. However, its deployment is related to a large extent to new districts development and refurbishment programmes.

Impact on the integration of renewables and waste heat/cold sources in DHC

- The integration of the building-DHC nexus and the conversion to low-temperature networks is a key element for the development of **4th generation DHC systems,** as discussed in KSF 10. In Denmark, the conversion to **lower temperature regimes in buildings** was fostered by DH deployment, and a regime of 60°C supply / 40°C return was introduced in the building code in 1990s, resulting in improved energy efficiency.

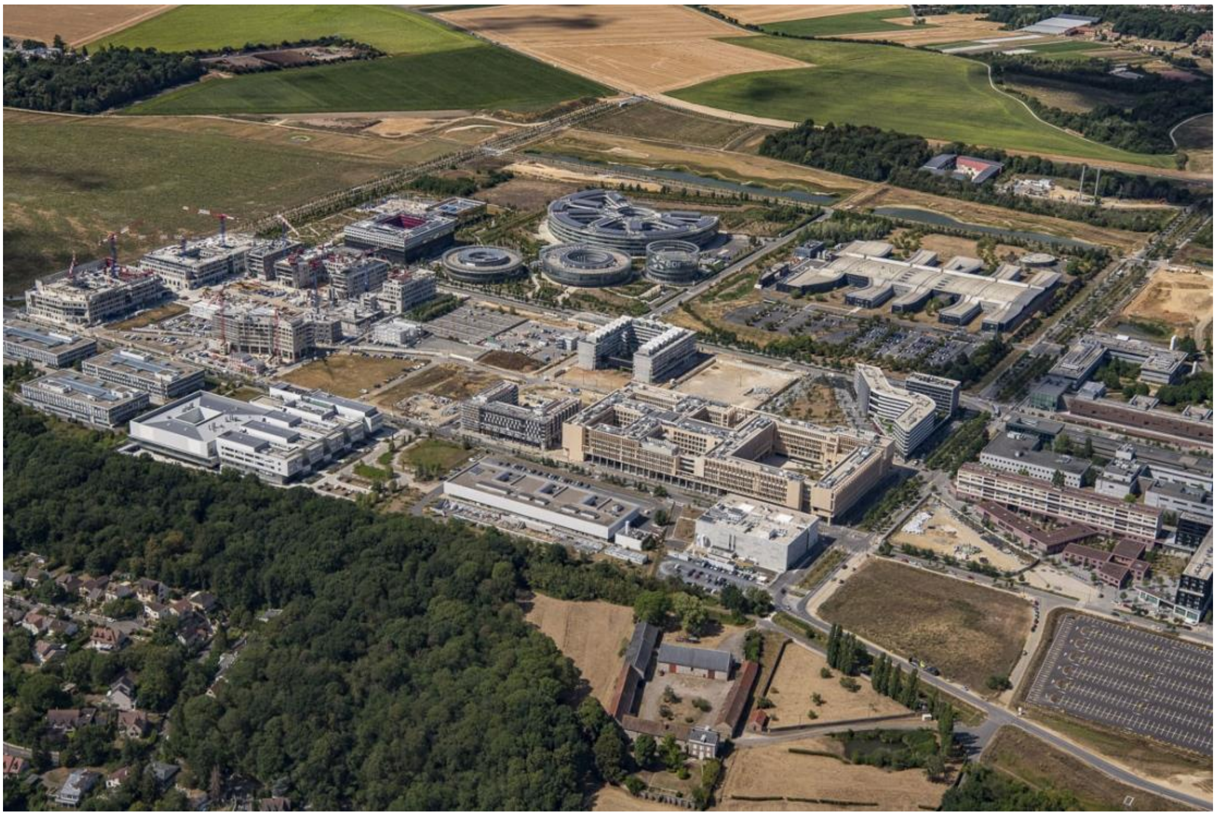


Figure 114: Paris-Saclay district (source: EPAPS)

KSF 6: Compatibility and competitiveness of local RES and waste heat/cold sources

The **potential of the different local RES and waste energy sources is mapped** and their respective **technical compatibility with the DHC network** (capacity, temperature levels, production profile…) is properly assessed. Comprehensive **economic evaluation** is also carried out to support the prioritisation of these sources and ensure the implementation of a competitive DHC system against the alternative H&C solutions available in the market.

Target audience	Impact on DHC project life cycle
• Authorities in charge of funding programmes • Local authorities • DHC operators	• Initial feasibility of the project • Long-term security of supply • Long-term economic equilibrium

Key facts and examples from case studies

- Beyond the mere existence of local RES and waste energy sources in the vicinity of the DHC network infrastructure, the critical condition to ensure efficient integration of these energy sources is the **comprehensive mapping of the potential sources**, and their **sustainability through time**. This is particularly important for sources related to complex physico-chemical processes (e.g. geothermal energy) and/or to third-party activities with possible competition of uses, e.g. biomass resources (e.g. DH vs local industry) or wastewater treatment plant (e.g. DHC vs internal processes and possible direct use).

- Understanding and forecasting the key **technical features of such sources** (capacity, temperature levels, production profile and availability…), which often vary significantly from one source to another, and assessing their **compatibility with the DHC network and connected buildings** is also key to develop reliable and flexible systems.

- Today, the development of new technologies (e.g. heat pumps with high/low temperature levels), the operational experience gained through the last decades and the building stock refurbishment involving more efficient heating equipment (e.g. low-temperature heat emitters) allow to mobilize a **wider spectrum of RES and waste energy sources**.

- These sources assessment and hierarchisation must also integrate the corresponding economic calculations to ensure **cost-efficient integration and prioritisation** of the different sources available.

Potential drivers	Potential barriers
• Sharing best-practices and operational feedback at national and European levels • **Continuous development of technologies** (for both production and optimization of the network operation) • Implementation of efficient heating-equipment in buildings (**low-temperature heat emitters**) • Resulting optimization of the cost (e.g. fuels)	• Maintaining relatively low oil and gas prices • Delays in building refurbishment programmes, or not taking into account the supply when doing so

Replicability

- This KSF relies mostly on best-practices and should be **easily replicable** in any country.

Impact on the integration of renewables and waste heat/cold sources in DHC

- DHC networks are ideal tools to mobilize the **various types of RES and waste energy sources that can be captured in the vicinity of urban areas**, a potential that often remains untapped until the arrival of the network (e.g. geothermal energy from a closed coal mine in Mieres or industrial waste heat in HafenCity). This is particularly true for DHC networks supplying modern buildings with low-temperature heat emitters, as illustrated by Paris-Saclay network which plans to mobilize various sources of excess heat to complete the main supply from low-temperature geothermal doublets.

- **Mixing different types of sources** with different technical features (like Milan DHC network which mobilizes waste-to-energy, geothermal energy and different sources of excess heat) has also proved to increase the efficiency and flexibility of the system (also discussed in KSF 10).

- An increasing number of DHC networks **naturally integrates RES and waste energy sources** (with no financial support, like Barcelona or Milan cases) **due to the low cost (or even nil in the case of geothermal energy or some types of excess heat e.g.) of the corresponding fuel**.

KSF 7: Power-to-Heat solutions valuing renewable electricity and low-temperature sources

DHC systems can be key flexible consumers for intermittent renewable electricity, supporting the stability of the electrical grid and benefitting from low-price surplus electricity. This **smart sector integration** is achieved through the implementation of PtH solutions using renewable electricity, such as electric boilers and large heat pumps coupled with thermal storage, or CHP plants driven by electricity prices. These PtH solutions also enable the integration of low-temperature sources.

Target audience	Impact on DHC project life cycle
• National and local authorities • DHC operators • Electricity Transport and Distribution System Operators	• Could impact the initial feasibility of the project • Long-term security of supply • Long-term economic equilibrium

Key facts and examples from case studies

- In countries where intermittent renewable electricity has increased significantly like in Denmark, DHC networks equipped with PtH solutions are used as smart multi-energy systems able to react to electricity price signals and **support the stability of the electricity grid**.

- Thanks to electrical boilers and large heat pumps coupled with thermal storage, DHC networks can provide balancing services while increasing their own **security of supply**, integrating a **higher share of RES** (notably intermittent electricity), and generating **more value** (increased revenues from balancing services and decreased fuel cost) by operating these thermo-electrical units when the electricity prices are low on the spot market.

- In parallel, the development of heat pumps also enables to **maximise the use of low-temperature RES** (e.g. geothermal and ambient energy) **and low-temperature waste heat** (e.g. from wastewater treatment plants or data centres), discussed in KSF 6 and related to KSF 5. When benefiting from decarbonized electricity, this combination may lead to 100% renewable thermo-electric solutions.

- In some cases (depending on the contractual obligations and the technical settings), **CHP** facilities can also provide complementary balancing services through an inverted scheme by feeding more electricity to the grid when the demand is high (up-regulation).

- The operation of such complex multi-energy systems requires to embrace the various operational and economic impacts on the DHC network. The optimization is run continuously by powerful **digital tools able to integrate numerous real-time and forecasted data related to the DHC network and the electricity market** (like in Jaegerspris).

- When comparing technologies for storing **intermittent renewables**, **thermal technologies are around 100 times cheaper than electric batteries in terms of unit investment cost**, and collective or larger systems also appear as cheaper than individual solutions[104], supporting the choice of smart sector integration through DHC.

Potential drivers	Potential barriers
• Development of electrical RES and increasing need for grid stability • Guidelines made at the European level • Deployment of balancing services offers • Market development of the corresponding equipment (large heat pumps and electrical boilers, seasonal thermal storage…)	• Lack of awareness on this opportunity, especially in emerging DHC markets • High taxes on electricity (when compared to gas, coal or heating oil) creating distortions in many EU Member States • Electricity network tariffs not considering demand side flexibility • Technical complexity to optimize and operate the system

[104] According to a keynote presented in Nov. 2020 by Aarlborg University, individual batteries have a unit cost of around 300 EUR/kWh, while large electric batteries cost 125 EUR/kWh. Individual thermal storages have a unit cost of 90 EUR/kWh, while **large thermal storage present a unit cost of 1 EUR/kWh** (2020, B. Vad Mathiesen, *Roadmap for net zero emissions with known technologies*)

Replicability

- The integration of PtH solutions is in general easy to replicate, and contributes to further decarbonisation of DHC systems in countries where electricity is already decarbonized to some extent.

- The essential condition to increase the interest in this type of systems is the **development of intermittent renewable electricity**, which induces infra-day market fluctuations and needs for grid stability.

- **National regulation on balancing services** should also be aligned to enable valuing the full potential of this synergy.

Impact on the integration of renewables and waste heat/cold sources in DHC

- This type of smart multi-energy systems has the great advantage to offer the possibility to integrate **renewable electricity in H&C**, an energy carrier rarely mobilized in DHC today.

- The flexibility brought by these systems, which rely on complementary production units and possibly short or long-term thermal storage facilities, is **very convenient to accommodate the surplus of renewable electricity** that is frequently observed now in some countries at mid-day and on windy days.

- These thermo-electric solutions also enable to **maximise the use of low-temperature RES and waste heat** as discussed in KSF 6.

Figure 115: Heat pumps in Taarnby DHC network (source: Taarnby Forsyning)

KSF 8: Sector integration[105]

Synergies with other networks (electricity, gas, water) and **urban infrastructure** (e.g. wastewater treatment plants, data centres, underground railway, etc.) are developed and create value for the community through increased efficiency (e.g. waste heat recovery) and flexibility (e.g. balancing services).

Target audience	Impact on DHC project life cycle
• National and local authorities • DHC operators • Urban infrastructure operators	• Initial feasibility of the project • Long-term security of supply • Long-term economic equilibrium

Key facts and examples from case studies

- Sector integration aims at **increasing the efficiency and flexibility of energy systems by integrating different energy carriers**, while remaining resource efficient and avoiding pollution and biodiversity loss. While models of separate silos have proved their limits, sector integration improves resilience and security of supply of energy systems, and strongly supports local circular energy and deep decarbonisation.

- As illustrated by several case studies, **DHC systems constitute ideal backbones for sector integration**: interconnection of several DHC networks (e.g. Taarnby), waste heat recovery from different infrastructures (e.g. waste treatment plant in Barcelona, industrial plant in Milan and HafenCity, wastewater in Taarnby), balancing services for the electricity grid (like in Jaegerspris), new use for closed coal mines (Mieres), etc. Besides, urban infrastructures shall also been considered as potential heat and cold consumers.

- DHC systems' development has also obvious **mutual impacts with the evolution of gas and electricity grids and with building refurbishment programmes**, and should be planned accordingly in a coordinated manner (cf. KSF 4 and 5).

- Again, **digitalisation** supports energy system integration: it enables dynamic and interlinked flows of energy carriers, allows for more diverse markets to be connected with another, and integrates real-time and forecasted data to match supply and demand at a more disaggregated level.

- The implementation of sector integration implies a **holistic approach for both large-scale and local infrastructure planning** (discussed in KSF 4).

Potential drivers	Potential barriers
• Guidelines made at the European level • Local urban development plan implementing this holistic approach (KSF 4) • Increasing awareness of the urban infrastructure on the opportunities brought by DHC systems (energy efficiency and extra-revenues)	• Planning mismatch between these heavy and long-term planned infrastructures • Technical complexity to optimize and operate the system • Financial barriers to undertake the needed investments

Replicability

- This KSF relies mostly on best-practices and should be **mostly replicable** in any country.

- The particular link with **gas and electricity grids** is not directly replicable from one country to another as the modalities to implement such synergies will significantly depend on the corresponding market and regulations (fiscal incentives or burdens, openness to competition…).

Impact on the integration of renewables and waste heat/cold sources in DHC

- Sector integration through DHC systems is a **great opportunity to maximise the use of various local waste energy sources** (from power plants, industrial plants, tertiary buildings, underground, data centres, electrical substations…).

- It also enables to integrate **intermittent renewable electricity** (see KSF 7) and **biogas** through consistent and coordinated planning of the respective energy networks.

[105] European Commission (COM), *Powering a climate-neutral economy: An EU Strategy for Energy System Integration*, 2020

KSF 9: District cooling

District cooling provides DHC systems a clear competitive and operational advantage and enables their integration in urban energy systems in the long term. It also allows to develop clear **synergies with district heating and possibilities to decarbonize cooling supply**, enabling the integration of ambient energy and waste energy sources otherwise not used.

Target audience	Impact on DHC project life cycle
• Policy makers • Local authorities • Housing and urban development agencies • Real estate developers • DHC operators	• Initial feasibility of the project • Contracting with clients

Key facts and examples from case studies

- Concerns on the **increasing cooling demand** worldwide have raised significantly over the last decade (cf. Figure 116). However, the opportunities for decarbonization and energy efficiency brought by DC are still not well known by policy makers and end-users (consumers), and individual solutions at building level (refrigeration compressors and dry coolers) remain the norm in Europe.

- DC is still at an early stage of development, but **some cities like Paris or Barcelona have started integrating cooling in their energy planning and urban regulations.** Besides, increasing levels of energy efficiency in building are also **increasing air quality standards**, making it mandatory to integrate cooling (e.g. new hotels and offices in Denmark).

- On top of being competitive for clients having a baseload cooling demand, DC presents **many benefits** when compared to individual solutions: cost reduction due to optimization of the installed capacity thanks to the simultaneity factor and economies of scale, space saving (which is often important in dense urban areas), possibility to **integrate ambient and waste energy sources** (water bodies, LNG terminals, laboratories, waste heat sources…), possibility to integrate **flexible (smart) solutions** responding to electricity signals (e.g. storage), reduction of urban heat island effect (even more when this is caused by AC systems), noise reduction, simpler operation and maintenance, reduction of the risk of legionellosis…

- **Synergies between DC and DH are numerous** and contribute to the development of these efficient systems: higher overall energy efficiency, pooling of civil works, use of the available heat in summer to produce cold through absorption or adsorption machines like in Barcelona, combined production of heating and cooling with excess heat and cold recovery like in Milan (showing high COP values)… These synergies are maximised when combined with seasonal storage (e.g. ATES in Taarnby, with a COP of 5.6) or mid-temperature loops (e.g. Paris Saclay), and when introduced reinforce the competitiveness of the initial DH solution.

Potential drivers	Potential barriers
• Guidelines made at the European level to consider DC as an energy efficiency measure • National and local political willingness for higher support to DC (KSF 1 and 3) • Established DH markets • Urban development plan integrating cooling (KSF 4) • Continuous development of technologies (e.g. heat pumps) to increase efficiency and environmental impact (types of refrigerant)	• Limited competencies at municipal level (energy and urban planning services) • Limited knowledge on cooling demand • Lobbying from existing alternative solutions • Competitiveness of DC which requires a pool of clients (often tertiary buildings) with baseload cooling demand (ca. 3-5 MW) and located in a limited area

Replicability
• The development of DC is obviously related to local weather conditions, but potentials exist in any country for tertiary and industrial needs at least (Sweden being the undisputed leader today in terms of installed capacity). Therefore, as this KSF relies mostly on best-practices, it should be **replicable to some extent** in any country.

Impact on the integration of renewables and waste heat/cold sources in DHC
• The role that will be played by the RES and waste energy sources in the huge development potential of DC is crucial. • DC can be fuelled by **green electricity** and act as another key player of the electricity grid stability by providing balancing services (discussed in KSF 7), especially when coupled with **thermal storage** infrastructures (like in the Barcelona or Taarnby). • As discussed earlier, DC can also be fuelled by **various RES or waste heat sources** (like in Paris-Saclay and Taarnby), increasing the opportunities for their integration in efficient systems (especially for low-temperature energy sources). Again, **short-term or seasonal thermal storage systems** (like ATES[106]) increase this integration by enhancing the match between the energy supply and demand.

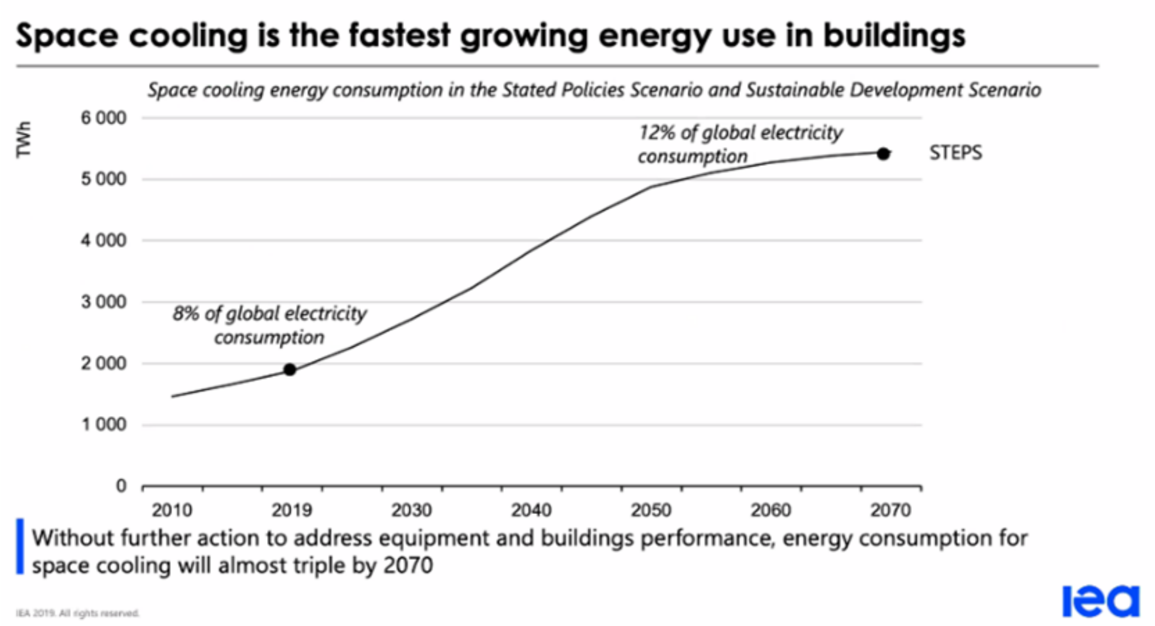


Figure 116: Space cooling world demand increase in buildings (source: IEA)

[106] Aquifer Thermal Energy Storage

KSF 10: Adaptability and continuous optimisation

Flexible strategies allow a better integration of the various RES and waste energy sources available and a better integration of the different buildings prospected through time. This can be achieved through modular architecture of the DHC network or heat cascading e.g.

Target audience	Impact on DHC project life cycle
• Local authorities • Housing and urban development agencies • DHC operators	• Whole project life cycle

Key facts and examples from case studies

- While DHC systems usually rely on heavy infrastructure, built in the public domain and based on long-term depreciation periods, they must be **designed from the beginning according to a flexible strategy** enabling the integration of new energy sources (e.g. new and more competitive waste-to-energy plant like in Vilnius), new technologies (e.g. solar, heat pumps, electric boilers…) and new or refurbished urban districts with lower temperature regimes, particularly adapted to low-temperature RES and waste energy sources (like in Milan).

- The establishment of a **long-term planning** built in concertation with local authorities, housing and urban development agencies, and other possible stakeholders from which synergies could emerge (e.g. waste and wastewater treatment plants) is key to anticipate the future evolution of the DHC network.

- Flexibility can be achieved in several ways:
    - **modular network architecture** like the mid-temperature loop with decentralised substations equipped with complementary production units in Paris-Saclay (particularly adapted to new districts),
    - **heat cascading** (e.g. returns from high temperature network feeding a low temperature network) like in Milan or Mieres,
    - **mobile heating and cooling units** to accommodate temporarily a demand increase like in Taarnby (particularly useful in ramp-up phase),
    - minimization of the **simultaneity factor** by mixing the buildings profiles (Taarnby).

- This smart and flexible approach requires **continuous optimisation** that is usually semi-automatized thanks to digital tools (continuously improved through data acquisition and analysis) as well as real-time monitoring and proactivity from the DHC operator teams.

Potential drivers	Potential barriers
• Long-term and integrated urban development strategy (KSF 4) • Policy and regulatory incentives for DHC decarbonisation (KSF 1) • Commitment of the various stakeholders (KSF 3) • Resulting optimization of the cost	• Technical complexity to optimize and operate the system • Lack of coordination between the different stakeholders

Replicability

- This KSF relies mostly on best-practices and should be **easily replicable** in any country.

Impact on the integration of renewables and waste heat/cold sources in DHC

- Such flexible strategy and research for continuous optimization pave the way to the evolution toward new generation DHC networks[107], where **RES and waste energy sources are at the heart of sober and efficient energy systems based on low operating temperatures, energy storage and sector integration**.

[107] See definitions in https://www.4dh.eu/about-4dh/4gdh-definition

6. Conclusion and Recommendations

There is no energy transition without a heating and cooling transition, and modern DHC systems have a key role to play in decarbonising H&C in a cost-effective way. H&C represents around 50% of the EU energy consumption, and is still dominated by fossil fuels[108]. The situation is however different across Member States, and those having achieved already a mostly decarbonised H&C supply, are also countries where DHC presents a strong market position, mostly based on RES and waste heat and cold sources (cf. Figure 117 left graph), acting as a backbone for local energy strategies.

Despite a growing policy awareness on the importance of decarbonising H&C to meet the common climate objectives, evidence shows an acceleration is needed. During the last decades, energy transition policies in most of the EU Member States have focused on renewable electricity, sometimes leaving H&C almost unaddressed. More focused and comprehensive H&C policy measures are needed, addressing simultaneously energy efficiency, integration of RES and waste energy sources and sector integration in a cost-effective, socially just and inclusive manner. The current progress done in renewable electricity production is an asset, as this electricity is already being used for H&C through individual heat pumps or DHC.

The key role that DHC systems can play in the efficient integration of a wide range of RES and waste heat and cold sources is still not sufficiently recognised, especially in less mature DHC markets. While biomass remains the main RES used in DH, an increasing number of DHC systems are integrating other local RES (e.g. geothermal, solar, or ambient energy), and waste (excess) energies that otherwise would be untapped (waste heat from industries, data centres, supermarkets…). Besides, through the use of large heat pumps and electric boilers coupled with thermal storage, DHC systems also enable the use of intermittent renewable electricity for H&C and the provision of balancing services to the electricity grid in a cost-effective manner. This type of **smart sector integration** approaches is spreading in some countries like Denmark or Sweden, and could be replicated in others, especially those with highest renewable share in electricity (cf. Figure 117 right graph).

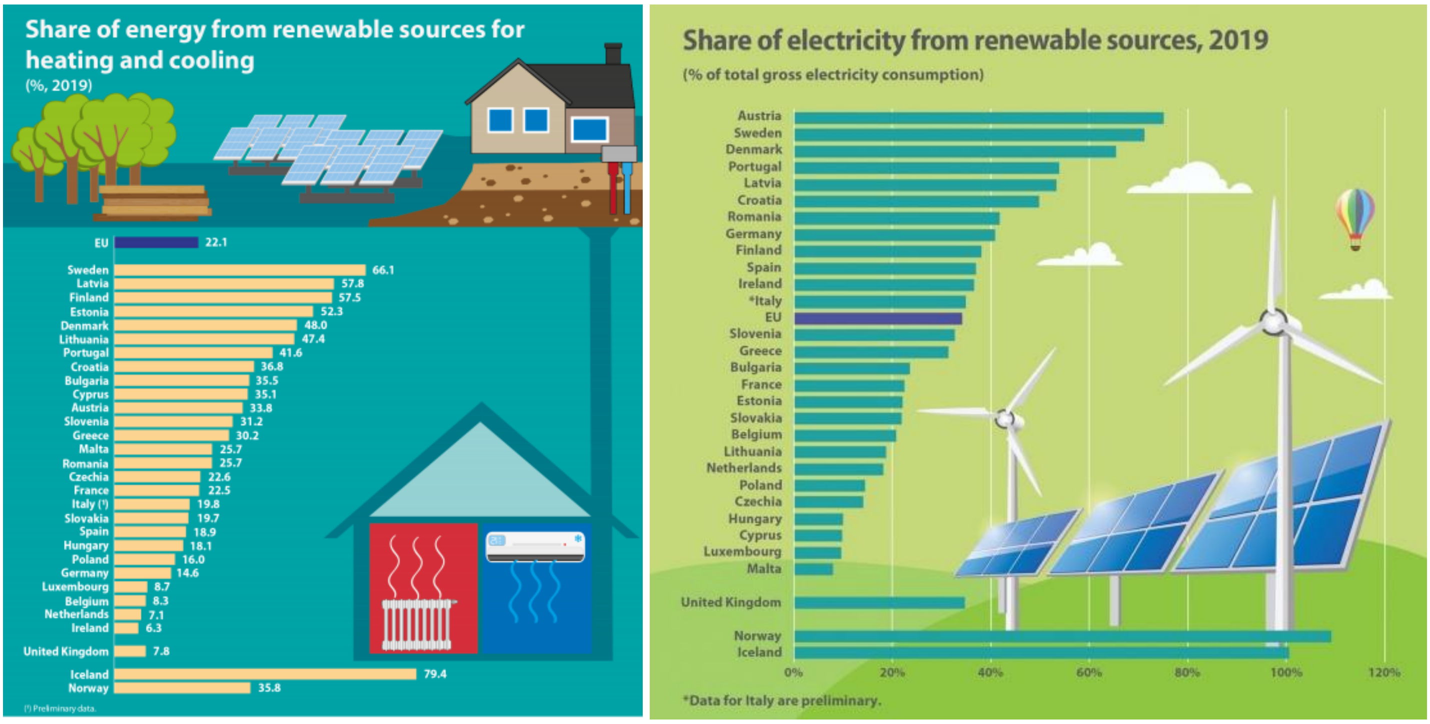


Figure 117: Member States starting point with regards to RES in H&C (left) and in electricity production (right) (source: Eurostat)

[108] According to 2018 figures from Eurostat, 75% of heating and cooling is still generated from fossil fuels while only 19% is generated from renewable energy. Preliminary data from 2019 shows a similar trend.

In this context of increasing, but still insufficient public and policy awareness on the multiple benefits of the deployment of efficient DHC systems using RES and waste heat and cold energy sources, **bottom-up approaches like case study analyses can feed the discussions with concrete, operational examples of best practices** on H&C decarbonisation through DHC.

The analysis of the 8 case studies presented before allows to shed light on some **key features, replicable by policy makers, DHC operators, municipalities, urban planners, and other key stakeholders**, that could foster H&C decarbonisation through efficient DHC networks.

6.1 Accelerating the integration of RES and waste energy sources in DHC through a comprehensive and coherent set of policies and support schemes

Achieving in-depth decarbonisation will require reaching climate targets across all sectors in a coordinated manner at all policy levels, namely EU, national, regional and local, **as well as support schemes driving investments in this direction.** The holistic approach needed to meet the EU Green Deal objectives will require further cooperation, valuing synergies at district and municipal levels and addressing existing incoherencies and barriers.

While an increasing number of countries and communities are setting ambitious **objectives for H&C decarbonisation**, operational details on how this will be done are often unclear, and the role that DHC could play in increasing the use of RES and waste energy sources is still largely underestimated, especially in countries with an emerging DHC market. In most EU countries, further efforts are required at all levels to **increase the awareness on the multiple benefits of DHC**, to improve transparency and consumer protection in the H&C market, and to prepare a detailed plan to **progressively phase out fossil fuels while assuring affordability and cost-efficiency**.

Numerous barriers remain for decarbonisation through DHC. **Urban planning** does not systematically include energy planning, **building codes** in several countries are still penalising efficient DHC with respect to its alternatives (e.g. with PEF equivalent to fossil fuels in some countries, or higher than individual heat pumps), **waste heat and cold sources** are not always considered as "renewable" in funding programmes or other support schemes, and **smart sector integration through DHC** is in general not subject to reduced electricity taxes or smart electricity network tariffs recognising the flexibility of these systems, which can act as flexible consumers and provide balancing services to the electricity grid.

Besides, as market prices often do not reflect the numerous socio-economic benefits of DHC based on low-carbon fuels, **adequate and well-targeted financial support** is still needed to make DHC projects financially viable. Those socio-economic benefits are rarely quantified, but in countries like Denmark where this is mainstreamed, new DHC investments show a very high socio-economic rate of return (41% in Taarnby). Financial support could be indirect (environmental taxation, DH regulation…) or direct, for example through technical assistance and/or investment subsidies for municipalities, DHC operators and waste heat/cold suppliers. To ensure an **effective and efficient integration of low-carbon energy sources** (c.f. Section 6.4) while contributing to building-up the learning curve, investment subsidies could be conditioned to technical criteria and common procedures, as done in some countries (e.g. ADEME's Heat Fund in France).

6.2 Building a local and participative governance, based on cooperation and value-sharing

DHC developments are steered at local level, usually at a municipal or district scale. Even if national policies and regulations can strongly influence those developments, **municipalities appear as key change agents** for the integration of RES and waste energy sources through DHC. They can prioritize long-term and integrated approaches for urban planning, including energy planning, support DHC grids by connecting their public buildings, or participating in the utility's ownership, and facilitate cooperation between local actors and urban infrastructure.

Indeed, the analysed case studies showcase how **participatory approaches integrating all stakeholders** (city services, DHC operator, private actors including waste energy suppliers, end-users, citizens, national actors, etc.) **constitute a key success factor to maximise the overall efficiency of DHC developments and to foster local value creation** (reduced energy bill and CO_2 emissions, local job creation, return on investments for the utility and for the municipality...). Integrating participative schemes, like citizen **energy communities**, fosters transparency, value-sharing with consumers, and cost-efficiency. **New forms of public-private cooperation** can also further empower communities and DHC operators, bringing up-to-date industry knowledge and additional resources to ensure the highest economic and environmental performance.

Digital solutions also contribute to empowering consumers, e.g. through smart meters, which can raise consumer awareness on energy consumption patterns and enable tariffs incentivising DHC system efficiency (cf. Section 6.5).

6.3 Applying the energy-efficiency-first principle across sectors, to move towards more integrated energy systems

When developing integrated and long-term urban strategies for local decarbonisation, **the "energy-efficiency-first" principle should apply**, ensuring only the needed energy is produced. **Comprehensive heating and cooling planning** usually builds on 3 main pillars:

- Performing an exhaustive analysis of the building stock and the **demand**;
- Designing an **optimal energy supply**, based on RES and waste heat/cold sources (often DHC appears as the optimal solution for such integrated approaches in urban areas);
- **Integrating energy efficiency measures on the demand and supply sides into the different documents within an urban development project** (e.g., building refurbishment measures, technical characteristics for new buildings, or obligation to connect within certain conditions as part of the permit procedures).

Potential **synergies between DHC and other urban infrastructure** must be continuously sought and prioritised. For instance, the analysed case studies value **waste energy** from local industries, wastewater treatment plants, power plants, waste incinerators, data centres, laboratories, and ambient energy from the air and water bodies. All this **potential would remain untapped if DHC grids had not been there**. Underground railways and tertiary buildings are also promising sources of waste energy for DHC grids. Other potential synergies include the use of biogas from **agricultural activities**, especially in rural areas, the synergies with the **electricity grids** mentioned before, or the use of geothermal energy from **closed coal mines** like in Mieres, showcasing how DHC could contribute to coal regions in transition. Besides, urban infrastructures shall be considered as potential H&C consumers.

Buildings are also an integral part of DHC systems, and directly impact their deployment and performance. Indeed, the **DHC-building nexus** is large: **heat emitters** must be compatible with DHC for a building to connect (e.g. central heating with same temperature regime) and the energy performance of buildings influences the efficiency of the DHC systems (e.g. higher **return temperatures** in DH result in poorer DHC performance). In order to integrate a higher share of RES and waste energy sources, **low-temperature technologies should be encouraged in heat emitters**, and energy renovation of buildings should also address supply optimisation aiming at higher integration of efficient technologies and low-carbon fuels, as well as smart solutions enabling further system optimisation, including valorising synergies and economies of scale at district level.

6.4 Making the right technology choices to progressively integrate low-carbon energy sources and district cooling

Today, it is possible to mobilize a **large spectrum of RES and waste energy sources in DHC**. This has been enabled, for instance, by the development of new technologies (e.g. heat pumps with high/low temperature levels), the operational experience gained through the last decades, and the building stock refurbishment involving more efficient heating equipment (e.g. low-temperature heat emitters).

However, **understanding and forecasting the key technical features of those energy sources** (capacity, temperature levels, production profile and availability…), which often vary significantly from one source to another, and **assessing their compatibility with the DHC network and connected buildings** in the frame of an operational energy planning study is key to integrate them and to develop reliable, flexible and cost-efficient DHC systems.

Moreover, the case studies analysed demonstrate that **DHC systems are evolutive systems, which can integrate technologies as they develop, and value previously untapped sustainable energy sources** (e.g. ambient energy or waste heat/cold) if a comprehensive planning following the principles just mentioned is undertaken. While the creation of DHC grids can be the outcome of different national and local situations (e.g., national heat planning strategy in Denmark in the 1980s, creation of new eco-districts in Barcelona, Hamburg or Paris-Saclay, or the existence of a closed coal mine in Mieres), more mature markets like Denmark or Sweden show how these grids evolve towards higher flexibility in demand and supply, introducing smart sector integration solutions and district cooling, as relevant. In those mature markets, increasing energy efficiency levels in buildings has therefore resulted in increased DHC system efficiency, in order to remain competitive against its alternatives.

As cooling demand rapidly increases, mainly addressed through individual AC solutions and resulting in significant negative climate impacts, the key role of **district cooling must gain higher visibility at policy level** (lower environmental impacts than individual solutions, higher energy efficiency, enhanced flexibility for the electricity grid, reduced urban heat island effect…). **For DH operators, DC can be seen as a source of energy efficiency, a way to strengthen their offer and remain competitive against individual heat pumps, and a new source of revenues** in the context of decreasing heating consumption.

6.5 Creating a robust business case for modern and evolutive DHC systems

Taking into account the guiding principles above, a DHC project sponsor should have the main ingredients for a successful project addressing H&C decarbonisation through DHC. However, **this needs to be reflected in a robust and viable business model**, allowing to undertake the required investments.

Selecting the most appropriate governance model, carrying out the in-depth energy planning exercise identifying the optimal DHC solution, mobilising the required stakeholders and funding needs, and organising the procurement and construction of the network is a long process that lasts several years, and **requires a wide range of**

expertise (technical, economical, organisational, operational, legal, financial…). When it does not exist in-house, public-private cooperation schemes as well as technical assistance are relevant and useful.

Innovative tariff structures, reflecting to the extent possible the network costs and their evolution through time, and **encouraging consumers to contribute to the overall system efficiency** (e.g. through bonus/malus tariffs to optimise return temperatures, or through seasonal tariffs), are expected to spread across modern DHC systems in the coming years.

Finally, the increasing trend of **participative and inclusive approaches including energy communities**, resulting in a more balanced share of costs and benefits across actors, and higher transparency standards, will probably also become a pillar of new business models for modern DHC.

7. Annexes

7.1 ANNEX 1 Country Profile: DENMARK

Country Profile **Denmark**

Summary

Population (2018) : 5,797,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 3,054
Average cooling degree days (2014-2018) : 3 *source: Eurostat*

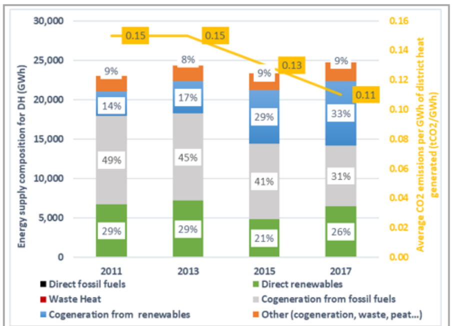
Main sources:
- Euroheat & Power, Country by Country 2019 (link)
- International Energy Agency, 2017 Denmark Review

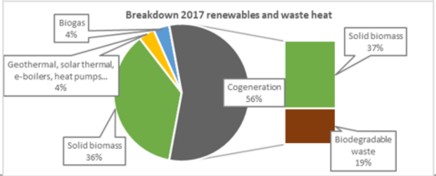
District Heating (2017)
- 400 DH systems
- 30,391 GWh sold to customers
- Dominant source of heating, 64% of residential sector
- Competition with individual gas boilers and heat pumps in rural areas
- Competitive prices ensured through heat planning procedure
- High implication from customers

District Cooling (2017)
- 5 km of DC systems
- 4,147 MWh sold to customers
- High demand, growing

District Heating: 60% from renewable sources and waste heat (2017)

Energy supply composition for DH





Key figures

Key figures	In 2017	Since 2015
Heating degree days	3,117	➡ 0%
Market share of district heating in the total heat market in residential sector	64%	↗ +1%
Total installed DH capacity (MWth)	N.a.	N.a.
Trench length of DH pipeline system (km)	30,800	➡ 0%
Number of district heating systems	400	➡ 0%
Number of citizens served by DH	3,647,000	↗ +3%
Total DH sales to customers (GWh)	30,391	↗ +4%
Average nominal DH price (Euro/MWh) (excl VAT)	79	↘ -1%
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	57	↘ -4%

Key actors

Ownership (in terms of number, 2019)	• Municipality owned companies (60%) • Consumer-owned cooperatives (35%) • Private companies (5%)
Main operators	• Municipality owned companies: HOFOR, AffaldVarme Aarhus, VEKS, Fjernvarme fyn, Aalborg, TVIS, Vestforbraending
DH association	• Danish District Heating Association (*Dansk Fjernvarme*)
Regulator / Supervision authority	• Danish Utility Regulator (*Forsyningstilsynet*) • Other authorities: Energy Supplies Complaint Board (*Ankenævnet på Energiområdet*): issues complaints not regulated by the heat supply act
Role of municipalities	• Main owners and operators • Develop and review the local heat plans, approve new projects when they have the highest socioeconomic benefits
Other actors	• Danish Energy Agency • State of Green: exports Danish green solutions around the world including DHC • Danish Board of District Heating (DBDH): promotes DH and facilitates partnership between members
CHP and RES support schemes	• Electricity production subsidy for CHP using RES • Direct premium tariff for use of biogas • RES exempt from fossil energy taxes
Taxes and tax exemptions for DHC	• Fossil energy tax on fossil fuels and electricity • Pollutants taxes (CO2, NOx, SO2) on fossil fuels, wood and straw • Environmental taxes
Available funding for DHC	• Morgage type low interest rate loans • Investment subsidies for connection to DH

Regulation and incentives

Market	• Regulated • Non-for-profit principle • Main clients (in terms of sales, 2017): 65% residential, 30% tertiary, 5% industrial
National energy and climate strategy (2018)	• Net zero emissions by 2050 • Independant of fossil fuel by 2050
Key policies	• Heat Supply Act (1979) • Local heat plannings as part of urban planning • Energy Savings Obligation Scheme (2006)
Building and urban regulations	• Danish Building Regulations 2018 (*BR18*) • The municipalities could until 2018 choose to oblige or not the connection to DH through the local heat planning (zoning)

District Cooling

Key figures	In 2017	Since 2015
Cooling degree days	0	↘ -100%
Total installed DC capacity (MWth)	22	N.a.
Trench length of DC pipeline system (km)	5	N.a.
Number of DC systems	N.a.	N.a.
Total DC sales to customers (MWh)	4,147	↗ +64%
Average nominal DC price (euro/MWh)	N.a.	N.a.
Average CO2 emissions (kg/kWh)	N.a.	N.a.

Main technologies used
- Free cooling
- Compression chilling
- Heat pumps
- Absorption cooling

Objectives
- No DC objectives in the national energy strategy

Key actors
- Mainly owned and operated by municipalities

Key policies
- District Cooling Act (2008)

Market
- No specific regulation, business-to-business approach
- 58 customers, mainly tertiary

Incentives
- Investments by municipalities

7.2 ANNEX 2 Country Profile: FRANCE

Country Profile **France**

Summary

Population (2018) : 66,966,000 inhabitants	*source: World Bank*
Average heating degree days (2014-2018) : 2,252 Average cooling degree days (2014-2018) : 54	*source: Eurostat*

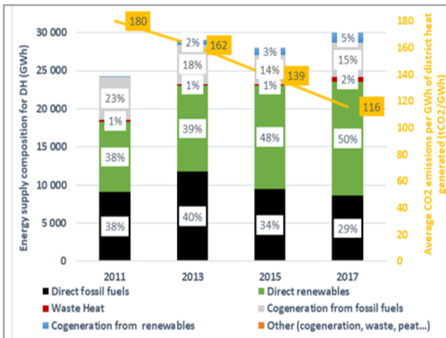
Main sources:
- SNCU annual DHC survey (link)
- Euroheat & Power, Country by Country 2019 (link)
- ADEME

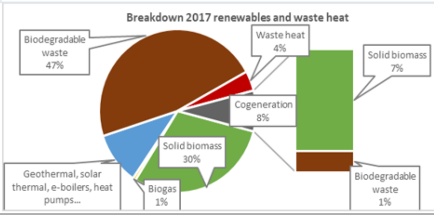
District Heating (2017)
- 761 DH systems
- 25,078 GWh sold to customers
- Fast development and high objectives in terms of RES integration Multiple incentives going from tax incentives to subsidies (Heat Fund or certificates for Energy Savings)

District Cooling (2017)
- 23 DC systems
- 980 GWh sold to customers
- One of the first european countries in terms of sales.
- Strong development due to high cooling demand

District Heating: 56% from renewable sources and waste heat (2017)

Energy supply composition for DH





Key figures	In 2017	Since 2015
Heating degree days	2,338	+4%
Market share of district heating in the total heat market in residential sector	5%	0%
Total installed DH capacity (MWth)	24,707	+11%
Trench length of DH pipeline system (km)	5,397	+14%
Number of district heating systems	761	+20%
Number of citizens served by DH	5,424,000	+6%
Total DH sales to customers (GWh)	25,078	+10%
Average nominal DH price (Euro/MWh) (excl VAT)	70	+4%
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	65	0%

Key actors

Ownership (In terms of sales, 2018)	• 89% Public: 7% direct management, 82% concession • 11% Private
Main operators (In terms of turnover, 2017)	• Dalkia (44%), Engie réseaux (22%), Engie Cofely (11%), Coriance (7%), Idex (7%)
DH association	• National district heating association (*SNCU*) • Member of the Fedene (*Fédération des Services Energie Environnement*)
Regulator / Supervision authority	• DHC is not a regulated activity in France • Other authorities: French national competition authority, DGCCRF (*Direction générale de la concurrence, de la consommation et de la répression des fraudes*)
Role of municipalities	• Responsible of the public distribution of heat • Owner of most of the networks
Other actors	• Agency for Environment and Energy Management (*ADEME*): provides funding through the Heat Fund

Regulation and incentives

Market	• Not regulated market • Main clients (in terms of sales, 2018): 54% residential, 33% tertiary, 5% industrial, 8% others
National energy and climate strategy	• Energy Transition Act (*LTECV*), 2015: Multiplication by 5 of the sales of district heat from RES and waste heat sources between 2012 and 2030 • PPE, 2019 : 65% RES and waste heat in DH in 2030
Key policies	• No policies specific to DH
Building and urban regulations	• New and renovated buildings within a "classified area" (zoning) are obliged to be connected to DH • Costs related to the connection to DH, and related expenses, borne by the end consumer • Thermal regulation for building (*RT2012*): provides a construction bonus for virtuous DH networks

CHP and RES support schemes	• Heat Fund (*Fonds Chaleur*): supports production from RES and waste heat sources • Support scheme for CHP: obligation to purchase electricity produced, could be stopped for the natural gas CHP (ongoing discussion). • White certificates: finances energy saving actions (e.g. pipe insulation, connection of buildings to a DH network using RES, changing current networks to low temperature heating systems)
Taxes and tax exemptions	• Reduced VAT rate for DH networks using at least 50% of RES and waste heat sources (5.5% instead of 20%)
Available funding for DHC	• Heat Fund (*Fonds Chaleur*) for DH networks using at least 50% of RES and waste heat sources

District Cooling

Key figures	In 2017	Since 2015
Cooling degree days	66	- 13%
Total installed DC capacity (MWth)	761	-2%
Trench length of DC pipeline system (km)	198	+8%
Number of DC systems	23	+15%
Total DC sales to customers (MWh)	980,000	+5%
Average nominal DC price (euro/Mwh)	139.5	N.a.
Average CO2 emisions (kg/kWh)	0.011	N.a.

Key actors
- Municipalities and regional authorities own most of the networks
- Ownership in terms of sales, 2018: 78% public (concession), 22% private

Market
- Clients repartition in terms of sales, 2018: 94% tertiary, 4% industrial, 2% residential

Main technologies used (in terms of sales, 2017)
- Compression chilling (96%)
- Heat pump (2%)
- Free cooling (2%)

Objectives
- Multiplication by 5 of the sales of DHC from RES and waste heat sources between 2012 and 2030 (*LTECV*)
- Multiplication of DC deliveries by 3 to 2030

Key policies
- No policies specific to DC

Incentives
- Scheme of Energy Savings Certificates
- Since 2018, eligible for the Heat Fund for the creation of networks with cold substations linked to new renewable cold production

7.3 ANNEX 3 Country Profile: SPAIN

Annexe : Country Profile **Spain**

Summary

Population (2018) : 46,724,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 1,667
Average cooling degree days (2014-2018) : 256 *source: Eurostat*

Main sources:
- Euroheat & Power, Country by Country 2019 (link)
- National District Heating Association ADHAC (link)

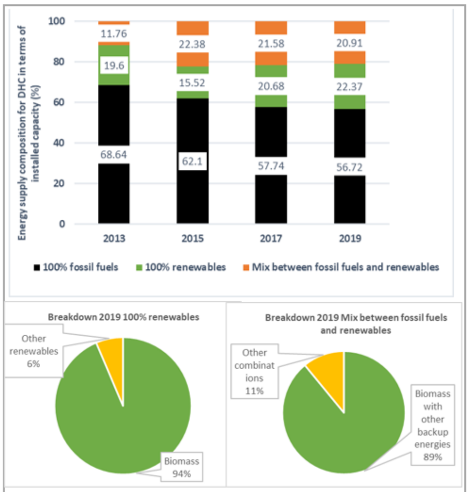
District Heating (2019)

- 410 DH systems
- Installed capacity of 1,182 MW
- DH represents ca. 1% of the total heat market, which is dominated by individual heating systems (mainly gas)
- Emerging market

District Cooling (2019)
- 40 DHC systems incuding 4 DC (only cooling)
- 394 MW of installed capacity
- Emerging market

District Heating: 41% from renewable sources (2019)

Energy supply composition for DH (installed capacity)*



* Data in terms of energy sales are not available

CO2 emissions avoided by DHC are estimated at 303,493 t/year in 2019

Regulation and incentives

Market	• Not regulated market • Main clients (in terms of sales, 2017): 33% residential, 49% tertiary, 18% industrial
National energy and climate strategy (2019)	• Draft National Energy and Climate Plan: all buildings free of CO2 emissions by 2050, 42% RES in final energy consumption by2030
Key policies	• National Energy Efficiency Plan 2017-2020 • National Sustainable Energy Plan 2011-2020
Building and urban regulations	• Regulation of Thermal Installations in Buildings (2007): obligation to analyse the possibility of connection to DH for every new building over 1 000 m²

Key figures	In 2017	Since 2015
Heating degree days	1,598	-3%
Market share of district heating in the total heat market	<1%	N.a.
Total installed DH capacity (MWth) in 2019	1,182	+44%
Trench length of DHC pipeline system (km) in 2018	680	+55%
Number of district heating systems in 2019	410	+63%
Number of citizens served by DH	117,550	N.a.
Total DHC sales to customers (GWh)	1,102	+65%
Average nominal DH price (Euro/MWh) (excl VAT)	54	N.a.
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	58	N.a.

Key actors

Ownership (in terms of capacity, 2019)	• Public-Private Partnership (PPP) (33%) • Private (35%) • Public (32%)
Main operators	• Veolia, Engie, San José, Sacyr, REBI, Hunosa, Ferroser
DH association	• Asociación de Empresas de Redes de Calor y Frío (*ADHAC*)
Regulator / Supervision authority	• DHC is not a regulated activity in Spain • Other authorities: National Commission on Markets and Competition (*CNMC*)
Role of municipalities	• Support DH through urban and energy strategies, connexion of public buildings
Other actors	• Institute for the Diversification and Saving of Energy (*IDAE*): informs about DH, proposes training activities and funding for innovative projects

CHP and RES support schemes	• Premium tariff scheme for CHP electricity • IDAE aid programs • Guarantees of Origin for renewable electricity • Obligation for new industrial plants or DH network with a capacity over 20MW to analyse the possibility of CHP
Available funding for DHC	• European structural funds (ERDF) • IDAE aid programs
Other incentives	• CO2 savings showed in building energy labelling

District Cooling

Key figures	In 2017	Since 2015
Cooling degree days	307	+7%
Total installed DC capacity (MWth) in 2019	394	+5%
Trench length of DC pipeline system (km)	Taken into account in DH figures	N.a.
Number of DC systems in 2019	40	+24%
Total DC sales to customers (MWh)	Taken into account in DH figures	N.a.
Average nominal DC price (euro/MWh)	38	N.a.
Average CO2 emissions (kg/kWh)	N.a.	N.a.

Key actors
- In general same actors as DH
- Main operators : Veolia, Engie Cofely

Market
- Main clients (in terms of number, 2012): 63% tertiary, 28% residential, 9% industrial

Main technologies used
- Compression chilling
- Free cooling
- Heat pumps
- Solar cooling

Objectives
- No DC objectives in the national energy strategy

Key policies
- National Energy Efficiency Plan 2017-2020
- National Sustainable Energy Plan 2011-2020
- Draft National Energy and Climate Plan (2019)

Incentives
- IDAE funds
- European funds

7.4 ANNEX 4 Country Profile: GERMANY

Annexe : Country Profile **Germany**

Summary

Population (2018) : 82,928,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 2,863
Average cooling degree days (2014-2018) : 28 *source: Eurostat*

Main sources:

- Euroheat & Power, Country by Country 2019 (link)
- International Energy Agency, 2020 Germany Energy Policy Review
- German energy efficiency association for heating, cooling and CHP, Main report 2018 (Link)
- German Association of Energy and Water Industries BDEW (Link)

District Heating (2017)

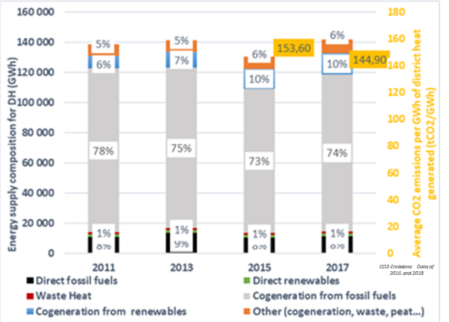
- 1,454 DH systems
- 121,000 GWh sold to customers
- 84% of the heat supplied by high efficient CHP plants
- Strong legal framework
- Strong pression for natural gas and oil heating systems supported in some states (Länder) by regional laws
- Competitive prices

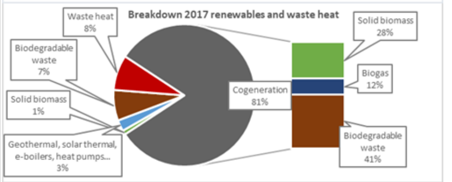
District Cooling

- 76 km of DC systems
- 291,111 MWh sold to customers
- Limited cooling demand

District Heating: 12% from renewable sources and waste heat (2017)

Energy supply composition for DH





Regulation and incentives

Market	• Liberalised in 1998 • DHC Main clients (in terms of sales, 2020): 41% residential, 38% industrial, 21% tertiary
National energy and climate strategy (2016)	• Reduction of 80% to 95% CO2 emissions by 2050 • 60% RES in gross final energy consumption • 120 TWh of electricity produced from CHP by 2025 • Climate-neutral building stock by 2050
Key policies	• Combined Heat and Power Act 2017 (*KWKG*), Update 2020 • Ordinance on general conditions for the supply of District Heating 1980 (*AVBFernwärmeV*) • Act on granting priority to renewable energy sources 2017 (*EEG*) • Local strategies in some states (Länder): can impose a mandatory connection
Building and urban regulations	• Building Energy Act (Gebäudeernergiegesetz GEG), 2020

Key figures

	In 2017	Since 2015
Heating degree days	2,964	+2%
Market share of district heating in the total heat market in residential sector	14%	+1%
Total installed DH capacity (MWth)	49,475	0%
Trench length of DH pipeline system (km)	21,610	+2%
Number of district heating systems	1,454	+6%
Number of citizens served by DH	12,338,611	+23%
Total DH sales to customers (GWh)	121,000	+4%
Average nominal DH price (Euro/MWh) (excl VAT)	72	-3%
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	70	-5%

Key actors

Ownership	• Public-Private Partnership (PPP) • Municipality owned • Citizen owned
Main operators and contractors	• Vattenfall, Stadtwerke München, Wärme Hamburg, MVV, EnBW, enercity AG • Dalkia, Engie, Getec
DH association	• Energy Efficiency Association for Heating, Cooling and CHP (*AGFW*)
Regulator / Supervision authority	• DHC is not a regulated activity in Germany • Other authorities: Federal Cartel Office (*Bundeskartellamt*), national competition authority
Role of municipal owned companies	• Main owners of CHP facilities and operators of DH systems • Can offer their utility services to other region of Germany • Can propose incentives through their local strategy

CHP and RES support schemes	• Feed-in premiums and tenders for renewable electricity • Market Incentive Programme (*MAP*) for renewable installations (funding explained below)
Taxes and tax exemptions	• Energy tax on fossil fuels • Environmental tax
Available funding for DHC	• Low interest rate loans and grants by the public bank KfW, through the MAP • Grants from the Federal Office for Economic Affairs and Export Control (*BAFA*), through the MAP • Heating Network Systems 4.0 Programme for DH covering 50% of the annual consumption with RES with low temperature

District Cooling

Key figures

	In 2017	Since 2015
Cooling degree days	9	-84%
Total installed DC capacity (MWth)	266	+23%
Trench length of DC pipeline system (km) *in 2018*	79	+30%
Number of DC systems *in 2018*	37	N.a.
Total DC sales to customers (MWh)	291,111	+6%
Average nominal DC price (euro/MWh)	N.a.	N.a.
Average CO2 emissions (kg/kWh)	N.a.	N.a.

Key actors

- Same actors as DH

Market

- Same market as DH

Main technologies used (in terms of number of production plants, 2018)

- Compression chilling (64%)
- Absorption cooling (36%)

Objectives

- No DC objectives in the national energy strategy

Key policies

- Same legal framework as DH

Incentives

- No strategy specific to DC

7.5 ANNEX 5 Country Profile: LITHUANIA

Annexe : Country Profile **Lithuania**

Summary

Population (2018) : 2,790,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 3,696
Average cooling degree days (2014-2018) : 15 *source: Eurostat*

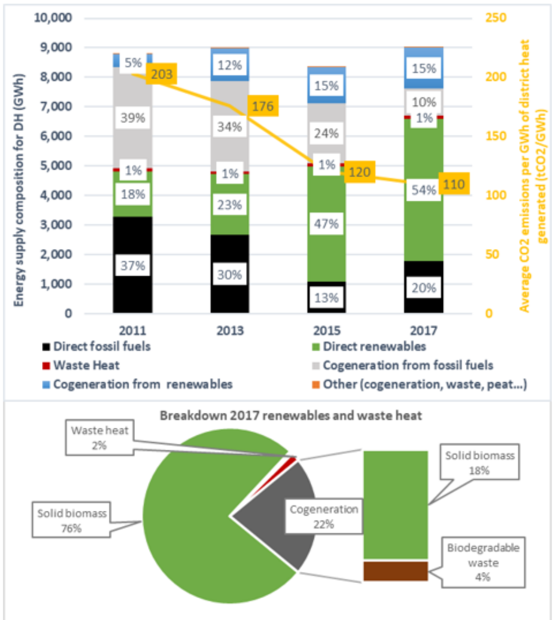
Main sources:
- Euroheat & Power, Country by Country 2019
- Lithuanian District Heating Association

District Heating (2017)
- 357 DH systems
- 7,609 GWh sold to customers
- 66% of the heat supplied by biomass. The price of biomass is 3 times less than the price of natural gas
- High average annual heat consumption in buildings

District Cooling (2017)
- DC is not yet developed
- Annual cooling demand estimated at 2-3 TWh

District Heating: 70% from renewable sources and waste heat (2017)

Energy supply composition for DH



Key figures	In 2017	Since 2015
Heating degree days	3,830	+8%
Market share of district heating in the total heat market in residential sector	56%	0%
Total installed DH capacity (MWth)	8,645	-15%
Trench length of DH pipeline system (km)	2,592	+2%
Number of district heating systems	357	0%
Number of citizens served by DH	1,630,000	+1%
Total DH sales to customers (GWh)	7,609	+10%
Average nominal DH price (Euro/MWh) (excl VAT)	48	-17%
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	80	-23%

Key actors

Ownership	• Municipalities
Main operators	• UAB Fortum, UAB Dalkia, AB Kauno energija, AB Panevėžio energija, UAB E energija, AB Vilniaus silumos tinklai
DH association	• Lithuanian District Heating Association (*Lietuvos šilumos tiekėjų asociacija*)
Regulator / Supervision authority	• National Energy Regulatory Council (*Valstybinė Energetikos Reguliavimo Taryba*) : regulates big heat supply companies • Municipalities : regulate smaller heat supply companies
Role of municipalities	• Own, regulate, develop local heat plannings, propose funds

Regulation and incentives

Market	• Regulated by the State • Main clients (in terms of sales, 2017): 73% residential, 14% industrial, 13% tertiary
National energy and climate strategy (2018)	• 100% RES for the production of all the country energy need by 2050 including in DH • 90% of buildings supplied by DH by 2050
Key policies	• Heat Law (2003) • National Heat Sector Development 2015-2021 Programme • Local heat plannings as part of urban planning
Building and urban regulations	• Building technical regulations (2015) • The municipalities can choose to oblige or not the connection to DH through the local heat planning (zoning)

CHP and RES support schemes	• Investments subsidies for biomass and biogas • Feed-in tariff for CHP with biomass and RES plants • Loans and subsidies for projects including RES through Climate Change Special Programme • Priority purchase of heat from RES
Taxes and tax exemptions for DHC	• Reduced VAT rate (9% instead of 21%) • Environmental pollution tax for fossil fuels
Available funding for DHC	• European structural funds (ERDF) • Compensation of payments for low-income families

District Cooling

There is no district cooling in Lithuania

7.6 ANNEX 6 Country Profile: ITALY

Annexe : Country Profile **Italy**

Summary

Population (2018) : 60,297,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 1,768
Average cooling degree days (2014-2018) : 232 *source: Eurostat*

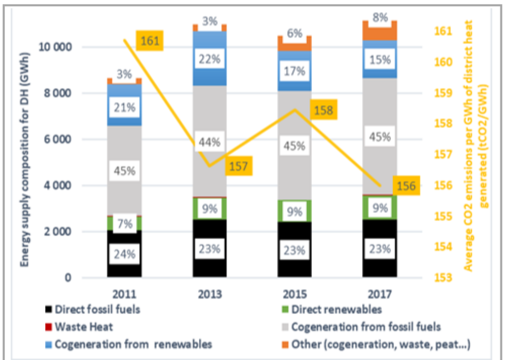
Main sources:
- Euroheat & Power, Country by Country 2019
- ARERA, ANNUAL REPORT 2019
- AIRU, Yearbook 2019

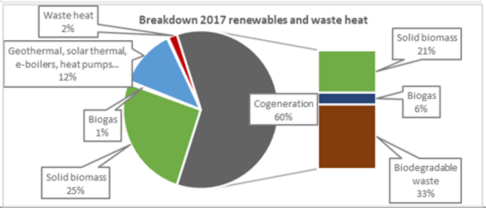
District Heating (2017)
- 338 DH systems
- 9,073 GWh sold to customers
- No particular regulation nor strong incentives for the development
- Emerging market, rapidly growing in the north of the country since 1972

District Cooling (2017)
- 204 MW of installed capacity
- 131 GWh sold to customers
- DC developments are mainly led by DH operators and linked to existing DH systems.

District Heating: 24% from renewable sources and waste heat (2017)

Energy supply composition for DH





Key figures	In 2017	Since 2015
Heating degree days	1,878	+4%
Market share of district heating in the total heat market in residential sector	3%	0%
Total installed DH capacity (MWth)	8,727	+2%
Trench length of DH pipeline system (km)	4,377	+7%
Number of district heating systems	338	+12%
Number of citizens served by DH	3,879,556	+6%
Total DH sales to customers (GWh)	9,073	+6%
Average nominal DH price (Euro/MWh) (excl VAT)	N.a.	N.a.
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	N.a.	N.a.

Key actors

Ownership	• Most of the systems were originally publicly owned • Newly developed systems are mostly privately owned and managed by the individual heat supply companies
Main operators	• A2A, IREN, HERA, EGEA
DH association	• *Associazione Italiana Riscaldamento Urbano (AIRU)*
Regulator / Supervision authority	• ARERA (*Autorita di Regolazione per Energia Reti e Ambiente*): defines the regulatory framework of DHC. It is focused on quality standards (technical and contractual guidelines) and market transparency (commercial processes). • Other authorities : AGCM (*Autorita Garante Della Concorrenza E Del Mercato*): national competition authority (independent from the government)
Role of municipalities	• No particular role • Set development strategies and rules followed by DHC operators

Regulation and incentives

Market	• Free market • Main clients (in terms of sales, 2017): 65% residential, 32% tertiary, 3% industrial
National energy and climate strategy (2017)	• 33% GHG emission reduction and 21.6% RES in the final energy consumption in 2050 • No specific objective is set for the development of DH but the Government is studying the potential for the next National Plan 2019-2021
Key policies	• Obligation for all municipalities above 50,000 inhabitants to establish development plans for DHC networks to increase the share of RES sources • No national legal framework for DH and legislation very limited
Building and urban regulations	• Not possible to enforce the connection to a DH grid • Technical-economic conditions for grid will be defined in the next strategic plan

CHP and RES support schemes	• No specific support framework for the use of CHP or RES in DH
Taxes and tax exemptions	• Reduced VAT rate for heat sales to residential consumers supplied with RES sources or CHP (10 % instead of 22 %) • Tax credit for DHC systems using geothermal or biomass energy source
Available funding for DHC	• Not many national incentives to DH and no specific investment grants for DH • Since 2016, reduction of the support of DH through the issue of white certificates (corresponding to the primary energy saved through the projects) because of a change in the support scheme

District Cooling

Key figures	In 2017	Since 2015
Cooling degree days	295	-3%
Total installed DC capacity (MWth)	204	+2%
Trench length of DC pipeline system (km)	72	+1%
Number of DC systems	N.a.	N.a.
Total DC sales to customers (MWh)	130,783	+4%
Average nominal DC price (euro/MWh)	N.a.	N.a.
Average CO2 emisions (kg/kWh)	N.a.	N.a.

Main technologies used (in terms of energy produced, 2017)
- Compression chilling (57%)
- Heat pumps (43%)

Objectives
- No specific objective is set for the development of DC yet

Key actors
- Only a few actors
- Same competitors panel as DH

Key policies
- No policies specific to DC

Market
- No regulated market
- Main clients: 98% tertiary, 1% residential and 1% industrial

Incentives
- No specific incentives for DC grids

7.7 ANNEX 7 Country Profile: SWEDEN

Annexe : Country Profile **Sweden**

Summary

Population (2018) : 10,183,000 inhabitants *source: World Bank*

Average heating degree days (2014-2018) : 5,061
Average cooling degree days (2014-2018) : 2 *source: Eurostat*

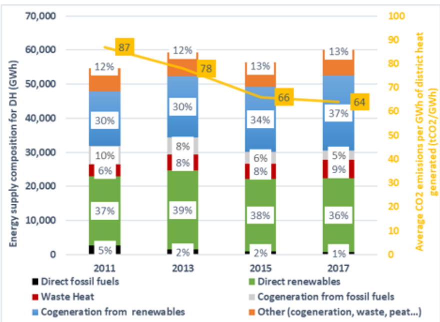
Main sources:
- Euroheat & Power, Country by Country 2019 (link)
- International Energy Agency, 2019 Sweden Review

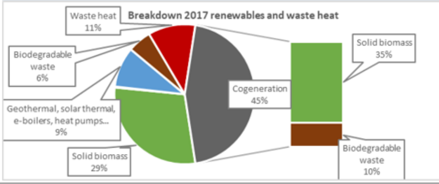
District Heating (2018)
- 424 DH systems
- 50,951 GWh sold to customers
- 90% market share in multi-dwelling buildings and 50% in total residential sector
- Competition with electric heat pumps because of low electricity prices
- Major incentive: CO2 and energy taxes on fossil fuels

District Cooling (2018)
- 627 km of DC systems
- 1,156 MWh sold to customers
- 25% market share in the climatization of public and commercial buildings
- Growing interest of customers, 50% expansion planned by 2030

District Heating: 82% from renewable sources and waste heat (2017)

Energy supply composition for DH





Regulation and incentives

Market	• Liberalised in 1996 • Main clients (in terms of sales): 60% residential, 28% tertiary, 12% industrial
National energy and climate strategy (2016)	• Carbon neutrality by 2045 • 100% RE in electricity generation by 2040
Key policies	• District Heating Act (2008)
Building and urban regulations	• National energy performance standard (2017) • A new building standard favouring DH over electricity is planned for 2020
Others	• The Price Dialogue (*Prisdialogen*): voluntary market initiative to set DH prices

Key figures	In 2018	Since 2015
Heating degree days	5,163	↗ +5%
Market share of district heating in the total heat market in residential sector	50%	→ 0%
Total installed DH capacity (MWth)	N.a.	N.a.
Trench length of DH pipeline system (km)	37,925	N.a.
Number of district heating systems	424	→ 0%
Number of citizens served by DH	355,956	N.a.
Total DH sales to customers (GWh)	50,951	↗ +10%
Average nominal DH price (Euro/MWh) (excl VAT)	62	↘ -13%
Average PPP-adjusted DH price (Euro/MWh) (excl VAT)	48	↘ -13%

Key actors

Ownership (in terms of number, 2019)	• 65% Municipality owned heat supply companies • 35% Others (private or state owned heat supply companies)
Main operators	• Main private: Fortum (coowner Stockholm exergi), Vattenfall, E.ON, Solör Bioenergi, Värmevärden, Adven
DH association	• Swedenergy (*Energiföretagen Sverige*)
Regulator / Supervision authority	• DHC is not a regulated activity in Sweden • Other authorities: Swedish Competition Authority (*Konkurrensverket*): safeguards competition and supervises procurement
Role of municipalities	• No longer operate but still own some systems • Influence strategies to align with climate goals
Other actors	• Swedish Energy Agency (*Energimyndigheten*) • Swedish District Heating Board (part of the Energy Agency) : mediator • Swedish Energy Markets Inspectorate: monitors the compliance with the District Heating Act
CHP and RES support schemes	• Electricity Certificate Scheme: supports RES-based CHP • All renewable energies are exempt from taxes
Taxes and tax exemptions	• Energy and CO2 taxes for fossil fuels • Nitrous oxide fee for combustion plants • Sulphur tax for heavy fuel oil, coal and peat • Tax reductions for households
Available funding for DHC	• DHC support available for investments in small scale DHC systems below 20 MW installed capacity « *Klimatklivet* » (outside EU ETS)

District Cooling

Key figures	In 2018	Since 2015
Cooling degree days	5	↗ +98%
Total installed DC capacity (MWth) *in 2017*	5,787	N.a.
Trench length of DC pipeline system (km)	627	↗ +10%
Number of DC systems	N.a.	N.a.
Total DC sales to customers (MWh)	1,156	↗ +20%
Average nominal DC price (euro/MWh)	N.a.	N.a.
Average CO2 emisions (kg/kWh)	N.a.	N.a.

Key actors
- Same actors as DH

Market
- 1,698 customers

Main technologies used (in terms of production, 2018)
- Absorption cooling (28%)
- Compression chilling (27%)
- Free cooling (26%)
- Heat pumps (18%)

Objectives
- DC expansion plan (2019) : 50% sales expansion by 2030

Key policies
- A District Cooling Act is planned for 2021

Incentives
- No specific incentives for DC

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