Efficient district heating and cooling systems in the EU

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

Prepared by Tilia GmbH for the JRC

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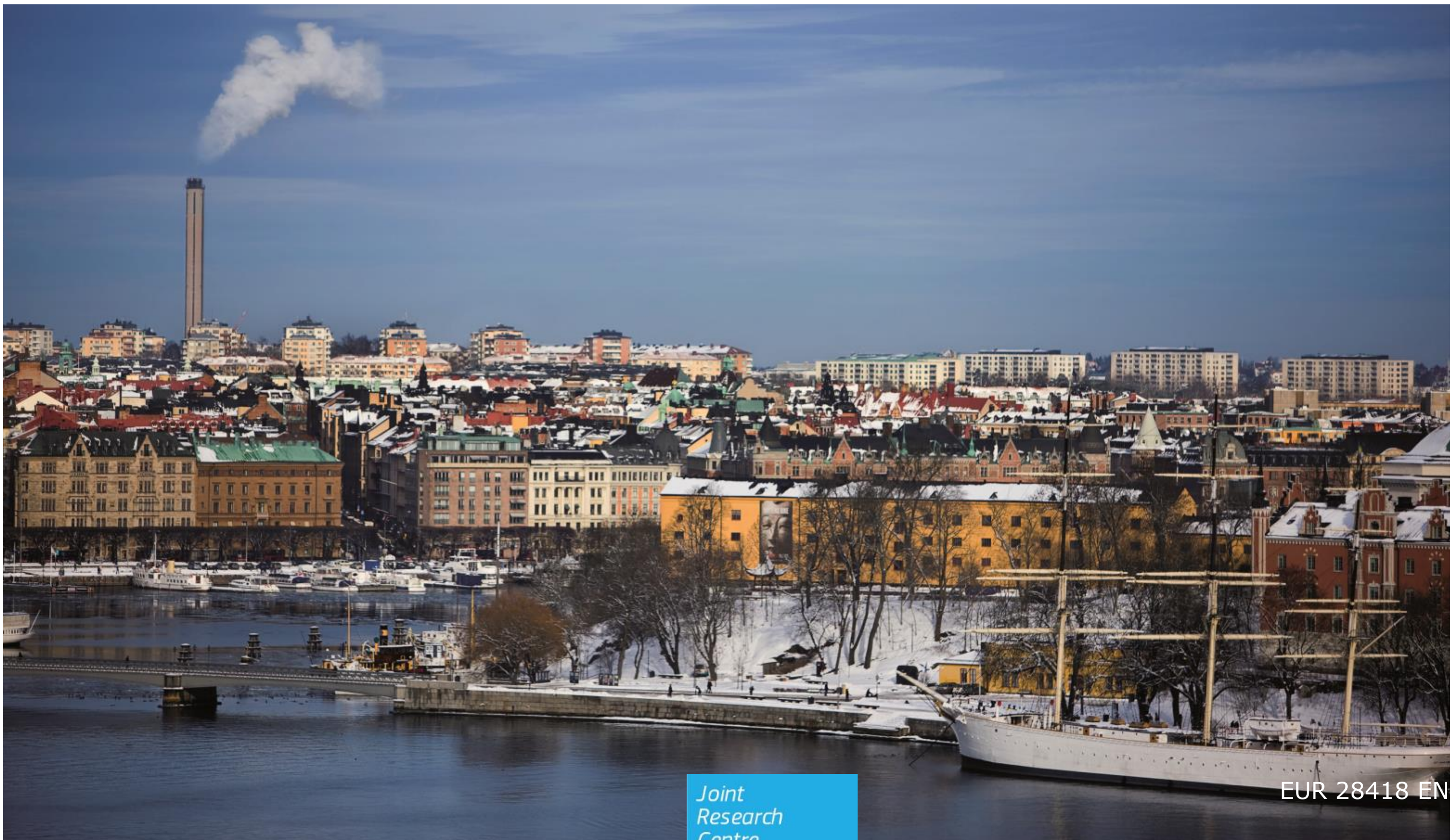

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Title Efficient District heating and cooling systems in the EU

Abstract

Based on a holistic case studies analysis of 8 efficient district heating and cooling systems in different European Member States (Denmark, Estonia, France, Germany, Italy, Spain and Sweden), the study identifies the key factors enabling to develop high quality, efficient and low-carbon DHC systems, discusses how these key success factors can be replicated in the EU and provides a better view on the role and features of these systems, which can provide an evolutive backbone to balanced energy transitions. Finally, it suggests some potential policy guidelines to support their deployment.

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List of acronyms

ATES	Aquifer Thermal Energy Storage
B2B	Business to Business
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CHP	Cogeneration Heat and Power
COP	Coefficient of Performance
DBO	Design, Build, Operate
DC	District Cooling
DH	District Heating
DHC	District Heating and Cooling
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization
EE	Energy Efficiency
EIB	European Investment Bank
EPC	Engineering, Procurement, Construction
ETS	Emissions Trading System
EU	European Union
HDD	Heating Degree Days
HOB	Heat Only Boiler
H&C	Heating and Cooling
HSE	Health, Safety and Environment
JRC	Joint Research Centre
KSF	Key Success Factor
LNG	Liquefied Natural Gas
O&M	Operation and Maintenance
OPEX	Operational Expenditure
PPP	Public Private Partnership
PV	Photovoltaic
RDI	Research, Development and Innovation
RE	Renewable Energy
RONA	Return on Net Assets
SPV	Special Purpose Vehicle
TSO	Transmission System Operator
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital
WTE	Waste-to-energy

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1. EXECUTIVE SUMMARY

A. Context

Efficient district heating and cooling (DHC) systems can play a key role in achieving the Energy Union's objectives. They improve energy efficiency (EE) and enable to increase the share of local renewable and recycled energies in heating and cooling (H&C). Moreover, a higher share of these systems in H&C markets can facilitate the integration of intermittent renewable energy (RE) in the electricity mix, providing balancing to the grid (e.g. through thermal storage or flexible CHP production) and, overall, increase the EU's security of energy supply.

DHC systems have already proved their effectiveness in some EU countries like Denmark and Sweden, where they allowed **aggregating heat loads to progressively optimise the energy supply** and switch to more sustainable fuels. Many European cities are already aware of these benefits and are integrating them in their energy strategies, but there is still a high potential for deployment.

B. Objectives and approach

This study investigates the key success factors (KSF) enabling to develop **high quality, efficient and low-carbon DHC systems**, discusses how these KSF can be replicated in the EU and provides a better view on the role and features of these systems, as well as a few potential policy guidelines to support their deployment.

To do so, some of the most efficient DHC systems in the EU have been thoroughly analysed from a **holistic perspective**, i.e. from national policy frameworks to specific local conditions and business model. This in-depth study is to a large extent based on meetings and exchanges with DHC operators, national and local authorities during site visits and to Tilia's own experience in developing efficient DHC systems.

The **eight case studies** presented in this report are at least partly replicable, and cover a wide range of technologies, energy sources, management modes and types of DHC systems, from older systems that have been progressively upgraded and decarbonised to new systems recently developed based on a low-carbon design.

Efficient DHC systems main indicators

- ✓ **Economically viable** (robust business model)
- ✓ **Affordable** prices for heating and cooling
- ✓ Stable and **resilient** supply
- ✓ **High quality** service
- ✓ Mid-to long term **adaptability** of the service
- ✓ **Low-CO_2** emissions and global environmental footprint

Case studies analysed

Case studies (and year of commissioning)	**Capacity and production** (2015/2016)	**Low-carbon energy sources**
DE – Hafencity (2014)	DH: 7 MW; 6 GWh/y	Biogas, biomass
DK - Greater Copenhagen (1920's)	DH: 3000 MW; 10 000 GWh/y DC: ~50 MW	Biomass, waste-to energy, RE electricity through heat pumps
DK – Gram (2015)	DH: 10 MWth; 20 GWh/y	Solar thermal, RE electricity (through electric boiler, heat pump and seasonal storage pit), surplus heat
ES – Ecoenergies Barcelona (2012)	DH: 23 MW; 12 GWh/y DC: 14 MW; 8 GWh/y	Biomass, waste cold recovery from LNG terminal
EST- Tartu (1967)	DH: 328 MW; 500 GWh/y DC: 13 MW; 1.3 GWh/y	Biomass, free cooling from the river
FR – Paris-Saclay (2017)	DH: 37 MW; 40 GWh/y DC: 10 MW; 10 GWh/y	Geothermal
IT – Brescia (1972)	DH: 710 MW; 1266 GWh/y DC: 23 MW; 33 MWh/y	Waste to energy, surplus heat
SE – Stockholm (1953)	DH: 3600 MW; 7.4-10.8 TWh/y DC: 220 MW; 380-440 GWh/y	Biomass, waste-to-energy, bio oil, surplus heat (from industry and DC), RE electricity (through heat pumps), free cooling from water bodies

C. Main results

There is not a one-size fits-all model to develop efficient DHC systems. The case study analysis suggests that each system has a distinctive architecture and has relied, throughout its development, on primarily local dynamics, combining partly **replicable key success factors** in various ways. These KSF are presented in the sidebar and come along with two main messages and some potential policy guidelines:

1 Efficient DHC systems often provide an evolutive backbone to balanced energy transitions

They are **powerful and cost-efficient enablers to develop low-carbon and resilient local energy systems**. At one end, DHC grids can be supplied by a very broad range of **renewable and recycled energies**, providing an off-take base for those local energies and stimulating their development. They are also linked, at the other end, to **EE in buildings** and can be integrated in a joint EE strategy, providing a more flexible supply that can be periodically re-engineered as part of a **smart multi-energy system**.

Coupling the electricity and heating systems through **DHC can help to efficiently manage intermittency from wind and solar PV at an affordable cost.** This can be done through the optimised use of thermo-electric equipment like heat pumps, electric boilers and CHP, together with thermal storage, which is already contributing to a higher integration of intermittent generation in some countries like Denmark.

2 The development of those efficient DHC systems relies on a new balance between cooperation and competition within open, evolutive systems

The models for DHC systems have changed quite radically. Large DH systems developed during the 1970-80's relied mainly on centralised, fossil fuel based energy supply, economies of scale and urban density, bearing a certain degree of rigidity, little transparency and leaving little space to consumer choice. New DHC systems follow different goals and development paths, relying on partly different economics. Still closely connected to urban planning, most of these new systems aim, on the one hand, at making the best of a broad spectrum of local energy sources in line with CO_2 reduction targets and, on the other hand, at providing new city districts a flexible collective infrastructure that can be progressively developed and upgraded following the actual needs.

Key Success Factors to develop efficient DHC systems

1. **Adequate national policy and regulatory environment**
   - Support to CHP and RE in H&C
   - Ambitious CO_2 targets
2. **Direct/indirect financial support** to efficient DHC investments
   - Investment subsidies and long-term debt funding
   - Relevant tax incentives (environmental taxes, reduced VAT…)
3. **Focused local policy and coherence with urban planning**
   - Integrated long-term approach for urban planning, including energy supply
   - Development of compact and mixed-use districts. Study the relevance of mandatory connection to the grid
4. **Alignment of interests / Cooperation maturity**
   - Especially between DHC operators, local authorities and consumers
5. **Availability and relevance of local resources**
   - REs, waste-to-energy, surplus / waste H&C
6. **Comprehensive project development**
   - Sound analysis of the demand
   - Secured and optimised supply
   - Continuity and coherence throughout the system's lifespan
7. **Price competitiveness against alternative energy solutions**
   - Maintained throughout the system's life (optimising and upgrading as relevant)
8. **Flexible heat and cold production**
   - Diversified and complementary energy mix
   - CHP and thermal storage
   - Dynamic (continuous) optimisation of the operation
9. **Combining technical and non-technical innovation**
   - Use best-available technologies and invest in RDI
   - Governance modes and social initiatives (citizen empowerment, raise awareness on the benefits of efficient DHC systems…)

As a consequence of this evolution, **DHC systems have become more open to competition, but also to stakeholders participation and cooperation.**

2.1 Competition as such should play a part at four stages in the development, construction and operation of efficient DHC systems

- At planning stage, when energy supply options are benchmarked against one another. It is of significant importance that cities follow a long-term integrated approach and transparent procedures, i.e. clarify the principles along which they make their **energy planning decisions**, especially in new urban areas.
- **Competition for the market** remains relevant for the construction, financing and operation of DHC systems.
- The contractual / organisational patterns have to **secure that scope and incentives for ongoing supply organisation are in place** and that efficient options of energy supply are integrated into the system as they are developed.
- Finally, even if mandatory connection rules can support the business case for DHC, an **opt-out possibility for potential users proposing a more competitive solution** has to be designed, provided this comparison takes also into account the broader benefits of DHC in terms of EE, CO_2 emissions, etc.

2.2 Yet cooperation is equally important to optimise those systems and maximise their community benefits and collective value for money

- **Cooperation between DHC project managers and urban planners** as a first step to assess the relevance of the energy supply scheme and economic viability of a DHC system.
- **Cooperation with real estate developers and building owners** to adjust the supply based on robust demand forecasts and the system's optimal design.
- **Cooperation with potential surplus heat/cold providers** should be actively sought and specifically supported, as these bring huge socio-economic benefits and can be hampered by conflicts of interest.
- **Cooperation with other DHC operators,** to share best practices and optimise the overall competitiveness of DHC in specific areas, e.g. through grid interconnections and joint dispatch procedures.
- **Cooperation with end users and consumer associations** on prices can be integrated in price setting mechanisms, to provide insights on the affordability and consumer perception of the service.
- **Cooperation with entities managing other energy services,** to foster the deployment of smart and multi-energy systems.

Potential implications on some policy guidelines

✓ **Supporting the in-depth design and comparison of optimal new local systems**

- Programmes and initiatives supporting in-depth, **upstream, pre-optimisation work** (pre-conception and modelling work) are helpful
- **Holistic assessment of energy supply options**, criteria to be decided by local authorities and disclosed (enhanced transparency)

✓ **Revisiting regulatory patterns**

- National benchmarks and contractual patterns/ guidelines
- Stronger customer involvement at local level

✓ **Better supporting cogeneration and trigeneration**

- CHP and trigeneration plants are the cornerstone of a **smart local system** including DHC grids, providing high systemic benefits
- Market design and corresponding **support schemes** should better value the positive systemic externalities of these technologies

✓ **Putting a greater focus on DHC grids in the overall smart grid and innovation programmes**

- Focus on **multi-energy systems**, integrate a stronger DHC grid component
- Up-scale new European research programs to enable public authorities to develop **new system architectures** (improved flexibility, link with e-mobility…)

2. Introduction

Improving energy efficiency is a priority of the EU's Energy Union strategy. Energy efficiency has been identified as a key element for fostering European competitiveness, and for ensuring a secure energy supply and the reduction of greenhouse gas emissions. This has been translated into the 2030 objectives of the Energy Union, notably reducing Europe's energy use by at least 27 % compared to the baseline, and a 27 % share of renewable energy consumption.

Since heating and cooling represent about 50 % of the final energy consumed in the EU, potential savings in this area have to be identified and promoted. Indeed, 84 % of heating and cooling in the EU is still generated from fossil fuels while only 16 % is generated from renewable energy. In order to fulfil the EU’s climate and energy goals, the heating and cooling sector must sharply reduce its energy consumption and cut its use of fossil fuels.

In February 2016, the European Commission proposed a strategy to make heating and cooling in the EU more efficient and sustainable. This strategy highlights the capacity of district energy systems to integrate the increasing share of renewable electricity generation (e.g. through the use of thermoelectric equipment) and to replace fossil fuels with waste heat and cold from industrial processes, waste-to-energy and renewable energy sources such as geothermal, biomass, solar thermal.

Efficient district energy systems can play a key role in the energy transition towards a low-carbon economy, acting as an evolutive backbone towards efficient local energy systems. Some European cities have already recognised the benefits of these systems and developed efficient and sustainable heating and cooling systems, which are well-functioning and result in a high-quality, efficient and low-carbon heat and cold supply to its buildings and industries.

The purpose of this study is to investigate the design and operation of some of these efficient district heating and cooling markets. To do so, eight case studies have been identified in the EU and analysed from a holistic perspective – from national policy frameworks to specific local conditions and business model – to understand the key factors that make them well-functioning, and to finally explore whether some of the best practices can be replicated in other Member States. The study has been carried out by Tilia GmbH under the supervision of the Institute for Energy and Transport of the Joint Research Centre (JRC) of the European Commission.

After identifying a representative group of case studies in Section 3, these are presented and analysed in Section 4, which also provides a list of indicators allowing identifying efficient DHC systems as well as the main key success factors influencing their development. The replicability potential of the best practices is then evaluated in Section 5; which is followed by a conclusion and some potential policy recommendations in Section 6.

3. Case study selection

3.1 Methodology

Choosing the right case studies is critical to the quality and relevance of the analysis. The selected case studies have to be representative and complementary in order to allow for a comprehensive analysis of well-functioning and innovative District Heating and Cooling (DHC) systems in the EU. They also have to be well documented and accurate in order to guarantee a good level of reliability of the study's outcome. The methodology used to select the case studies is explained below.

3.1.1 Selection of suitable case studies

The first step consisted in performing a **review of district heating and cooling systems in the EU** including a comprehensive inventory of well-functioning and innovative projects with their main characteristics: country policies and regulations, climate factors, urban characteristics and dynamics, technical characteristics, governance and financial frameworks, performance and trends. To identify potential case studies, the consultant performed a thorough literature review, contacted national and EU DHC Associations, DHC companies and other DHC professionals within its network. It also relied on its own, first hand operational knowledge of some of the most efficient systems in Europe to analyse and benchmark various cases.

Based on this first review, a **preliminary questionnaire** was developed including the main project-specific criteria to take into account for the selection of case studies (cf. Annex 1). In particular, a set of questions and indicators was defined to assess:

- The complementarity of the case studies in terms of location, regulation, type of network, customer structure, energy sources, access model, size and business model;
- The performance of the network in terms market share, price, environmental aspects and innovation; and
- The data availability and willingness to collaborate in the study, if selected.

The answers to the preliminary questionnaires were integrated in a worksheet providing the main characteristics of the **preselected DHC networks**. These characteristics included, on top of the project-specific indicators provided by the questionnaires, the national regulatory framework for DHC prices.

3.1.2 Evaluation of preselected DHC networks and selection of a suitable group of 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 consultant and the JRC (cf. Annex 2).

1. Well-functioning business model
    - Economically viable
    - Allows the expansion of the district heating and cooling network
2. Price competitiveness
    - 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 (eg. storage, linkages with other markets such as electricity); iii) environmental and social aspects
4. Growing market
    - Growing market share for DHC
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, behaviour changes)
8. Willingness to cooperate and actively contribute to the study.

As a result, the preselected cases obtained a performance score, allowing to establish a ranking of the DHC systems.

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

- Geographical coverage: The south, central and northern EU should be covered in at least one case study each;
- Type of network: different types of energy supplied (i.e. heating or heating and cooling), different scales and urban frameworks;
- Regulatory framework: More than half of the case studies should concern a heat market that uses locally regulated heat prices and at least one case study should treat a heat market with nationally centralised regulation;
- Access model: Different models for competitive DHC systems should be covered, e.g. single-buyer model[1] or network access model[2];
- Balanced coverage of the main customer segments (residential, service, and industry);
- Diverse sources of heat/cold supply: e.g. co-generation, waste heat/cold from industry, renewable energy (e.g. geothermal, solar, biomass), heat pumps, thermal storage, etc.

3.2 Final group of case studies

The above criteria were applied to the 13 preselected networks, and enabled us to design the final group of **8 case studies**, listed below:

- Brescia (IT), Copenhagen (DK), Ecoenergies Barcelona (ES), Gram (DK), Hafencity (DE), Saclay (FR), Stockholm (SE) and Tartu (EST).

The evaluation and selection results are available in Annex 2.

[1] In the single-buyer model, the heat supplier/network operator offers heat to similar end-customers on equal terms and prices, although the ownership of different parts of heat networks varies. This can be achieved if the overall responsibility for heat retail to end-customers is directed into one body—e.g. the main heat network. Under this model, the vertically integrated network operator needs to provide access to third-party producers and its own production source on equivalent terms. This model is the most common design of DH systems across Europe, and is usually stipulated in the respective country legislation.

[2] In the network access model, producers have access to heat networks provided that the producers are supplying heat to their own end-customers via open heat networks. This model is possible under current energy law in Poland, also experimented in Hafencity (Germany), but it is otherwise practically never implemented due to its complexity.

4. Case study analysis

4.1 Methodology

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

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

1. First of all, a detailed questionnaire was developed covering all the topics to be analysed for the study. This questionnaire was shared with the contact person of each case study to identify the most appropriate actors (stakeholders) to answer each of the ca. 100 questions, covering the following 12 topics:

    A. National policies, regulations and standards
    B. Organization, governance and management of DHC systems
    C. Local physical and climate factors
    D. Heating (and cooling) market
    E. Demand factors (other than directly linked to physical local factors)
    F. Heat and cold supply factors (incl. third-party-access)
    G. Customer information and participation
    H. Economic factors
    I. Profitability and financing capability
    J. Framework for innovation
    K. Managerial aspects
    L. Replicability

    For each identified respondent, a tailored questionnaire containing only the questions relevant to him/her was sent before the site visits.

2. A thorough **literature review** was undertaken before the visits to further prepare the site visits, and meetings with the main stakeholders were scheduled.
3. **Site visits** of 1-2 days to each of the concerned cities/municipalities took place between May and June 2016. These visits included **meetings** with national and local authorities, DHC grid operators (and its consultants) 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** met during the site visits for their **review**.
5. Finally, the analysis was reviewed and validated by the **JRC**.

4.2 Case studies

This section includes the main findings of the 8 case study analyses.

Each case study begins with a summary box providing a brief presentation of the DHC system and the main key success factors identified.

4.2.1. DENMARK: Integrated District Heating and Cooling in Greater Copenhagen

Denmark is one of the most energy efficient countries in the world. The widespread use of district heating systems and CHP supported by national energy policies since the 1970's has proved to be a successful way to improve the energy efficiency and tackle climate change and security of supply in Danish cities.

These successful results can be illustrated through Greater Copenhagen's integrated DHC system. The City and 24 surrounding municipalities have developed since the 1980's a world-class DHC system which today covers 98% of the total heat demand in the district heating zones, mainly through CHP and waste-to-energy. Some of the key factors contributing to the overall efficiency of the network include: i) a coherent and stable ***policy framework*** *focusing on cost-efficiency in heating solutions and heat planning; ii) an* ***optimised and flexible DHC system*** *allowing to integrate efficient and renewable technologies (therefore minimising* CO_2 *emissions) and offering* ***competitive prices*** *for heat and cold; iii) the* ***availability of sound expertise*** *and* ***competitive debt funding*** *for network investments; and iv) a* ***focus on customers****, through citizen empowerment and continuous efforts in lowering the prices and improving the quality of the service.*

I. National context

I.I Drivers for DHC in Denmark

Denmark has a long tradition in district heating (DH) and has found in these systems an **efficient way to enhance its security of supply and achieve its ambitious environmental targets**.

The first DH systems were developed in the 1920's and represented a market share of 30 % in the 1970's. Following the energy crisis in 1973-74, cost-effectiveness and security of supply became a priority for the Danish Government, who strongly supported DH and CHP through new energy policies and instruments aiming at increasing energy efficiency and therefore decreasing dependency on imported oil.

These policies, together with the discovery of natural gas resources and the development of gas infrastructure, allowed Denmark to become **energy self-sufficient** by 1997. Today the degree of self-sufficiency is 92 %[3] and the market share of DH has reached 63 % of the total heat demand. In the 1980's, the Danish Government together with municipalities started a comprehensive **national heat planning**. The objective was to replace oil demand in a cost-effective way, through the extension of DH networks based on coal-fuelled CHP plants and waste-to-energy or through new natural gas infrastructure. The planning consisted mainly in identifying an optimal zoning for district heating (mainly large buildings) and for natural gas (mainly one family areas).

During the 1990's the main infrastructure for DH and natural gas was in operation and environmental issues became a priority. Ambitious targets on **CO_2 emissions and renewable energy** generation were established. A new heat planning system for new and existing urban areas was introduced, in which municipalities were responsible for improving the old heat plans through a "project proposal" procedure demonstrating that the most cost efficient heating solution is retained. In that way, natural gas zones could shift from gas to district heating. At the same time, gas was introduced at some of the new CHP plants and most small DH companies established decentralised gas-fuelled CHP plants with heat storages. Additional incentives through subsidies and taxation supported these developments as well as the increase of

[3] Danish Energy Agency (2014). *Energy in Denmark 2014*

renewable energy production, improving the overall environmental performance of the Danish electricity and heating systems.

In 2012, Denmark established an Energy Policy Agreement to become **independent of fossil fuels by 2050.** DH is expected to play a crucial role in achieving this target, as it has proved to be an efficient tool for switching to more sustainable fuels in heating and for integrating intermittent electricity generation from renewables. Indeed, DH allows aggregating heat loads and optimising progressively the heat production. The development of District Cooling (DC) is also expected to lead to further energy efficiencies. It can reduce cooling energy use and related costs through economies of scale (through the use of a single central production unit to replace multiple individual units) and the possibility of using free cooling sources such as rivers or lakes, while presenting synergies with the DH system. In the longer term, combined production of DH and cooling via Aquifer Thermal Energy Storage (ATES) systems and chilled water storages is expected to become the main supply for district cooling.

I.II Policy tools and incentives supporting DHC

Denmark has developed a **coherent package of policy tools and incentives** aiming at supporting a secure, sustainable and cost-efficient energy supply:

Heat Supply Act

District Heating in Denmark is mainly **regulated** through the Heat Supply Act since its adoption in 1979. It applies to all distribution grids for natural gas and district heating and for heat production plants larger than 250 kW. It has two main objectives:

1. Promoting **socioeconomic and environmental performance** in heat and domestic hot water supply of buildings; and
2. Promoting the highest possible degree of **CHP**.

The key aspects governing Danish DH markets are ruled by this Act, as summarised below:

- **Non-for-profit principle**: All DH companies in Denmark covered under the Heat Supply Act are non-for-profit. The return on invested capital is limited to 7-8 % and the price of heat is only allowed to include the necessary costs for production and distribution to the end-user. The main reason behind this principle is maximising efficiency to the benefit of consumers. As a result, 99 % of the DH companies are owned and controlled by the consumers through cooperatives or local public utilities.
- **Heat Planning and cost-effective zoning**: City councils are responsible for heat planning in their cities, to ensure that the most economical heating option is retained. Heating choices and zoning are based on a 20-year cost-benefit analysis (CBA) taking into account environmental externalities, residual value and following a methodology published by the Danish Energy Agency[4]. The project proposals also have to prove that the project is profitable for both the district heating company and new consumers. Once the project proposal is approved by the city council, the city has the option to impose existing and new buildings to connect to the preferred collective heating supply in their zone (DH or natural gas). This power provided by the Act was used by many municipalities in the beginning (1980-1995), but now it is rarely used, as DH has become highly competitive as shown in the graphic below.

[4] The discount rate in fixed prices is currently 4 %

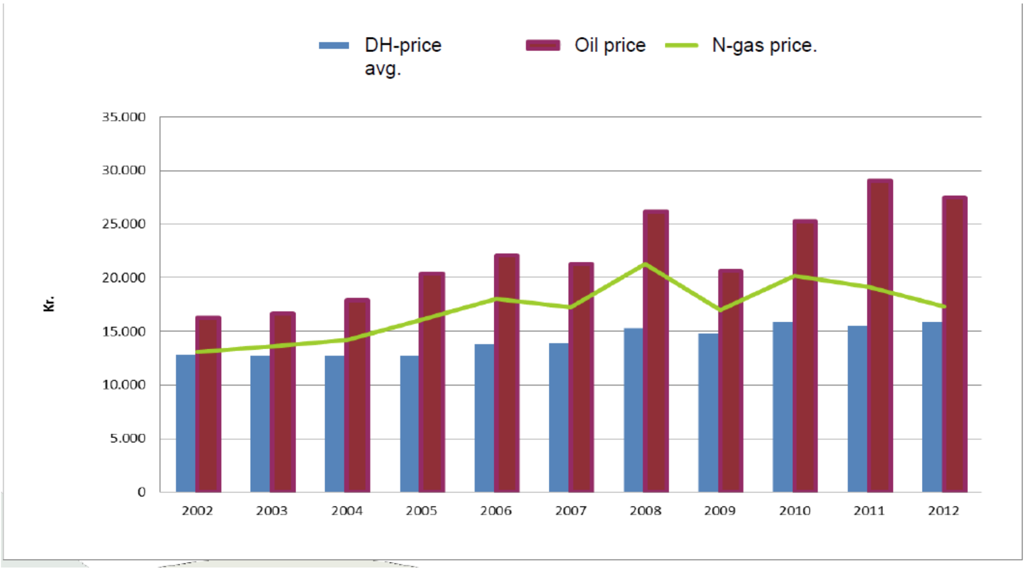

Figure 1 Heat supply price evolution for a standard house (Source: Danish DH Association)

- **Protection of consumers**: The Danish Energy Regulatory Authority oversees the DH sector and ensures the protection of consumers. All DH companies have the obligation to submit information to this Authority on prices and conditions, so that it can deal with complaints and objections. The national Energy Regulatory Authority is also responsible for the **benchmarking**[5] of DH companies against each other, which is performed on a voluntarily basis in order to promote efficiency and efforts in lowering heat prices. This way, the companies can compare their performance with other similar companies. Consumers can appeal to the Energy Appeal Board in case of discrepancy with the tariffs proposed by DH companies.
- **General ban on electric and oil boilers**, with few exemptions.
- Conversion of existing heat-only boilers (HOB) to **CHP** and preference for CHP when building new heating capacity.

Subsidies and taxes

The Danish Government has used subsidies to support the energy transition. During the 1990's, **investment subsidies** were introduced to support energy efficiency, CHP and renewable energy generation. Most of these grants are no longer available for new DHC investments. However, decentralised CHP plants operating in the electricity market receive a premium tariff (the so-called capacity credit) on top of the market price plus an electricity production subsidy (in the case of gas and waste-fuelled plants) or a "surcharge"[6] (for biomass or biogas-fuelled plants)[7]. As of 2018, this premium will only be available for CHP plants using renewable energy.

Since late 1980's, **taxes** and **tax exemptions** have strongly supported the development of CHP and DH systems based on surplus heat and renewable energy while taking into account that the State needs a stable tax revenue from the energy sector. They represent one of the strongest incentives to energy efficiency and higher share of renewables in heating.

[5] Each DH company communicates annually their price for a standard single-family house of 130 m^2 consuming 18.1 MWh/y of heat and domestic hot water

[6] This "surcharge" is a subsidy paid by the electricity consumers, while the subsidy received by gas and waste-fuelled plants is paid by the State

[7] This support scheme is granted for 20 years and allow natural gas and waste to energy CHP plants to receive total incomes (i.e. market price + support scheme) up to 45 Øre/kWh (cEUR 6/kWh) while CHP plants based on biomass or biogas receive up to Øre 60/kWh (cEUR 8/kWh),

Financial instruments

Financing through competitive loans is easily accessible for DH investments, at interest rates of ca. 1 %. The Danish "Kommune bank" is a revolving fund benefiting from a State guarantee and offering **competitive long-term debt funding** to Danish municipalities, which often finances 100 % of their DH investments with these loans based on a municipal guarantee.

For DC the interest rate is higher, as it is a new business and there is not yet possible to receive a municipal guarantee for DC investments. Consumer-owned companies are financing their debts at interest rates of around 2-3 %, while municipality-owned companies having available capital (e.g. from selling their electricity grid) are financing these investments through their own capital. All other municipal companies have currently difficulties to finance DC projects at an acceptable interest rate.

II. Presentation of Greater Copenhagen's DHC system

The map below illustrates the integrated DHC system in Greater Copenhagen. Its main characteristics are summarised below:

- **Large system**: 1 million people (of which Copenhagen represents around 50 %), 25 municipalities
- **Multiple actors:** 3 transmission companies (VEKS, CTR and Vestforbraending), 24 distribution companies owned by municipalities or consumers
- **Optimised production (heat market unit):**
  - 2 multi fuel and 1 biomass CHP plants (70 %)
  - 4 waste to energy CHP plants (25 %)
  - More than 40 peak boilers, fuelled by gas or oil (5 %)
  - 3 x 24 000 m^3 thermal storages (coupled with CHP)
- **District Cooling**: 5 DC plants in operation, many more in the pipeline

Key facts and figures

DH market share	98 %
Heating & Cooling capacity	DH: 3 000 MW DC: ~50 MW
Heat &Cold production	DH: 10 000 GWh/y DC: N.a.
Km network (double-pipe)	DH: 1 500 km DC: ~20 km
CO_2 emissions (heating)	110 kg/MWh

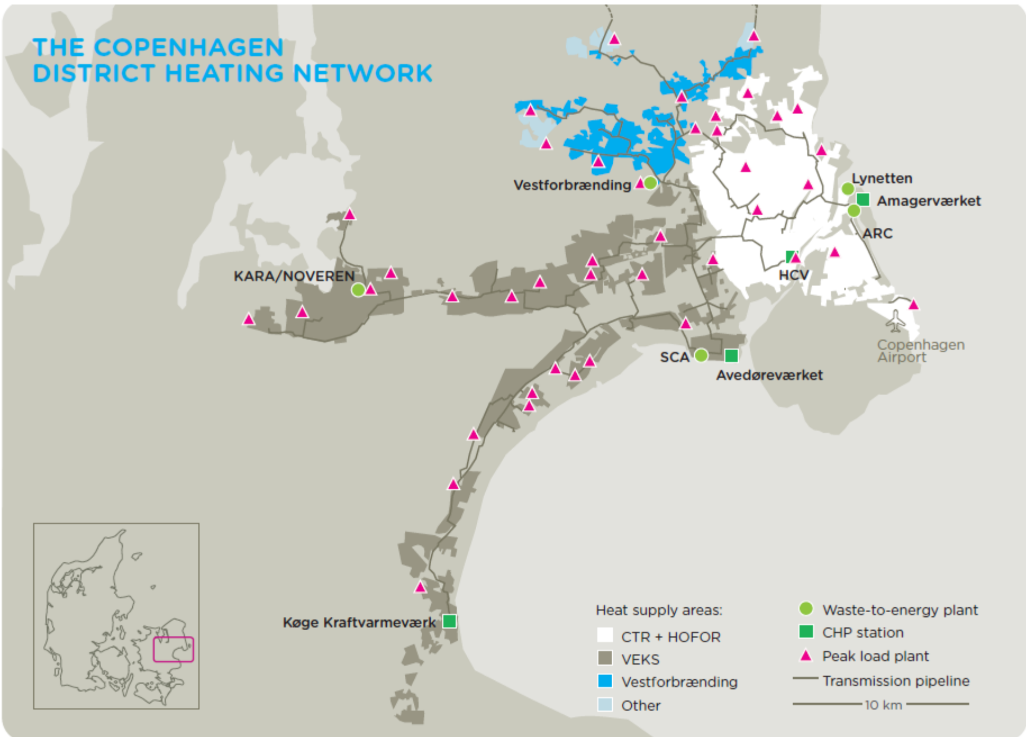

Figure 2 DH system in Greater Copenhagen (Source: Ramboll)

The DH system of Greater Copenhagen is one of the largest in the world and keeps growing. It supplies mainly the **residential and tertiary sectors,** principally through CHP facilities. Practically all buildings larger than one-family house are connected to DH as well as a minor share of one-family houses.

The energy mix of the DH system is described in Figure 3, while Figure 4 provides further details on the production capacity of the system.

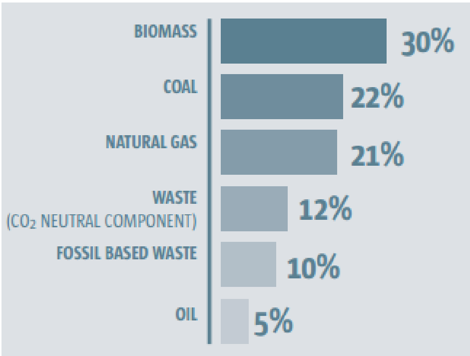

Figure 3 Fuel sources used for DH in Copenhagen (2014)

CHP Plants		Fuel	Heat capacity (MWth)	Electricity capacity (MWe)
Amagerværket (AMV)	Unit 1	Biomass, coal, fuel oil	250	80
	Unit 2	Biomass, fuel oil	166	95
	Unit 3	Coal, fuel oil	331	263
	Unit 4 (under construction)	Biomass	500	n.a.
Avedøreværket (AVV)	Unit 1	Coal, fuel oil	330	250
	Unit 2	Gas, biomass, fuel oil	570	570
Waste incineration Plants				
Amagerforbrændingen (AMF)	Unit 1	Waste	120	25
	Unit 2 (under construction)	Waste	218	n.a.
Vestforbrændngen (VF)		Waste	204	31
KARA/NOVEREN		Waste	69	12

Figure 4 Heat production in G. Copenhagen (Source: Ramboll)

III. Urban development and expansion of DHC

Copenhagen is among the largest and most successful "smart cities" in the world. The city has implemented a comprehensive set of "**smart solutions**" in the fields of transport, energy, waste management, water and governance, aiming at improving citizen's quality of life and the efficiency of its public services.

Coherent urban planning is at the core of the city's strategy. The city is characterised by a **high population density** (ca. 850 persons/ha), which is also promoted in new urban areas and leads to more efficient public services, including energy supply.

As explained in section I.II, the Heat Supply Act assigns municipalities a key role in heat planning and expanding DH systems. The first **Heat Plan of Copenhagen** was adopted by the city council in 1984 and led to an obligation for end-users to connect to the DH network in certain areas. A massive development of the DH system followed: two new CHP plants were built (Amager and Avadore) as well as new heat transmission system owned by the transmission companies CTR and VEKS (cf. section IV.I.1) and the market share for DH reached 80 % in 1995.

The **obligation to connect** buildings to the DH network was one of the main reasons for the success of the current system. This decision benefitted from a large **public acceptance**, mainly due to:

- the **transparency** of the "project approval" process, which has to evidence that DH is the most cost-efficient heating supply option for the concerned area and that connexion will lead to a decrease in heating costs and better air quality; and

- the **citizen involvement** in managing - directly or indirectly - the DH companies operating the system, which ensures a focus on decreasing prices and providing a quality service.

Today Copenhagen aims at being the first carbon neutral capital in the world by 2025, and DH will play a major role in achieving this target. The roadmap to reach this ambitious target (**Copenhagen's Climate Plan**[8]) includes a set of measures to reduce by 75 % CO_2 emissions from energy supply with respect to 2005 levels. It plans to switch from coal to biomass in CHP plants, to upgrade the DH networks and waste incineration plants in order to improve their efficiency, to improve the cooperation among different DH companies and to increase the share of renewable energy in electricity generation.

IV. Local heating and cooling markets

IV.I Heating market

The Greater Copenhagen area has developed a **flexible, transparent and efficient** model for heating supply that allows meeting the demand at the lowest cost for the system (and therefore lowest price for end-users).

IV.I.1 Demand and supply

The weather conditions and urban density of Copenhagen are favourable for district heating. The city has an annual heating demand of ca. **3 000 heating degree-days**[9], almost completely supplied through district heating (sales of ca. 8 500 MWh/y, 98 % of total demand). Consumers include tertiary buildings, all residential buildings other than one-family houses plus some one-family houses. Each area can be supplied only by one distribution company (consumers do not choose their heat provider).

Energy use in buildings is decreasing due to energy efficiency measures. Existing buildings have an average consumption of 100 kWh/m^2/y (incl. heating and domestic hot water) while new buildings consume ca. 50 kWh/m^2/y. The return temperature and supply temperature have decreased as well, resulting in an increase of the grid capacity. This allows DH companies to prepare project proposals for **new extensions and connections** to the network, which are cost-effective and therefore reduce the heat price for the existing consumers.

The Danish district heating market benefits from a **well-developed supply chain.** As DH networks gained market share, national DH expertise was gradually developed, which results today in a world-class offer of technology suppliers, consulting and engineering companies to which DH companies can outsource some of their activities - such as strategic studies, project preparation and implementation, RDI... There is a high level of **cooperation** and knowledge exchange among these actors, promoted among others by the national DH Association. The DH system of Greater Copenhagen has benefited from this fact to integrate state-of-the-art technologies and operational modes to progressively optimise its operation.

[8] http://www.energycommunity.org/documents/copenhagen.pdf

[9] **Heating degree day (HDD)** is a measurement designed to measure the demand for energy needed to heat a building. HDD is derived from measurements of outside air temperature. The heating requirements for a given building at a specific location are considered to be directly proportional to the number of HDD at that location. Heating degree days are defined relative to a base temperature—the outside temperature above which a building needs no heating. The most appropriate base temperature for any particular building depends on the temperature that the building is heated to, and the nature of the building (including the heat-generating occupants and equipment within it). The base temperature is usually an indoor temperature of 18 °C or 19 °C which is adequate for human comfort (internal gains increase this temperature by about 1 to 2 °C).

Heating in Greater Copenhagen is mainly supplied through an **integrated DH system**, including 24 distribution companies and 3 transmission companies, which collaborate to optimise the operation of the overall system[10]. The public heat transmission companies were created in the 1980's to optimise the system. They are owned by the municipalities they supply and are responsible for the peak capacity and part of the heat production on behalf of the connected distribution companies. They own their networks and production facilities and sell their heat on equal terms to the distribution companies (at pool prices).

The system has a high level of **security of supply**, and offers a large scope for optimisation, as it is connected to large heat storage tanks and different production units using different fuels, which makes it less vulnerable to fluctuating fuel prices. Each of the distribution companies owns some production capacity to secure its supply and purchase additional heat from the transmission companies or nearby networks if this is cheaper.

Since 2009, a **heat dispatch unit** (Varmelast.dk[11]) coordinated by 2 transmission companies and Hofor -the distribution company in the city of Copenhagen- allows **optimising the daily production of heat and electricity** on an hourly basis. It grants **priority dispatch** to heat from waste incinerators and geothermal sources (base load). The rest of the base load is supplied through CHP units and peak load through HOBs at the lowest possible cost.

Figure 5 illustrates the net costs of heat production per technology as a function of electricity prices, where net costs means variable costs minus electricity sales. The inflection points on CHP curves reflect the opportunity cost of producing heat instead of electricity when electricity prices are high.

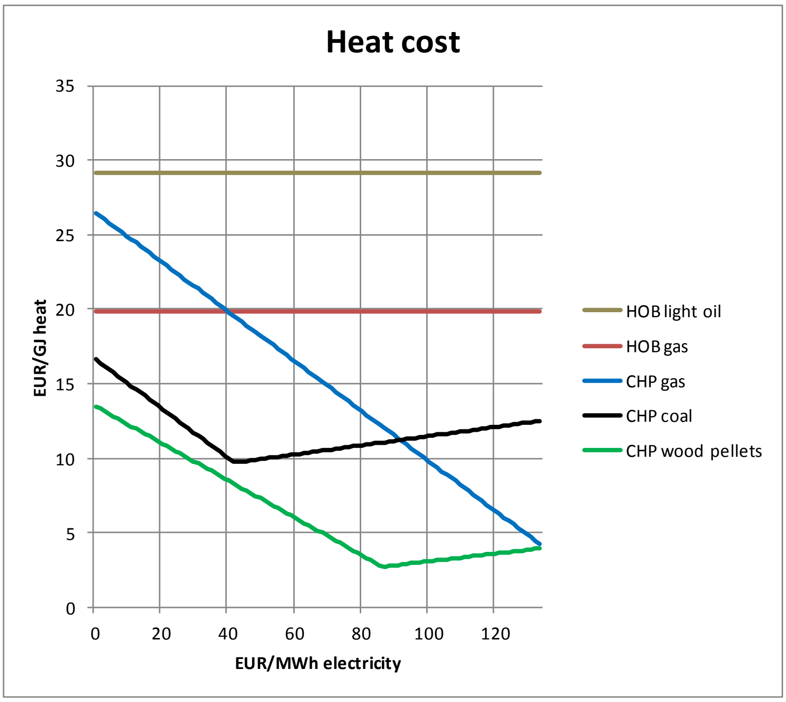

Figure 5 Net cost of heat production (Source: CTR)

The daily procedures to establish **heat pool prices** –as agreed among the different DH companies- are mainly undertaken in the morning, as summarised in the figure below. The resulting **daily heat plan** is updated with new marginal heat costs 3 times a day, based on electricity prices in the after-markets and

10 Details on the system, installed capacity and ownership of transmission companies available on this link

11 Details on the dispatch unit operation available on http://www.varmelast.dk/

deviations from demand forecasts. The corresponding electricity production of the CHP plants is sold on the Nord Pool Spot market.

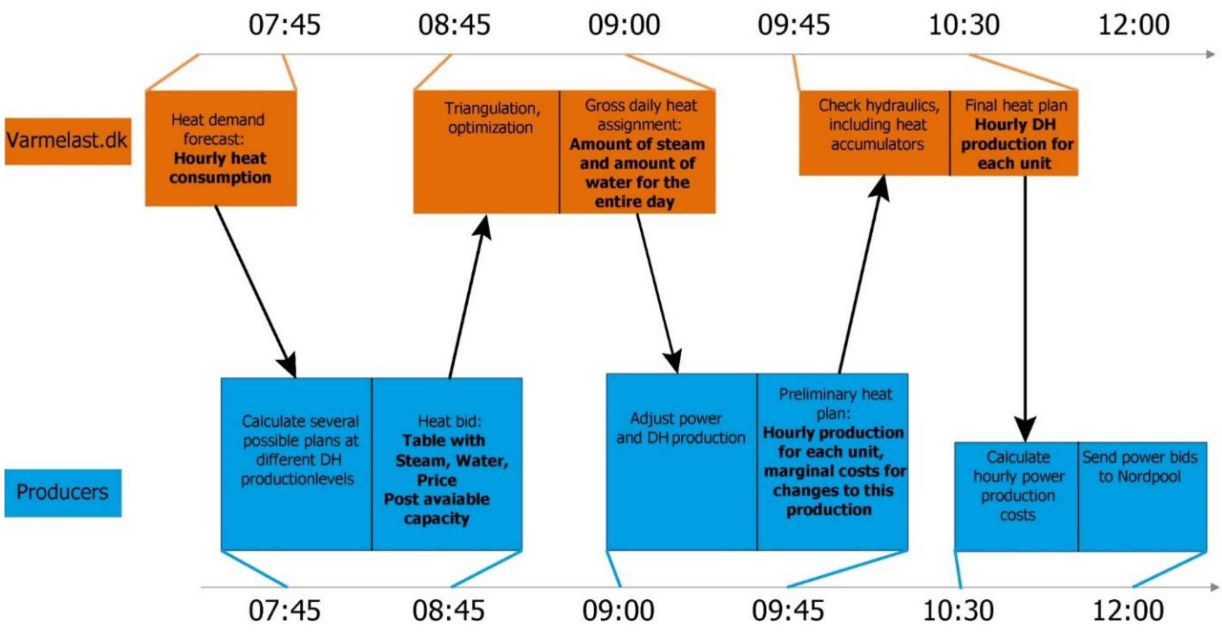

Figure 6 Day-ahead procedures (Source: CTR)

IV.I.2 Price competitiveness

The main alternative to DH consist in using individual gas boilers (in existing areas) or heat pumps (in new areas), which is generally more expensive than DH. The **competition between different heating options takes place at planning stage**, through the "project proposal" procedure and heating zoning.

However, it is possible to switch a "zoned" area from gas to DH if the latter becomes a cheaper option. To incentivise this, the Energy Authority established in a secondary act April 20 2013 a compensation procedure that entitles a gas distributor to receive a payment from the DH company taking over its clients. This procedure includes a requirement for gas companies to inform about the gas consumption for each consumer in the three previous years. These principles and procedures were negotiated between the Energy Authority and each of the three gas distribution companies in the country. The resulting compensation amounts allow gas distributors to pay their debts, and are established by an Executive Order[12].

The average price for DH is EUR **89/MWh** including taxes. Tariff structure is explained in section V.II below. In the national statistics, the distribution companies in Greater Copenhagen are among the 50 % cheapest companies, and competitive against gas boilers.

IV.II Cooling market

District cooling is rapidly growing in the city and becoming a competitive alternative to traditional cooling options such as individual heat pumps or chillers. It is supplied through DC networks that in some cases present synergies with existing DH systems, such as the ones presented below.

[12] Executive Order nr. 825 of 24.06.2016

As **cooling demand grows** – mainly due to the increasing demand for comfort and for appropriate ventilation in airtight (efficient) buildings - cold consumers are increasing their interest in DC. These consumers consist mainly of **tertiary buildings** such as hospitals, hotels, shopping centres and offices. The perceived benefits of DC include, among others:

- **Energy and cost savings** achieved mainly through economies of scale and the use free cooling sources, thermal storage... Cost and CO_2 emission savings are estimated at 40 % and 70 % respectively;
- **High reliability and simplicity**, providing a complete thermal comfort solution for building owners;
- An opportunity to **free up expensive space** in basements and rooftops, that can be converted into rooftop terraces or other profitable activities;
- **Synergies with DH**, such as using surplus heat from cooling for DH through absorption machines (e.g. at Hofor's network), heat pumps for heating and cooling (e.g. Høje Taastrup distribution company[13]) or ATES systems for DHC.

Figure 7 represents the cold production from Hofor. Free cooling from seawater covers most of the demand, while absorption cooling is produced using seawater and steam from the district heating network. The average price of the cold provided through this system is EUR 188/MWh, which is ca. 35 % lower than the average price for the alternative local cooling. Tariff structure is explained in section V.II.

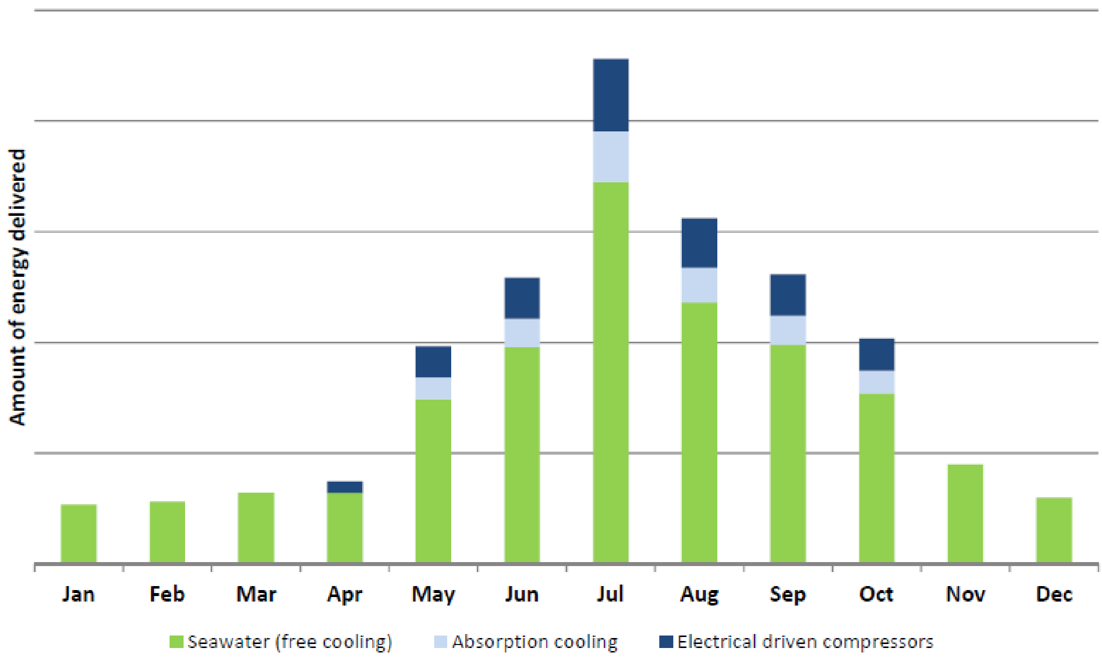

Figure 7 Hofor's district cooling annual production (source: HOFOR)

Unlike DH, DC is a **commercial business** following a business-to-business (B2B) approach. DC is a relatively new business and so far no specific regulation has been developed. DH companies in Greater Copenhagen are increasingly implementing DC projects since 2010. These must be undertaken through a separate company, to avoid cross-subsidisation between DC and DH. The profit from DC business can be transferred either to the local budget (for municipality-owned companies) or to heat or heat and cold consumers (for consumer-owned cooperatives).

[13] Consumer-owned distribution company in Greater Copenhagen

V. Business model

V.I Governance and strategy

Out of the 24 DH distribution companies in Greater Copenhagen, 13 are municipal companies and the rest consumer-owned cooperatives. Each of these companies have a **board of directors** that oversees the company's activities and represents its stakeholders. Board members are nominated by the municipalities or elected by the members of the cooperative (who are also district heating consumers). In the case of municipal companies, regular meetings are held with large consumers such as housing associations or the energy manager of the municipality. DH **customers are empowered** and become essential stakeholders, influencing the company's decisions.

As DH in Denmark is a non-for-profit business, DH companies typically express their objectives in terms of **cost reduction, quality of the service** and **CO_2 emission** targets. All profits have to be paid back to the consumers, or rather, the annual heat tariff has to be adjusted to reach a zero profit. The board and management are responsible for taking key strategic decisions on how to increase the efficiency and cost effectiveness of the system in order to reduce tariffs (e.g. investing in upgrading the network, supplying new districts, switching to low-carbon fuels…). The typical development model is illustrated in Figure 8, which shows how the benefits from cheaper heat sources are usually used to finance more expensive renewable heating sources.

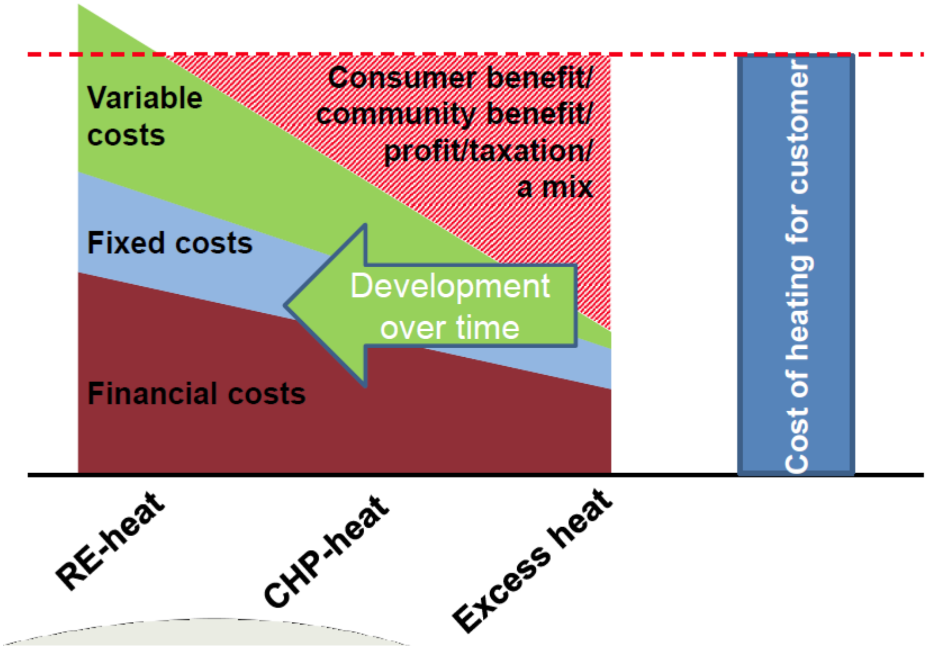

Figure 8 District Heating development (Source: Danish DH association)

Network efficiency and client satisfaction are at the core of the DH companies' strategy. In general, these companies are vertically integrated to ensure security of supply and influence the production mix and costs. Water losses are practically zero, while heat losses are very low (ca. 4-7 % in central parts, 10 % in suburbs and up to 25 % in areas with single-family houses). Effective HSE[14] procedures are in place.

[14] Health, Safety and Environment

V.II Financial model

DHC bills in Copenhagen depend on the **cost of production** for consumed energy. The typical cost structure is 70 % fuel costs, 25 % production and distribution and 5 % administrative costs. Individual metering is widespread, and sub-meters are installed in all apartments. Smart meters are being rolled-out by DH companies.

The typical **tariff structure** for DH has two components, as follows:

1. Fixed component: calculated as a function of the installed capacity (MW), m^2 or average consumption during the previous 3 years and implicitly integrating a discount to large consumers;
2. Variable component: unit price per MWh consumed.

In many cases, a tariff penalty is applied to DH consumers not achieving low return temperature (typically 50 °C or lower) and a reward for lower return temperature, to incentivise the system's efficiency. Some companies are also introducing seasonal tariffs, with higher prices in winter to reflect real costs.

A similar tariff structure is proposed for DC. In the case of Hofor, the DC tariff has 3 components: a fixed component based on installed capacity; a variable part based on consumption and a penalty applied in case of not achieving the required return temperature.

The **cost of connection** to the network can be offered by the DH company or paid by the consumer (it depends on the company's policy). For instance, Vestfor[15] applies a connection fee only to consumers below 40 MWh/y. In DC, the cost of connection is usually payed by the client.

Invoicing usually takes place once a month for large consumers, and every 3 months for small ones. Tariffs are updated on an annual basis by the DH companies and presented to the price regulator. DC tariffs are also updated on an annual basis.

V.III Client relationships and energy efficiency initiatives

Consumers are in general **very satisfied** with the quality of the service. All DH companies have a dedicated team to support their clients. The level of **transparency** of the prices and strategy is very high, and customer satisfaction surveys are performed on an annual basis. There are almost no voluntary disconnections from the network.

DH companies have the **obligation to encourage energy efficiency** among its clients, as requested by the Heat Supply Act. This can be done, for instance, through energy efficiency campaigns or free energy audits for the less efficient clients having a high return temperature. For companies owned by the consumers it becomes, however, a natural task to reduce the final cost of heat supply.

VI. Framework for innovation

Innovation is key for DHC companies operating in Greater Copenhagen, as it allows improving the efficiency in their systems. An important number of Research, Development and Innovation (RDI) projects are ongoing, such as a first-of-a-kind 800 m deep heat storage at 80 °C in limestone, large-scale solar water heating, no-dig methods for preinsulated pipes crossing rail roads and large roads etc. DH companies typically work together with universities, research centres, consultants, the Danish DH association, etc.

[15] http://www.vestfor.dk/

VII. Perspectives

As previously mentioned, district heating and cooling is expected to play a major role in achieving the ambitious environmental targets in Greater Copenhagen.

- Copenhagen's Climate Plan 2025 targets a **carbon neutral district heating** system. This is expected to be achieved by phasing out coal and switching to biomass-fuelled CHP plants. The conversion will be accompanied with an extensive programme of energy efficiency measures in buildings to avoid an increase in heating bills.
- **DH connections are expected to keep growing**, as most of the areas currently being supplied by gas or steam-based DH will be converted into water-based DH. The new building codes BR2015 and BR2020 incentivise DH and ban gas boilers in new districts.
- The system's **flexibility is expected to be enhanced** through additional heat storage capacity, new interconnections of DHC networks and a larger use of electric boilers and large heat pumps. The latter are expected to be used for both H&C and play an important role in responding to fluctuating electricity prices, as they allow load dispatching when combined with storages and other heat sources, resulting in further optimisations in the whole system.
- **DC** is expected to keep expanding. Several DH companies have included DC in their strategy to reduce CO_2 emissions.
- **RDI** efforts will continue to support the development of efficient, flexible and sustainable options for energy supply.

VIII. Conclusion: Key Success Factors

The integrated DHC system in Greater Copenhagen is one of the best-functioning systems in the world. The key success factors contributing to this can be summarised as follows:

i. **Coherent and stable policy framework for DHC**: The Heat Supply Act clearly defines the roles of key DH players and main procedures for municipalities to make choices on heat supply. This Act is in line with national energy policies aiming at improving security of supply and reducing CO_2 emissions.

ii. **Coherent urban planning, including heat mapping.** The above national framework is applied to existing and new urban developments through heat planning ("project proposal"), zoning and the possibility to establish mandatory connection to a DH network.

iii. **Alignment of interests between municipalities, DHC companies and final users**. All of them seek the most cost-efficient and sustainable option for energy supply, and a good quality service. The non-for-profit principle and ownership structure of DH companies in Denmark facilitate this alignment.

iv. **Competitive prices.** DHC is only viable when it proves to be more cost-efficient than the alternative option for heat or cold supply. Energy taxes, access to competitive debt funding and the long-term CBA approach retained for evaluating the best heating option makes DHC highly competitive in Copenhagen.

v. **Relevant tax incentives:** High taxes on electricity and fossil fuels have been essential to promote energy efficiency and support the energy transition in Denmark.

vi. **High flexibility in the system's operation.** Its integrated approach, with interconnected DH networks, a diversified energy mix based on CHP, heat storage capacity and daily optimisation of the heat and electricity production makes Greater Copenhagen's DHC system very flexible, cost-efficient and capable of integrating renewable energy sources.

vii. **Customer's empowerment.** Customers are at the core of the DH business and its main stakeholders. DH companies focus their efforts on enhancing their services and lowering their prices and customers are directly or indirectly behind these decisions. The transparency of the prices and comparison at national level through benchmarking support the decision-making process, while cultural aspects such as the long tradition of cooperatives in the country make it natural for citizens to undertake an active role in managing DHC systems, facilitating the local acceptance of DHC projects.

viii. **Well-developed supply chain.** As DH became a mature market in Denmark, a worldwide-recognised expertise was developed. Collaboration and knowledge exchange are common between DHC players. DH companies (and ultimately final users) benefit from this available expertise to outsource non-core activities and optimise their networks.

ix. **Innovation.** The system uses state-of-the-art technology and operational modes and relies on RDI activities to keep improving its economic and environmental performance.

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4.2.2 DENMARK: Solar District Heating with Seasonal Storage Pit in Gram

Gram is a 2 500 population town in the Municipality of Haderslev (Southern Jutland, Denmark). Its solar district heating system with seasonal storage pit represents a successful model for innovative, cost-efficient and flexible heat supply. The DH system is owned and operated by a consumer-owned cooperative and supplies heat to almost all buildings in the town. Its energy mix has been progressively upgraded to integrate a higher share of renewable energies. Some of the key factors contributing to the overall well-functionality of the system include: i) a coherent and stable ***policy framework*** *focusing on cost-efficiency in heating solutions and heat planning; ii)* ***customer empowerment*** *and willingness to continuously improve the cost-efficiency and environmental performance of the DH system; iii) the* ***availability of sound expertise*** *to help the cooperative in undertaking its project; iv) the access to* ***competitive debt funding*** *for these investments; v) an* ***optimised and flexible DH model*** *allowing to integrate a high share of renewable energy sources at* ***competitive prices*** *through the vi)* ***connexion of the electricity and heating markets****.*

I. National context

I.I Integrating and balancing renewable energy in Denmark

The main drivers for district heating in Denmark, policy framework and supporting tools were previously presented in section 4.2.1 for Copenhagen's case study, and remain applicable to Gram. Nevertheless, it is worth providing some further details on how Denmark is integrating and balancing its increasing share of renewable energies, which will be later illustrated throughout the case study analysis.

Denmark has experienced a major **increase of renewable energies** in its electricity mix since the 1990's, as illustrated in Figure 9. In 2015, wind power generation represented 42 % of the electricity consumption, and this share is expected to continue growing.

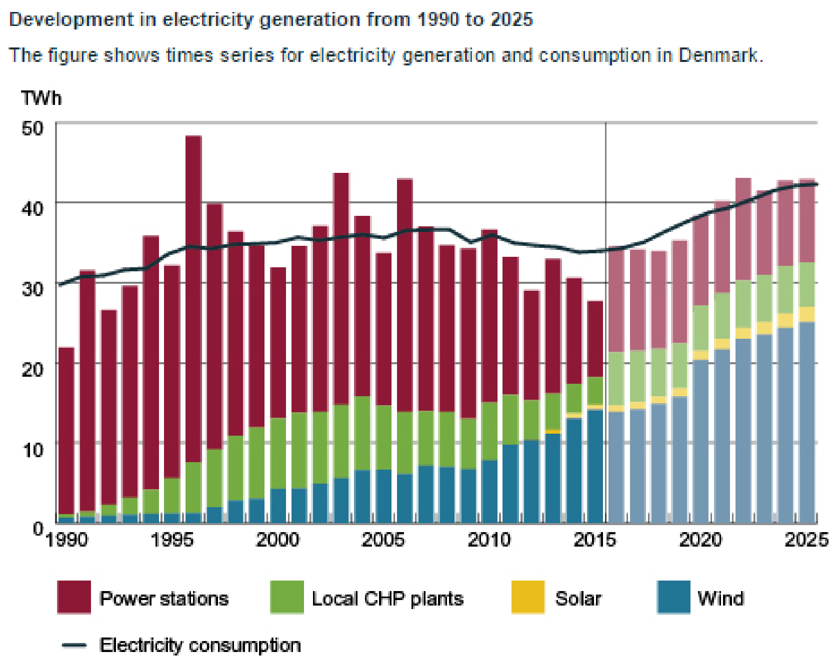


Figure 9 Electricity consumption and generation in Denmark 1990-2025 (source: Energinet)

The issue of **integrating and balancing intermittent energy sources** (i.e. wind and solar PV) has been efficiently tackled since the beginning of the expansion of these technologies. A comprehensive set of policy tools and market mechanisms is allowing Denmark to reach its environmental targets while securing the reliability of its electricity system. The main factors of this success are summarised below[16]:

- Strong **inter-connexion** with the neighbouring electricity systems;
- **Coupling the electricity and heating** markets, in order to use the latter for balancing through thermal storages. CHP plants are usually coupled with thermal storage systems and can regulate their electricity output depending on the wind power generation, therefore providing balancing. Moreover, as many CHP plants are fuelled with biomass this balancing remains RE-based.
- **Flexible operation of coal plants**, which can operate at minimum levels of 10-20 % rated output compared to typical levels of 60-70 % or 45-55 % in Germany.
- Integration of **advanced day-ahead weather forecasts** into the operation of the power system, improving the predictability of intermittent electricity generation. Moreover, the Danish TSO is able to compare real time production and demand and correct the forecast errors, enhancing the reliability of the system.
- Comprehensive **planning of the electricity transmission network**, to gradually upgrade it to integrate the growing share of renewables.
- Participation in the Nordic Pool electricity market, including the ancillary or **balancing markets.** All power plants in Denmark can sell a reserve capacity in the balancing markets, which are more lucrative than the wholesale markets.

All the above mechanisms allow the electricity market to react efficiently even to an extremely high wind production. This was the case one day in January 2014, when wind power generation reached 105 % of the national demand, resulting in electricity prices going down to zero. Most of the power plants providing firm capacity turned off and the rest sold their electricity to other countries in the Nord Pool. DH systems with seasonal storage pits took the opportunity to load the storage with heat pumps and electric boilers for free.

I.II Solar DH and seasonal storage pits

Solar DH is rapidly growing in Denmark[17]. It currently covers 3-5 % of the total DH demand and is expected to achieve 15 % by 2025. By the end of 2015 there were 63 plants operating in Denmark (with a total panel area of 628 000 m^2); 13 000 m^2 in Norway; and 39 000 m^2 in Chile. The installed capacity in Denmark is expected to grow by 75 % to reach 1 million m^2 by the end of 2016, and 8 million m^2 by 2035.

The first solar DH plants were commissioned in the 1990's, in Denmark, and were supported through national and EU subsidies. A national expertise has been built since then and Danish **solar DH experts** are currently worldwide recognised. The concept consist in supplying a DH network with solar thermal energy coming from a solar field and is usually combined with other fuels and a heat storage system[18]. The lifespan of such a system is around 30 years. It has proved to be an efficient technology for DH companies to reduce their fossil-fuel dependence and guarantee stable and competitive prices to their clients.

[16] Eric Marinot (2015). *How is Denmark integrating balancing renewable energy today?*

[17] Real time data on solar irradiation and heat production of Danish plants is available on http://www.solvarmedata.dk/

[18] Details on the technology and deployment of solar district heating in the EU are provided on http://solar-district-heating.eu/ (EU supported project)

The use of **seasonal storage pits** allows shifting the delivery of solar heat from periods of higher production and lower demand (summer) to the heating season. The typical storage pit consist of an excavation in the ground covered with a watertight liner. The storage is filled with water and covered by a floating insulated cover. The first test and demonstration project for storage pits was established in Marstal (1993-2012) and was followed by second generation storage pits like the one in Dronninglund (in operation since 2014). Gram's neighbouring town, Vojens[19], has the world largest underground thermal storage pit with a capacity of 200 000 m^3.These systems have proved to be very efficient to increase flexibility in DH and allow integrating electricity from intermittent renewable sources, through electric boilers or heat pumps.

II. Presentation of Gram's DH system

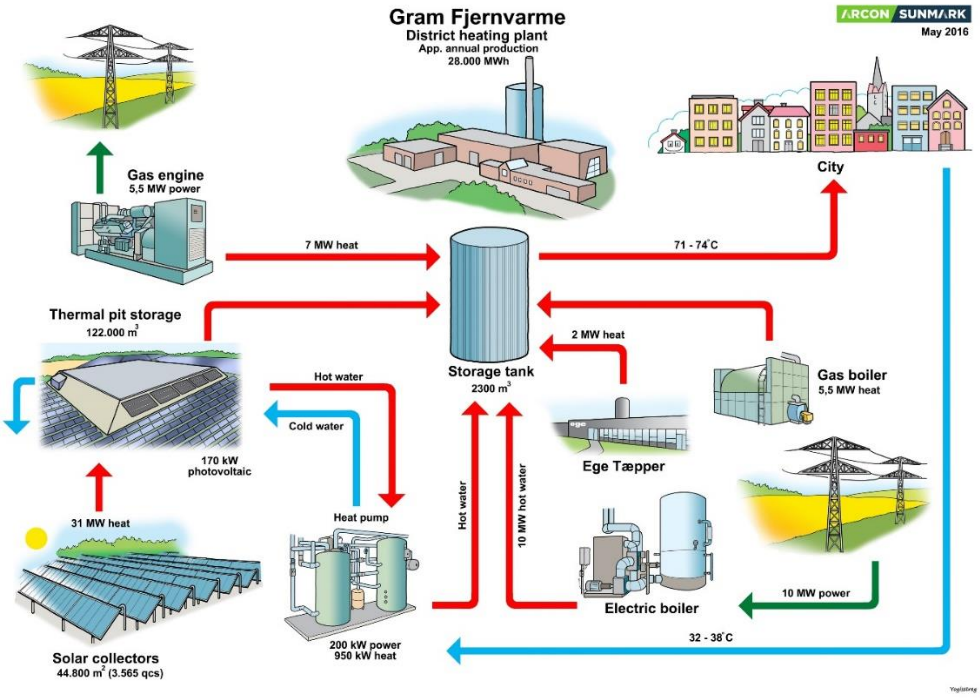
II.I Overview and history

Figure 10 illustrates the solar DH system with seasonal storage pit in Gram. Its main characteristics are summarised below, and further detailed in section II.II:

Key facts and figures

DH market share	~100 %
Maximal heat load	10 MW$_{th}$
Heat production	20 GWh/y (2015)
Km network (double-pipe)	21 km
CO_2 emissions	30 kg/MWh

- **Small system**: 1 171 clients (~2 500 people)
- **Consumer-owned cooperative**: Gram Fjernvarme (4 employees)
- **Flexible production, seasonal storage pit**:
  - 44 000 m^2 solar thermal panels (62 %)
  - A 10 MW electric boiler (14 %)
  - A 5 MW$_e$/6 MWth CHP gas engine (9 %)
  - A 5.5 MW gas boiler (7 %)
  - A 900 kW heat pump (5 %)
  - 2 MW industrial surplus heat (3 %)
  - 122 000 m^3 seasonal thermal storage pit (heat storage capacity: 8500 MWhth)



[19] More details on Vojens' system available on this link (https://stateofgreen.com)

Figure 10 DH system in Gram (Source: Gram Fjernvarme)

The first DH system of Gram was built in the 1960's, and was originally based on heavy oil. The energy mix has been progressively upgraded to integrate cost-efficient, renewable fuels. The latest upgrade ("the project" hereafter) was implemented between 2013 and 2015 and consisted in an increase of the existing solar field from 10 000 to 44 000 m^2, a new heat pump, an electric boiler, a surplus heat recovery system from a local carpet industry, a 122 000 m^3 seasonal storage pit and a new building for the cooperative offices and production units. It was commissioned in mid-2015 and supplies practically **all buildings in the town.**

The energy mix of the DH system for a standard year[20] is described in Figure 11. This energy mix is expected to vary from one year to another, depending on the electricity prices, to optimise the use of the electric boiler, CHP and heat pump.

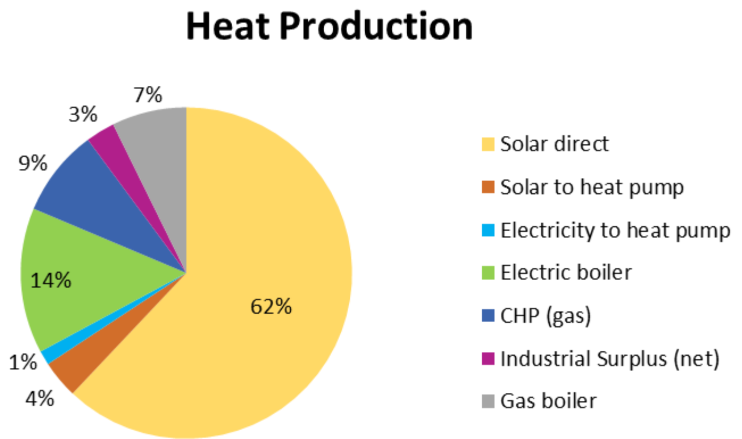


Figure 11 Fuel sources used for heat production in Gram (standard year)
Source: Ramboll[21]

II.II Main system components

II.II.1 Heat production

The characteristics of the production facilities of Gram's DH system are summarised below. These - as well as the land they are built on - are owned by the DH company and integrate complementary technologies able to optimise the heat production of the system:

i. **Solar thermal energy** was firstly introduced in Gram's DH system in 2009, with 10 073 m^2 of ground-mounted panels representing 16 % of the heat production. 34 727 m^2 additional panels were installed in 2015, resulting today in a total solar capacity of 31 MWth producing 18 GWh/y through 3 556 panels heating water to ca. 90 °C. This heated water can be used directly to heat the DH network through a heat exchanger or be stored in the seasonal storage pit.

Figure 12 Solar field and seasonal storage pit of Gram's DH system *(Source: Gram Fjernvarme)*

[20] At the time of writing this report, the system had not yet reached this "standard" production mix, as the seasonal storage pit needs between 2-3 years to adjust its operation.
[21] http://www.ramboll.com

ii. The 10 MW **electric boiler** allows using low-cost electricity -mainly produced by intermittent renewable energy sources such as wind and solar PV- for heating. The electricity used by Gram Fjernvarme for its electric boiler is mainly produced in Denmark and Germany. For the latter, Gram Fjernvarme has signed a contract with a **Balance Responsible Party**[22] (BRP) providing short-term trading optimisation services. In particular, when the German grid is overloaded due to high wind and solar penetration, the German TSO asks the Danish TSO for down regulating bids (a bid given to the balancing power market to reduce generation or increase consumption). The BRP acts on down regulating from the Danish TSO and Gram Fjernvarme gets free electricity to store in its DH system plus an availability fee for being able to take this electricity.

Denmark produced 42 % of its electricity from wind turbines in 2015 and this share is expected to increase in the coming years. **Coupling the electricity and heating systems** will facilitate achieving the national target of becoming fossil fuel-free by 2050.

iii. A 900 kW_{th}/200 kW_e **heat pump** with a COP of 4.5–5.0, which increases the heat production from the solar panels.

Even if both the electric boiler and the heat pump are fuelled by electricity, these technologies are complementary and play a different role in the system, which is able to optimise its generation in real time based on technical and economic criteria. The heat pump is indeed more efficient than the electric boiler, but has a lower capacity and is not aimed at providing balancing to the electricity grid.

iv. 1 000 MWh/y of net **surplus heat**, recovered from a local carpet industry which supplies the DH network with 2 000 MWh/y and consumes 1 000 MWh/y from it.

v. **A gas engine generating electricity and heat** at high electricity prices, usually taking over when the heat pump stops.

vi. And finally, a **gas boiler** for peak and back-up capacity.

II.II.2 Seasonal storage

Gram's seasonal storage pit is the key element providing a high degree of flexibility to the operation of the DH system.

It is a 110 x 125 x 15 m ground-buried storage pit filled with 122 000 m^3 of water, able to store up to 8.500 MWh of heat. Water tightness is obtained by covering the soil with a high-density polyethylene (HDPE) liner and the top surface with an insulated floating cover. In order to transfer heat to and from the storage there are four pipe connections at different heights of the storage pit (one on top, one at the bottom and two in the middle with 1 m space in height), allowing to use the lower part for lower temperatures (e.g. as a cold source for the heat pump) and the top part for higher temperatures (mainly to supply the DH grid). A temperature gradient is thus created in the storage pit, going from 20 °C to 74 °C and determining its energy storage capacity.

During the first 2-3 years[23] of operation, the system **needs to be adjusted to reach design conditions** (including the expected heat production mix). Under these standard conditions, loading starts in April and the peak load is reached in September. Off-loading takes place between October and January, as illustrated in Figure 13 below.

[22] In this case, Neas Energy (http://www.neasenergy.com)
[23] It is needed ca. 1 year for heating the storage pit and 1-2 years to adjust the operation of the DH system

III. Local heating market

III.I Heating market

Gram's consumer-owned cooperative has progressively developed a **flexible and efficient** model for heat supply in the town that allows integrating a high share of **renewable energies** at competitive prices.

III.I.1. Demand and supply

Gram has an annual heating demand of ca. **3 000 heating degree-days**, supplied practically at 100 % through district heating.

The buildings connected to the DH network are **mainly one-family houses** (86.4 % of the total demand), and in a lower share apartment buildings (6.8 %), tertiary buildings (5.7 %) and a local industry (1.1 %). Residential buildings have a typical consumption of ca. 140 kWh/m^2/y (incl. heating and domestic hot water)[24]. The heat demand and client base (connections) have been slightly increasing during the last 5 years[25].

A **consumer-owned cooperative** -Gram Fjernvarme- owns and operates the DH system[26]. The diversified production mix, seasonal energy storage pit and automatic control unit makes the system **very flexible** and facilitates the **dynamic optimisation of the heat production and supply**. In particular, when the weather conditions are good and electricity prices are low, it is possible to stop the most expensive production from the gas boiler.

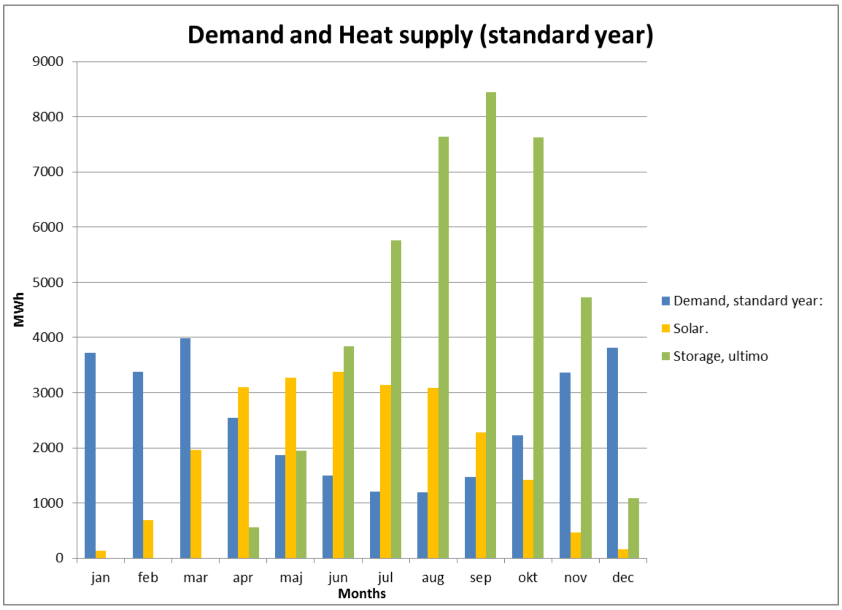


Figure 13 Monthly load profile of Gram DH system (Source: Ramboll)

The **monthly load profile** of the system is represented on Figure 13 above for a standard year. The chart shows the heat demand (in blue), solar thermal production (in yellow) and cumulated heat stored in the seasonal storage pit on the last hour of each month (in green). During the winter, the solar production and stored energy are not sufficient to meet the demand, and the heat is supplied through the surplus industrial heat, electric boiler, heat pump and gas CHP engine. The maximum storage capacity (ca. 8500 MWh) is only fully used in September. The rest of the year there is capacity available to store heat produced

24 Typical household of 130 m^2 consuming 18.1 MWh/y
25 Between 2-5 new connections per year
26 Details on the network (map) available on this link

by the electric boiler, the heat pump, the gas engine (depending on electricity prices) and surplus industrial heat.

An automatic control unit optimises the daily production of heat depending on the demand and electricity prices on the market. It grants priority dispatch to solar, industrial surplus and stored heat (in this order).

III.I.2 Price competitiveness

The main alternative to DH in Gram consist in using individual gas boilers, which would be more expensive than the current DH supply. As explained before, **competition between different heating** options (district heating grid, gas grid and individual heat sources) **takes place at planning stage**, through the "project proposal" procedure.

In 2016, the average price for DH in Gram is EUR **85.4/MWh** (including 25 % VAT)[27], which is 16.5 % lower than the previous year, mainly because of the project. Moreover, the project has made the DH system of Gram more resilient to fuel price fluctuations. Tariff structure is explained in section IV.II. In the national statistics, Gram Fjernvarme is among the 35 % cheapest companies.

IV. Business model

IV.I Governance and strategy

Gram Fjernvarme[28] is a **consumer-owned cooperative**, which is managed through a **board of directors**, elected annually at the General Assembly. The Board consist of 6 members, including 5 consumers and 1 representative of the municipality (due to the fact that it has provided a municipal guarantee for the loans of the cooperative). The first 5 board members are elected every 2 years on a voluntary basis and can be re-elected.

The strategy of the cooperative is in line with other DH companies in Denmark, namely providing a **high quality service, reducing the cost of heating** and **reducing CO_2 emissions**.

The cooperative currently employs 4 people: an operations manager, 2 administrative assistants and an O&M technician.

IV.II Financial model

Gram's project was one of the first solar district heating projects with heat storage pit in Denmark undertaken without any investment grant. The total **investment** was ca. EUR 15 million and was mainly financed through a loan from the *Kommune bank*[29] with a municipal guarantee. The depreciation of the investment and the expected payback time for the loan is 25 years corresponding to a depreciation of 4 % each year. The investment breakdown is described below.

Investment breakdown	EUR
Land	586 667
Seasonal storage pit	3 013 333
Buildings	1 733 333
Solar field, heat pump and electric boiler	9 066 667
Other	600 000
TOTAL	**15 000 000**

[27] In 2016 the average tariff is DKK 12,071/standard consumer (18.1 MWh)

[28] http://www.gram-fjernvarme.dk/

[29] Cf. Copenhagen's case study in section 4.2.1, section I.II (Financial instruments)

These investments are recovered mainly through the heat sales. The **heat tariff** has two components:

i. Fixed component: calculated as a function of the heated floor area in m^2 (3.2 EUR/m^2/y incl. TVA in 2016);
ii. Variable component: unit price per MWh of heat consumed (EUR 63/MWh incl. TVA in 2016).

For new connections, a **connection fee** of ca. EUR 17/m^2 is applied[30].
Due to the **non-for-profit** principle ruling Danish DH, the income is used to cover the company's costs. In 2015 the turnover of Gram Fjernvarme was EUR 2.4 million.

Each consumer has an **individual meter** and can check DH bills on the company's website.

Invoicing takes place every 3 months based on a consumption forecast, which is annually adjusted based on real (measured) consumption. Tariffs are updated on a quarterly basis.

IV.III Client relationships

Consumers are in general **very satisfied** with the quality of the service, as expressed in frequent exchanges with the cooperative's employees. The level of **transparency** of the prices, and strategy is very high and directly influenced by the consumers.

Among the cooperative's clients there is one "**prosumer**", a local carpet industry which has supplied the DH network with surplus heat since 2015. Both parties have agreed on the prices for the heat supplied from the industrial actor to the network and vice versa.

V. Framework for innovation

Gram's DH network is a pilot project demonstrating the high potential of renewable-energy-based DH systems coupled with a seasonal storage pit. Indeed, the larger deployment of this kind of systems could facilitate a higher integration of intermittent renewable energy production while reducing the carbon footprint of heat supply.

RDI activities have been crucial to achieve the maturity of the technologies used in Gram, in particular for solar DH and seasonal storage pit. The available **DH expertise in Denmark** (consultants, technology suppliers, research centres, etc.) is at the core of the new and innovative approaches to DH in the country aiming at improving the system's flexibility and ultimately reducing the cost of the heat supply and its environmental impact.

VI. Perspectives

Gram's DH cooperative is expected to continue its efforts to lower the cost and CO_2 emissions of its heat supply while sharing the lessons learnt and results of the project.

- The system is still ongoing some operational adjustments to reach design conditions (mainly for the load dispatch of the storage pit). After 2-3 years of fine-tuning, it is expected to **reach its optimal operation** and therefore realise all the benefits of the project.
- Gram experience can inspire other municipalities and its model for heat supply is expected to be **replicated** in Denmark and abroad. Its innovative DH system is

[30] 2016 prices, there is a fee cap defined per type of client (e.g. max. EUR 3023 incl. TVA for one-family houses)

gaining visibility worldwide, which could potentially have an additional positive impact on the local economy.

- Gram has gradually upgraded its DH system to improve its cost-efficiency and carbon footprint. However, there is still room for improvement notably through the use of biomass or a large heat pump.
  - National law imposes Gram to use the local natural gas infrastructure (CHP plant and gas engine). Nevertheless, the support framework for **biomass** may evolve in the coming years to support the ambitious national environmental targets, and could lead to a fuel switch from gas to biomass in Gram's DH system. However, gas engines in Gram will probably remain operative to provide peak capacity to the Danish electricity system and ensure security of supply, especially in dry years when hydro production is lower and the electricity prices are higher. Denmark is indeed investigating how to secure its future electricity system and pay the owners of gas engines to provide the needed peak capacity.
  - Another option could be a **large electric heat pump**, that would become particularly relevant if the electricity distribution tariff and the electricity tax reflected the benefits of a large "smart" consumer able to consume large amounts of electricity and be totally disrupted even during long periods in case of capacity constraints or high electricity prices, therefore facilitating the integration of intermittent wind generation.

VII. Conclusion: Key Success Factors

The solar DH system with seasonal storage pit in Gram shows how existing (mature) technology can be combined in an innovative way to increase the flexibility and efficiency of the heat supply in cities.

Most of the key success factors found on this DH system coincide with those mentioned before for the DHC system of Greater Copenhagen, as they are the basis of the "Danish model" for heat supply.

In particular, the fiscal and regulatory framework for district heating in Denmark played a crucial role in developing Gram's DH system:

i. **Coherent and stable policy framework for DH** established by the Heat Supply Act.

ii. **Relevant tax incentives.**

iii. **Coherent urban municipal heat supply planning, including heat mapping.** The "project proposal" procedure has allowed Gram to upgrade progressively its DH system in order to increase its efficiency, flexibility and ultimately lower the cost of heat for final users.

iv. **Well-developed supply chain.** Alike Greater Copenhagen, Gram has also benefited from the national DH expertise to enhance the performance of its DH system. Gram's DH cooperative hired a consultancy company for the design of the latest upgrades of the network, feasibility studies, project proposal and meetings the Authorities, works' supervision, commissioning and operation adjustment.

However, the success of Gram's DH system does not only lie in its national context. The specific key facts influencing the good performance of the system are described below:

v. **Alignment of interests between the municipality, DH company, potential producers and final users (governance efficiency)**. The board of the cooperative includes representatives of the municipality and final users and is responsible for improving the system's efficiency to meet the objectives in terms of quality of supply and low prices. Co-operation between different stakeholders and transparency facilitate the board's task of identifying the best possible solution given the local conditions. This high level of institutional efficiency is typical for the Danish DH model.

vi. **Customer's empowerment.** Customers are the owners and decision-makers of the DH system, through the cooperative Gram Fjernvarme. The long tradition of cooperatives in Denmark has brought efficient procedures for their management and operation, which can be seen in Gram. This organisational mode builds on cooperation and transparency to achieve common goals, and results in enhanced local acceptance of DH.

vii. **High flexibility in the system's operation.** Its diversified energy mix, seasonal storage pit and high degree of automatization for the daily optimisation of heat production and supply makes Gram's DH system very flexible and cost-efficient.

viii. **Connecting the electricity and heating markets**. The use of seasonal storage pits allows integrating intermittent renewable sources (namely wind and solar) to provide low-carbon heating to buildings and industries. Gram's model shows how the electricity and heating markets can be connected to improve their cost-efficiency and sustainability, resulting in higher capacity to integrate renewable energy sources, avoided balancing costs for these and a lower use of fossil fuels for heating.

ix. **Competitive prices.** The current scheme for DH in Gram has proved to be more cost-efficient than the alternative options for heat supply, namely gas boilers. This is mainly due to the flexibility of the system as well as the fiscal national framework for DH, access to competitive debt funding and the long-term approach (CBA) applied during the "project proposal" procedure.

x. **Innovation.** Gram's DH system uses state-of-the-art technology combined in an innovative way to provide flexibility and increase the share of renewable energy sources. The development of solar DH and seasonal storage pits has been strongly supported by RDI activities in Denmark, funded through national and EU funds at its first stages.

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2.2.3 ESTONIA: District Heating and Cooling in Tartu

In Estonia, 70 % of the heat demand is supplied through district heating. This is also the case in Tartu, the second Estonian city in terms of population (ca. 100.000), which has managed to upgrade its old DH network to turn it into a world-class system based on local renewable fuels.

*Some of the key factors contributing to the overall efficiency of the DHC system include: i) a **coherent policy framework** for DH; ii) a long-term visibility on prices; iii) a **comprehensive urban planning**, including DH zoning; iv) an **alignment of interests** between the municipality, DHC company and final users; v) the **strategic fuel shift** to use local biomass and peat through a CHP plant, resulting in more **competitive prices**; vi) a minimum **critical size** of the grid; and vii) the **technical and financial backup from its private operator**, Fortum Tartu.*

I National context

I.I Overview and drivers for DHC in Estonia

Estonia has a **long tradition in district heating** (DH), while district cooling (DC) is a new business. DH is today the most common option for heat supply, with a market share of 70 % and more than 200 DH networks, most of them **privately owned**. The only DC network in operation is located in Tartu, and it is also privately owned.

The main alternative to DH is natural gas, where available. The other main alternatives are individual heat pumps -which are increasing their presence due to the low prices of electricity (EUR 30-35/MWh in average) - and wood-burning stoves.

The district heating sector and its prices are **fully regulated at national level** through the regulatory tools described in section I.II. The Regulatory Authority is the Estonian Competition Authority[31] (ECA), which is today working on the progressive deregulation of DH, in close collaboration with the Ministry of Economic Affairs and Communications (MEAC). Indeed, Estonia is developing its **2030 National Energy Development Plan**, which includes among its core objectives 80 % renewable energy share in heating and a subsidy-free and sustainable DH sector.

The national Government promotes **energy efficiency** (EE) through several programmes providing grants and technical assistance to improve the EE in buildings, utilities, public lighting, DH, etc. In particular, the ECA requires DH companies to prove EE improvements or to present an energy efficiency plan for reducing heat losses or improving their generation efficiency. As a result, heat losses in DH have been reducing for the last 15 years, as illustrated in Figure 14, and this tendency is expected to continue. In 2016, these heat losses represented 16 % of the heat generation and are expected to be 15 % in 2017.

[31] The Estonian Competition Authority is a national independent regulator and national competition authority that exercises supervision in the fields of competition, electricity, natural gas, district heating, postal services, public water supply and sewerage and railways (http://www.konkurentsiamet.ee/)

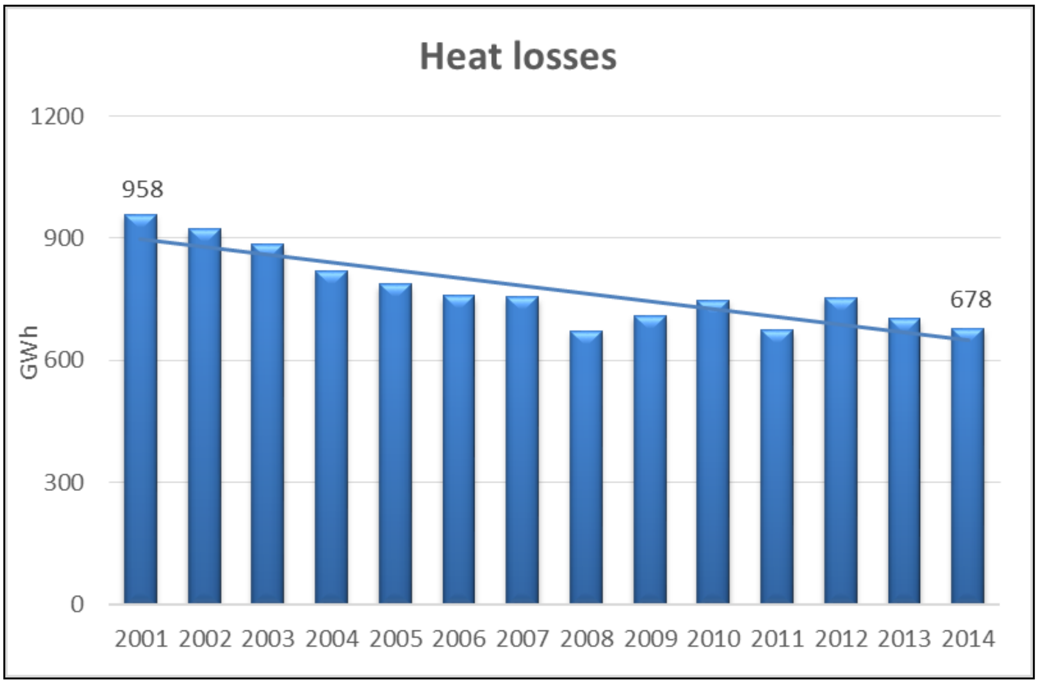


Figure 14 Heat losses in Estonian DH sector (Source: ECA)

The **DH fuel mix** has also significantly reduced its fossil-fuel share since 2000 to replace it with **biomass,** as presented in Figure 15. The use of biomass has been promoted since the end of the 1990's due to the availability of national resources (forests) at low and stable prices, providing a competitive alternative against fluctuating fossil fuel prices.

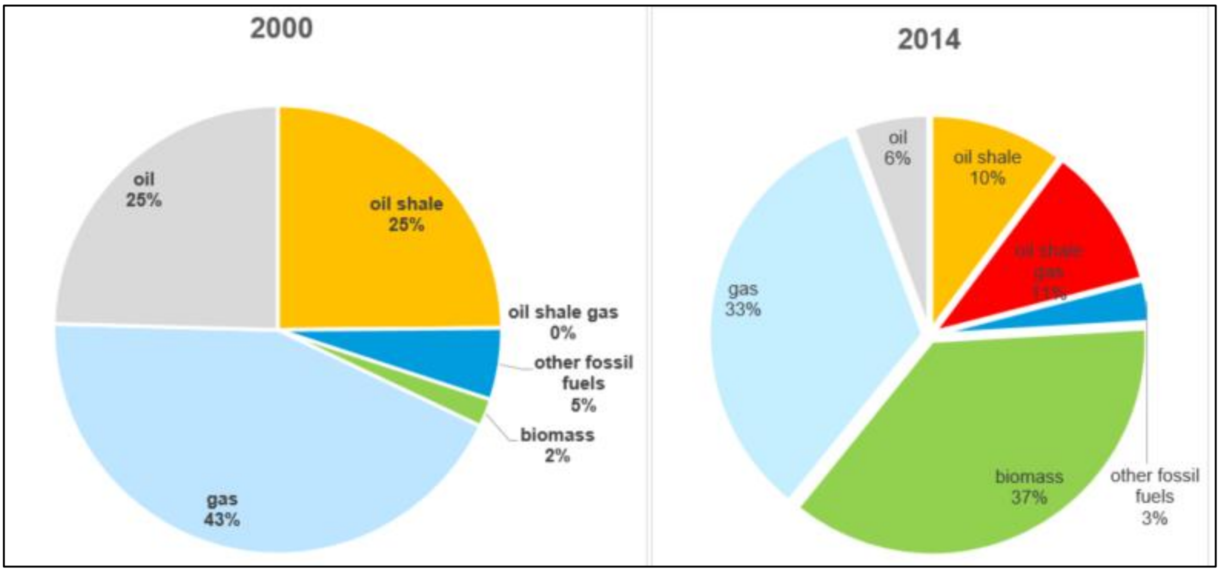


Figure 15 Energy mix of DH in 2000 and 2014 (Source: ECA)

The Government of Estonia supports **renewable electricity generation and CHP** through two separate feed-in premiums on top of the electricity spot market price. These are established by the Electricity Market Act from 2007 at EUR 53/MWh for renewable electricity and EUR 32/MWh for CHP-generated electricity.

I.II Legal and regulatory framework for DH

Estonia is often presented as a good example of a centrally regulated DH market, with a **coherent regulatory framework** where the roles and responsibilities of the different parties are clear and operational. This framework is currently being reviewed to make the first steps towards lighter regulation and paving the way for the de-regulation of the DH sector.

An **ex-ante cost-plus DH price regulation** is in place. The historical development of this regulation and its main characteristics are summarised below.

i. Until 1998 a soft type of price regulation was undertaken by municipalities.

ii. In 1998, the Energy Act introduces an **ex-ante price** for DH grids and heat-only boilers that is established on a case-by-case basis by a new national regulator (at that time, the Energy Market Inspectorate) as a maximum price for end-users (**DH price cap**). This price cap is based on a **cost-plus** approach, where price levels are established so that the DH operator can cover its costs (CAPEX and OPEX) and receive a "reasonable" return on net assets (RONA). The RONA is calculated as the Regulatory Asset Base (i.e. asset book value) multiplied by the Weighted Average Cost of Capital (WACC), which is today calculated following a methodology publicly available on ECA's website[32]. One of the main disadvantages of cost-plus prices is that it does not promote EE and cost reductions.

iii. Heat price from CHP plants is also regulated, and is established based on the total cost of an alternative heat-only boiler which would use the same fuel or fuel mix, i.e. the heat from a biomass-CHP is capped by the alternative total cost of a biomass heat-only boiler of similar size, using a cost-plus method (a "virtual heating plant").

iv. In 2004 the **District Heating Act** comes into force, allowing municipalities to establish **DH zones** where DH is the only option for heat supply, with the exception of fuel-free (i.e. heat pumps) or renewable energy sources. However, this Act does not provide a methodology or criteria to establish a DH zone, leaving it up to municipalities.

v. In 2010, the DH Act is amended to establish the ECA as the DH regulator as well as **third party access** rules. These rules consist mainly in the obligation for DH operators to organise a tender for new generation capacity, where tender documents have to be approved by the ECA.

vi. Since 2013, the ECA and Ministry (MEAC) are cooperating to develop a **New DH Act**, which is expected to come into force by the end of 2016.The main driver for this new Act is attracting investors for biomass generation capacity and EE improvements. In particular, the main new elements are as follows:

    - It allows a **two-component tariff,** i.e. a fixed component based on contracted capacity (EUR/kW) and a variable component based on heat delivered (EUR/MWh), while today there is only an one-component tariff based on heat consumption (EUR/MWh);

    - It introduces a **reference price** and allows DH companies offering prices lower than this reference price to operate on a commercial basis (i.e. without price regulation). Figure 16 below shows the current DH prices per city and the expected reference price level (EUR 54-55/MWh[33]). However, at the time of writing this report it had not been decided yet if the reference price will be established in the new DH Act.

[32] http://www.konkurentsiamet.ee

[33] Estimate as in May 2016

With this new Act, the Government aims at **supporting DH only when it is the most economical source of heat supply**, which is today not the case in some small cities.

The new DH Act is expected to lead to a more efficient heat supply, where cheap and efficient DH systems are promoted and inefficient and expensive ones are decommissioned and substituted by individual heating solutions. Estonia has already integrated these principles in its eligibility criteria for **EU structural funds**, requiring cities to prove the long-term[34] feasibility of DH investments and their competitiveness against the alternative source of heat supply. When an individual solution proves to be the preferred option, these EU funds can be used for decommissioning the DH network and realising the new investments for individual heat solutions.

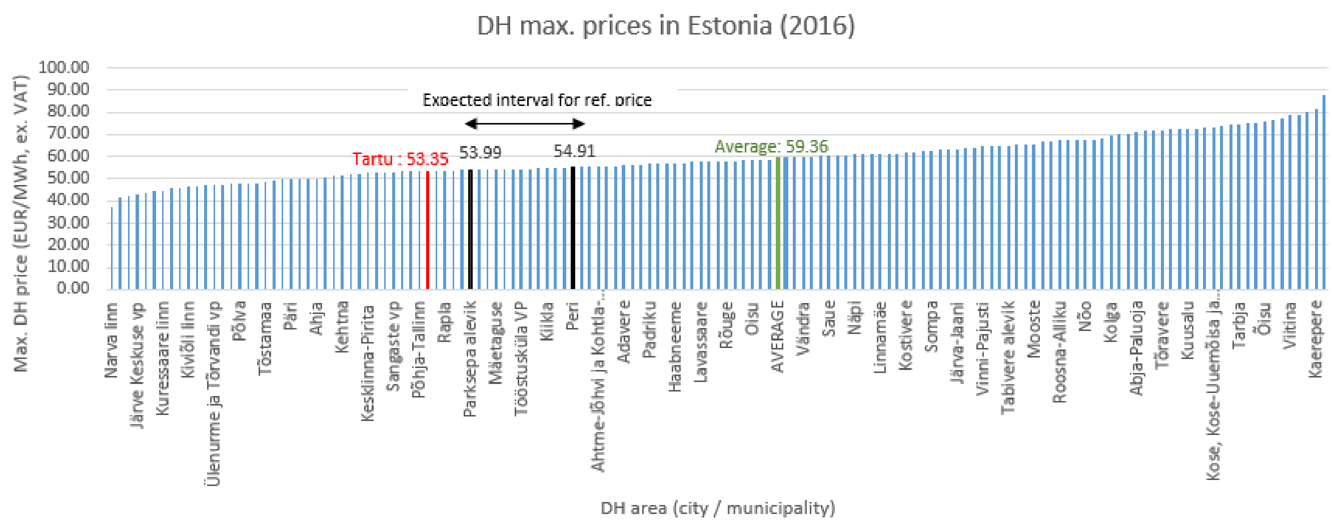


Figure 16 Maximum DH prices for end-users in Estonia and expected interval for reference DH price (Source: ECA)

II. Presentation of Tartu DHC system

The map below illustrates the DH system in Tartu. Its main characteristics are summarised below:

- **Medium-size system**: ~80 000 final users
- **Private network**: Owned and operated by Fortum Tartu
- **Efficient production**:
  - 50 MW_{th}/25 MW_{e} biomass CHP plant, equipped with 15 MW flue gas condenser
  - Gas boilers for peak capacity
  - Waste heat from a local paper industry
- **District Cooling**: 1 DC plant in operation, 3 more in the pipeline
  - Free cooling from the river
  - A heat pump and peak chiller ~13 MW

Key facts and figures

DH market share	50 % of buildings (75 % citizens)
Heating & Cooling capacity	DH: 328 MW DC: 13 MW
Heat &Cold production	DH: 500 GWh/y DC: 1.3 GWh/y
Km network (double-pipe)	DH: 163 km DC: N.a.
CO2 emissions (heating)	0.102 kg/MWh

[34] 15-20 years

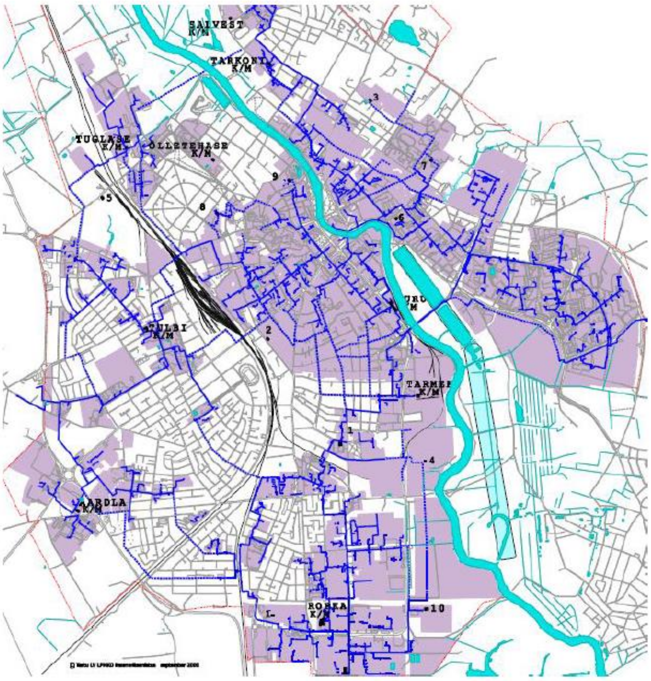


Figure 17 DH system in Tartu (coloured areas represent DH zoning)
Source: Fortum Tartu

Tartu’s DH system has undergone several **changes in ownership** and **technology upgrades** that make it one of the best functioning in the country.

DH was established in Tartu in 1967 and was firstly owned by the State and later by the municipality. In 1995, the system participated in a renovation programme financed by the World Bank and the EBRD[35] consisting in switching its fuel from gas and oil to **local and renewable sources**, namely peat and biomass. In year 2000, DH went through a **privatisation** process and became part of the Finish company Kotka Energy Holding SA, which sold its shares in 2004 to Fortum Heat and Power OY (60 %) and AS Giga (40 %) with the name AS **Fortum Tartu** (current situation). Since then, a number of new products were introduced and the network was extended, representing important investments and resulting in an improved efficiency and quality service. These are summarised below:

- In 2006, the company started its **own local fuel supply** (for biomass sourcing and peat production), to complete its vertical integration (from fuel production and sourcing to sales). Fortum Tartu has 25-year peat extraction contracts with the State, which remains the owner of the peatlands, while woodchips and wood waste are bought in the market.
- In 2007, Fortum Tartu starts the development of a new **CHP plant** fuelled by biomass and peat. This plant is commissioned in 2009, benefiting from the newly published CHP premium tariffs.
- Between 2009 and 2014 the system continues **expanding**, mainly through the acquisition of another local DH system in 2013 in the “Tamme” area (90 GWh of sales, 3 production units, 34 km pipeline) and the installation of new peak capacity.
- In 2014, the development of **district cooling** projects starts and the first DC plant is commissioned in May 2016, becoming the first DC network in the Baltics.

The DH system of Tartu supplies mainly the **residential and tertiary sectors**. Figure 18 below provides further details on the production capacity of the system, while its **energy**

[35] European Bank for Reconstruction and Development

mix is described in Figure 19 and dominated by local woodchips (76 %). The table below also indicates the generating units which can be controlled from a centralised control room (the so-called "remote controlled"). This allows an enhanced overall monitoring and operation of the system and reduces the reaction time in case of unavailability defaults.

Site	Type	Remote controlled	Boiler 1	Boiler 2	Boiler 3	Fuel	Build year (years left)	Real capacity total
Anne Soojus	CHP	Yes	50			Bio, peat	2009	50
Anne Soojus	FGC	Yes	15,7			Flue gas	2009	15,7
Anne	HOB	Yes	21x2	38,5x2		Bio, peat, NG	2014/1983	110
Anne	FGC	Yes	4,2				2005	4,2
Ropka	HOB	Yes	37	37		NG	2014	72
Turu 56	HOB		4			oil	1996	4
Tamme, Aardla113	HOB		6,5	7	7	Bio, NG	2013	22,5
Tamme, Aardla 113	FGC		2			Flue gas	2013	2
Tamme, Tulbi 12	HOB	Ongoing	15	15		NG	2013	30
Tamme, Vaksali 51	HOB	Yes	7x2	1,3x3		NG	2013	17,9
Summary								**328,3** MW

Figure 18 Heat production capacity in Tartu (Source: Fortum Tartu)

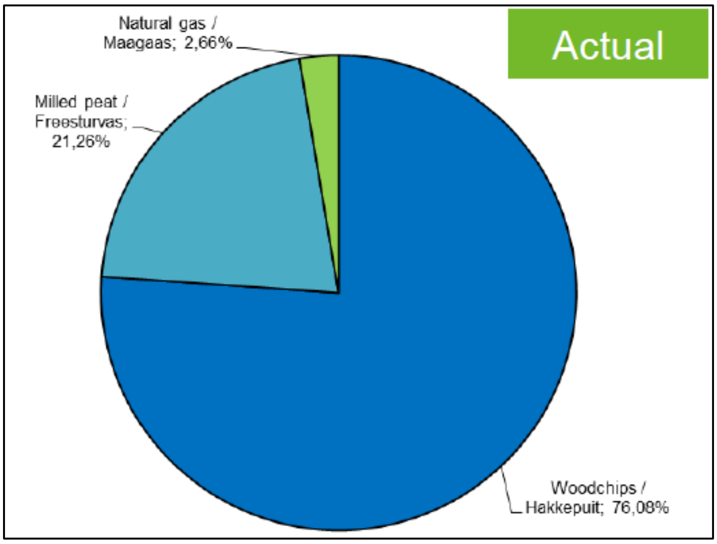


Figure 19 Energy mix of the heat supply (MWh) in 2015 (Source: Fortum Tartu)

III. Urban development and expansion of DHC

Tartu's City Council has strongly supported the deployment of DH in the city, mainly through a comprehensive city planning and DH zoning. There is a good level of **cooperation** between Fortum Tartu and the municipality, as both have managed to **align their interests** and establish a win-win relationship.

The first urban development **Master Plan** of Tartu was established in 1999 and focused on sustainable development. It included a **DH zoning,** aiming at improving the air quality in the city and avoiding DH disconnections. Indeed, **air quality** was very low at the time due to the extensive use of stoves in households –burning not only wood but also waste - and the lack of investments in the DH system, which had seriously affected the quality of the service and resulted in increasing disconnections. The City Council published a report and organised public campaigns to **raise awareness** about the risk of these stoves and to justify the DH zoning.

In the areas defined as **DH zones**, all new buildings and those undergoing a major renovation must be connected to the network. These areas are readjusted when the Master Plan is updated. The current DH areas where defined in 2006, following a negotiation process between Fortum Tartu and the city. Around 70 % of Fortum Tartu's clients are established in a DH zone, while the rest are connected to the network on a voluntary basis. The only **exceptions** to mandatory connection in the appointed district heating zones are houses having an energy demand below **40 kWh/m²/year** or being supplied with an **environmentally cleaner** heating (e.g. geothermal heating or solar thermal panels).

The City Council does not have a direct influence in the DH business, neither in the company's ownership nor in its operation. However, it takes into account DH needs when organising their **urban planning** (e.g. trying to densify the city and defining DH zones in energy dense areas close to the existing network).

The city's strategy gives an important role to **innovation.** Tartu participates in a **smart city** project[36] financed by Horizon 2020 which includes some initiatives in the fields of transport (electric vehicles for the public fleet and taxis), public lighting and building's thermal renovation. The latter focuses on an area with old and inefficient houses and mainly consists in retrofitting the building's envelope, connecting them to the DH grid and installing IT energy management systems. Other innovative initiatives such as the new **district cooling** network are also supported by the City Council.

IV. Local heating and cooling market

IV.I Heating market

Tartu DH network supplies around **50 % of the buildings** in the city and 75 % of its citizens.

IV.I.1 Demand and supply

The weather conditions in Tartu are favourable to DH: **3894 heating degree days[37]** (HDD) and a rather long heating season (7 months above 325 HDD).

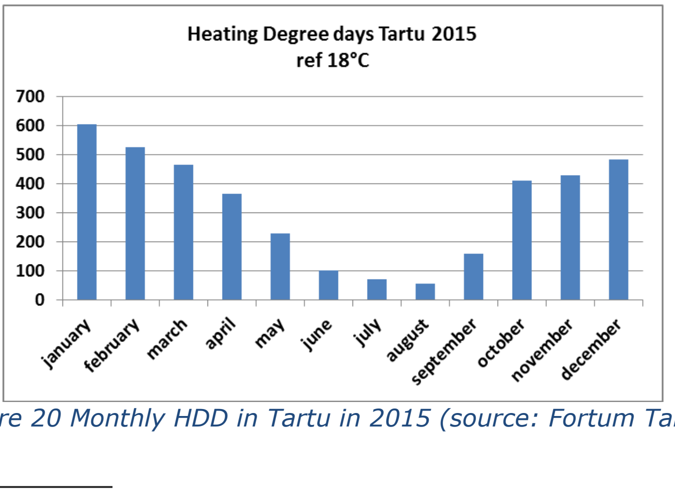


Figure 20 Monthly HDD in Tartu in 2015 (source: Fortum Tartu)

[36] *Towards Smart Zero CO_2 Cities across Europe* project (participating countries: EE, ES, DK, IT, BG, DE)
[37] with reference temperature of 18 °C

However, the linear thermal density of the network is not very high (507 GWh / 163 km = 3.11 GWh / km) compared to other European networks, which means that **densification is still possible** and expected to take place.

As explained before, DH zones are defined by the city's general planning in discussion with the DH company. The regulated zones are defined considering a minimum demand for residential buildings and a reasonable connection fee.

The typical heat consumption[38] for old buildings is **150-180 kWh/m²/y** and **80-110 kWh/m²/y** for new and renovated buildings (theoretical assumption).

As market prices of local biofuels are cheaper than natural gas (cf. Figure 21), the merit order is rather simple and fully controlled by Fortum, that also benefits from its own peat production, around 40% cheaper than market prices. Base load is covered through biomass CHP, then local fuel boilers are activated and finally peak load is covered with natural gas boilers. The possible peak capacity reaches **235 MW**, from which 120 MW is provided by gas boilers. However, gas usage is usually below 6 % of the total fuel consumption.

The graph below also shows the volatility of gas prices, while peat and woodchips prices have remained rather stable. The availability of peat and woodchips is indeed very good. The current market price for peat is EUR 11/MWh and for woodchips EUR 14/MWh.

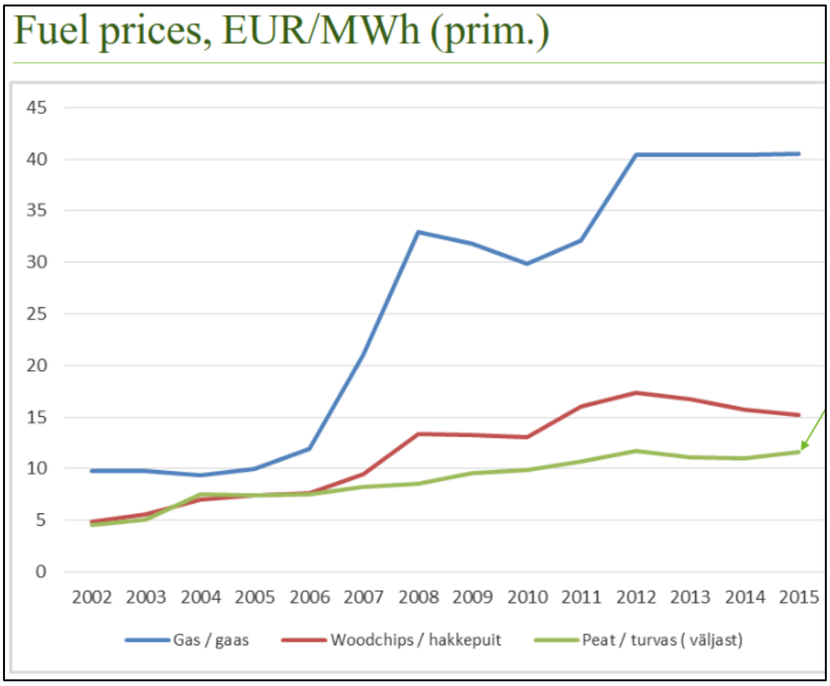


Figure 21 Fuel prices (source: Fortum Tartu)

IV.I.2 Price competitiveness

Tartu district heating price in 2016 is around EUR **51.05/MWh** (**ex. taxes**), which is lower than the average national price for DH (approximately EUR 60/MWh). Tartu DH price is based on a cost-plus based one-component tariff, which means rather high volatility of heating costs for an end-user, as annual outdoor temperatures can vary by more than 10 %. This is expected to change when the new DH Act allowing a two-component tariff enters into force.

[38] Including heat for heating and domestic hot water

The main competitors for DH are **individual natural gas boilers** and in some cases **wood-burning stoves** (mainly in one-family houses) or direct **electrical heating**. The graph below shows that Tartu's DH price was cheaper than natural gas until 2016, when both prices became comparable considering the following assumptions: EUR 30.6/MWh variable cost (i.e. cost of natural gas) and EUR 20.4/MWh fixed cost (i.e. O&M and amortization of the boiler)[39].

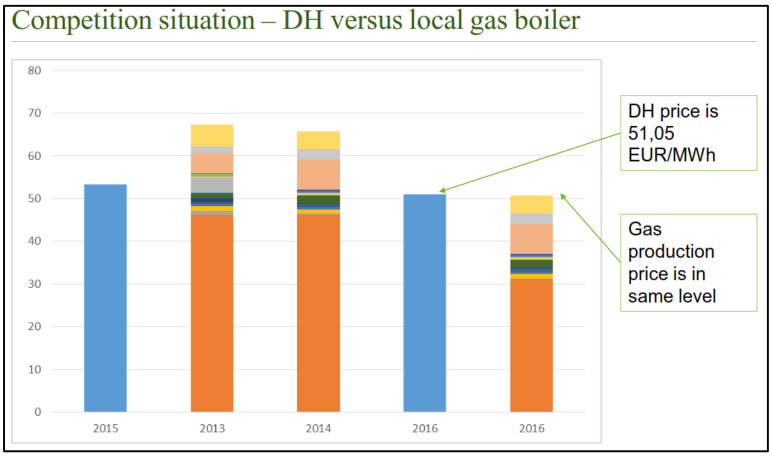
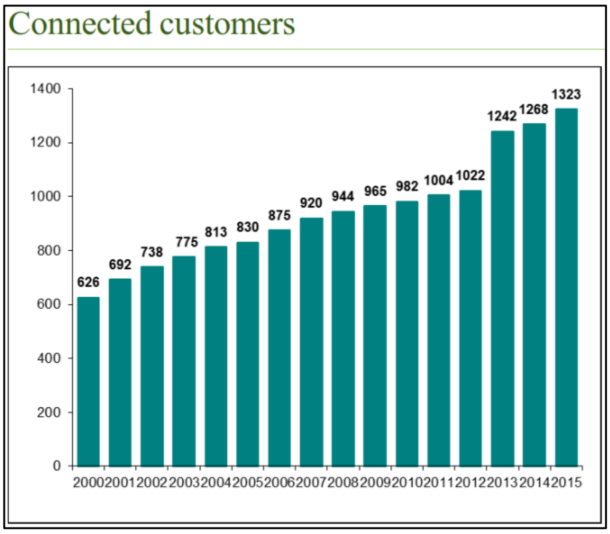
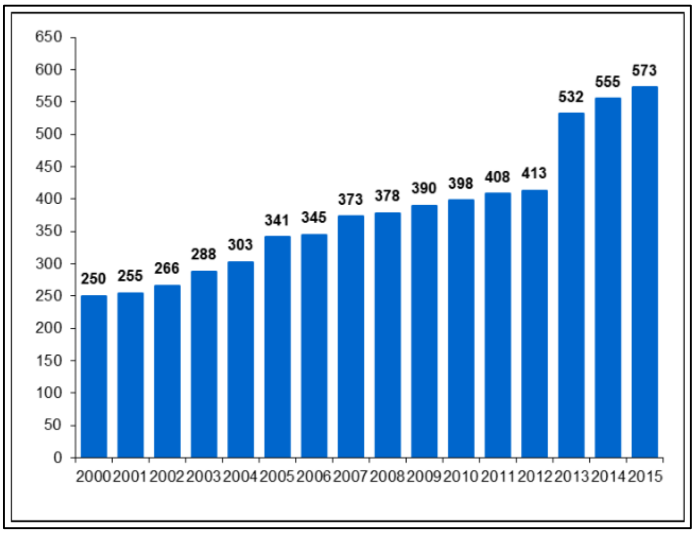


Figure 22 Comparison between DH and natural gas boiler prices in Tartu (source: Fortum Tartu)

The client base of Tartu's DH system has been increasing since 2000, as described in Figure 23. During the last 15 years, the average increase in capacity was 21.5 additional MW/year and the capacity was multiplied by 2.3, which shows the good health of DH system. In 2015, there was a capacity increase of 26.87 MW, corresponding to 55 new clients and 80 new connections.





Number of clients Connection capacity in MW

Figure 23 Evolution of connection to Tartu DH grid between 2000 and 2015. Stepwise increase in 2013 due to the acquisition of Tamme Soojus in Tartu (source: Fortum Tartu)

The **development strategy** of the DH company is fully supported by the city, mainly because of the identified air quality issues mentioned in section III. The market potential has been clearly identified: the short-term target is to connect all customers close to the existing network, roughly 46 clients currently using individual gas boilers in nearby residential areas.

[39] It should be noted that the cost of natural gas boiler does not include any CO_2 related environmental costs, which are applied to HOBs of bigger capacity

IV.II Cooling market

The new District Cooling network commissioned in May 2016 is the first DC network in the Baltics and is based on **free cooling from the city's river**. Its first customers were a new shopping centre and a hotel located in the city centre, and it will supply other tertiary buildings as the network grows. Most of the DC customers are expected to be also DH customers.

Fortum Tartu identified four areas for DC development, illustrated in Figure 24 below.

Figure 24 Areas identified for DC development (Source: Fortum Tartu)

- The total current potential of the city centre (area #1 in the map) is close to **15 MW,** with a short-term target of 11 MW (before 2019) and additional 4 MW in the long term (2019 to 2021).This corresponds to an estimated cooling demand of **18 GWh/y**. Following the latest publication of urban plans by the municipality, additional 5 MW are have been identified in this area.

- Other potential areas include Lõunakeskus trade park (area #4 in the map), with a potential of **8.4 MW** cooling capacity (classic centralized cooling production plant).

V. Business model

V.I Governance and strategy

AS Fortum Tartu is a private holding company, owning and operating Tartu's DH system since **2004**. It is owned by Fortum Heat and Power OY (60 %) and AS Giga (40 %).

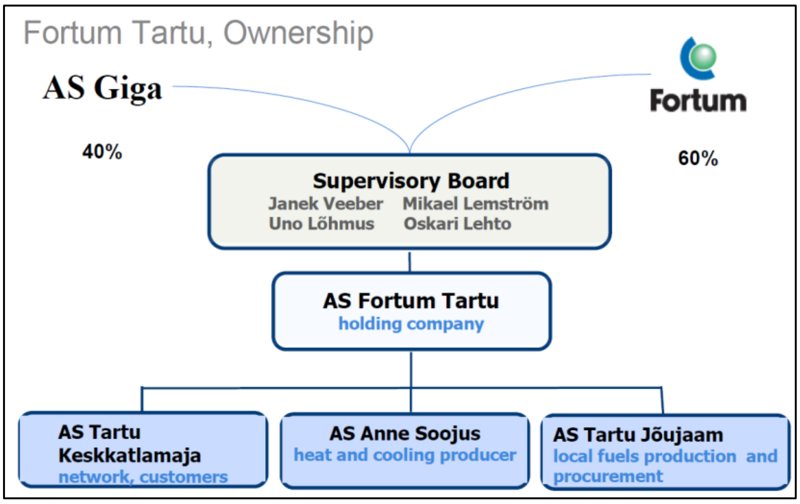


Figure 25 Fortum Tartu Ownership (source: Fortum Tartu)

The municipality is not involved in the ownership or operations of the Fortum Tartu, but influences its business development through city planning. Below the holding company, three companies are managing the different activities of the company:

- AS Tartu Keskkatlamaja for the **system's operation** and maintenance, and **customer interface (invoicing);**
- AS Anne Soojuse for heat, electricity and cooling **production;**
- AS Tartu Jõujaam for **local fuel production and procurement** (peat, wood chips, and wood waste).

There is a good communication between the three companies, based on weekly meetings. The business development manager belongs to the holding company.

The company is completely vertically integrated (i.e. Fortum Tartu produces, distributes and sales heat and/or cold). Third parties provide almost no energy (there is only one industrial supplier of surplus heat, providing less than 1 % of the heat).

V.II Financial model

As previously mentioned, DH operations are regulated at national level based on an ex-ante cost-plus DH regulation. Revenues from electricity production are not regulated. The profitability of the company is expressed by the firm's return on net assets (RONA) and was around **14 %** over the last 3 years.

The **heat price** for final users is defined by the national regulator in order to cover the cost of the DH company and to recoup a "reasonable" return (regulatory WACC) on the regulated assets base (historical assets and planned CAPEX). This scheme is therefore principally self-supporting. WACC includes notional financial costs of equity and debt based on notional capital structure. Actual financial costs (interest payments, amortization) and losses (i.e. non-payment by the end-customers) are not covered by the price-regulation, and DH companies have to do their best to maintain a good financial performance, as the regulator does not redefine the tariff on an annual basis. Besides, all Estonian DH companies are **exposed to interest rate risk**. The regulator sets up the price based on a theoretical (notional) profit allowance. Consequently, to manage the interets rate risk, Fortum Tartu splits its debt into floating and fixed interest rate exposures.

In some cases, an additional funding for investments is allowed by the regulator (for example for new CHP investments).

One of the main disadvantages of cost-plus prices is that it does not promote EE and cost reductions. However, better performing DH companies increase their customer base.

Concerning the split of costs, fuel represents 25 % of the typical cost structure, i.e. a 20 % change in fuel cost has an impact of around 5 % on the total price.

The profit level (net income/total assets) was 9 % over the last 3 years (2013-2015) and the turnover and net profit are shown on the graph below.

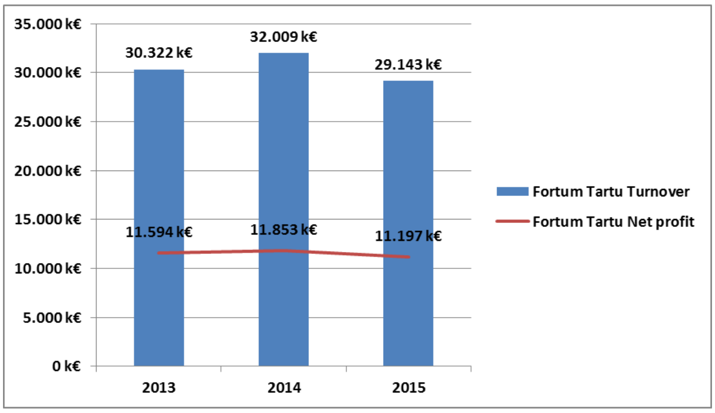
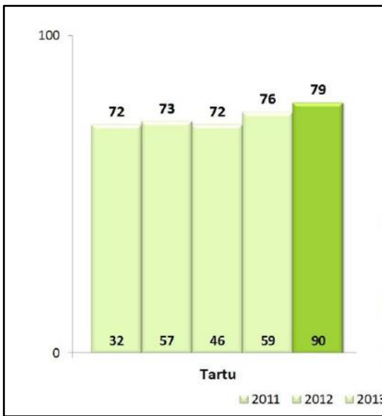


Figure 26 Fortum Tartu Turnover and Net Profit (source: Fortum Tartu)

District cooling is not regulated, and follows a **B2B** approach. Prices are negotiated with future customers and have to be competitive against industrial chillers and other cooling supply alternatives.

V.III Client relationships and energy efficiency initiatives

As mentioned before (and presented in Figure 23), there is a continuous increase in the customers base, which is a good indicator of the user acceptance of DH. Besides, a customer satisfaction survey is performed every year and shows that the **level of satisfaction is very good** and stable (cf. Figure 27 below).



	Heat CSI 2014	Heat CSI 2015
	Tartu	Tartu
Reputation index	**82**	**86**
Company that i trust	84	89
Company that i like	84	85
Company that i respect	83	84

Figure 27 Customer Satisfaction Index (left) and Reputation Index (right) in Tartu (Source: Fortum Tartu)

Energy metering, invoicing and energy efficiency measures (EE)

Every building has heat meters installed at its heat substation. Housing cooperatives divide the total heat invoices between flat owners according to their own methodology, which is usually based on m² and does not encourage individuals to save energy. Invoices are sent to the users on a monthly basis.

There are no particular EE initiatives in place for the clients. The reduction of energy consumption and CO_2 emissions implemented by Fortum Tartu has been mainly focused on improving production capacities (CHP) and reducing heat losses (cf. graph below).

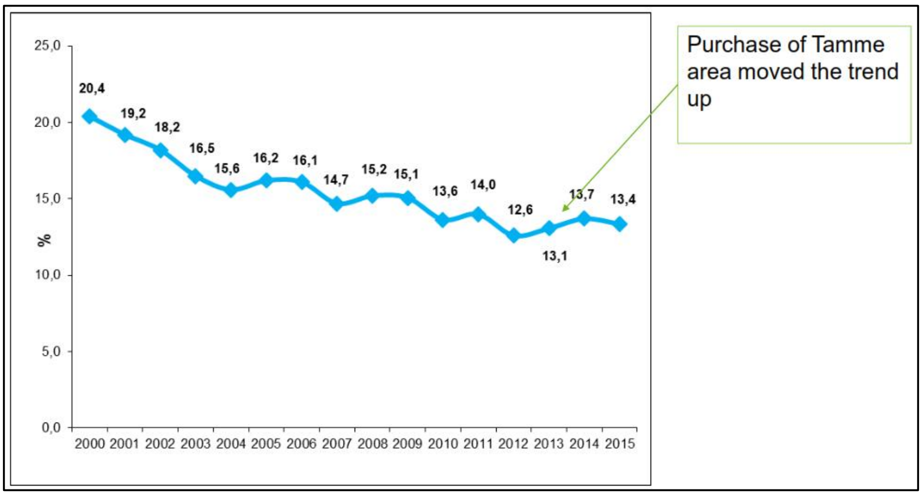


Figure 28 Network losses in % of production (Source: Fortum Tartu)

However, Fortum Tartu is considering starting a new ESCO business and has participated in two pilot projects of energy renovation of schools, where the city and the company share the investments and resulting benefits.

VI. Framework for innovation

Fortum Tartu has integrated in its DH system the main **technology upgrades** applicable to its business. In 2006, it started its own local fuel production and usage and a year later the project development for its biomass fluidized bed CHP plant. The most recent innovative product is its new district cooling network.

This new DC network takes advantage of the synergies with local resources and the DH system. In particular:

- It uses the water of the river Emajõgi for free cooling from October to April; and
- uses heat pumps to transform the excess heat coming from district cooling customers to heat up water for district heating customers.

Since its creation in 2004, Fortum Tartu has not been afraid of developing innovative and successful projects, as already shown by past and future developments. This demonstrates that even in a regulated "cost-plus" scheme, there is room for innovation as a way to improve its competitive position and environmental performance, which are the key factors to get support from the shareholders and the City Council.

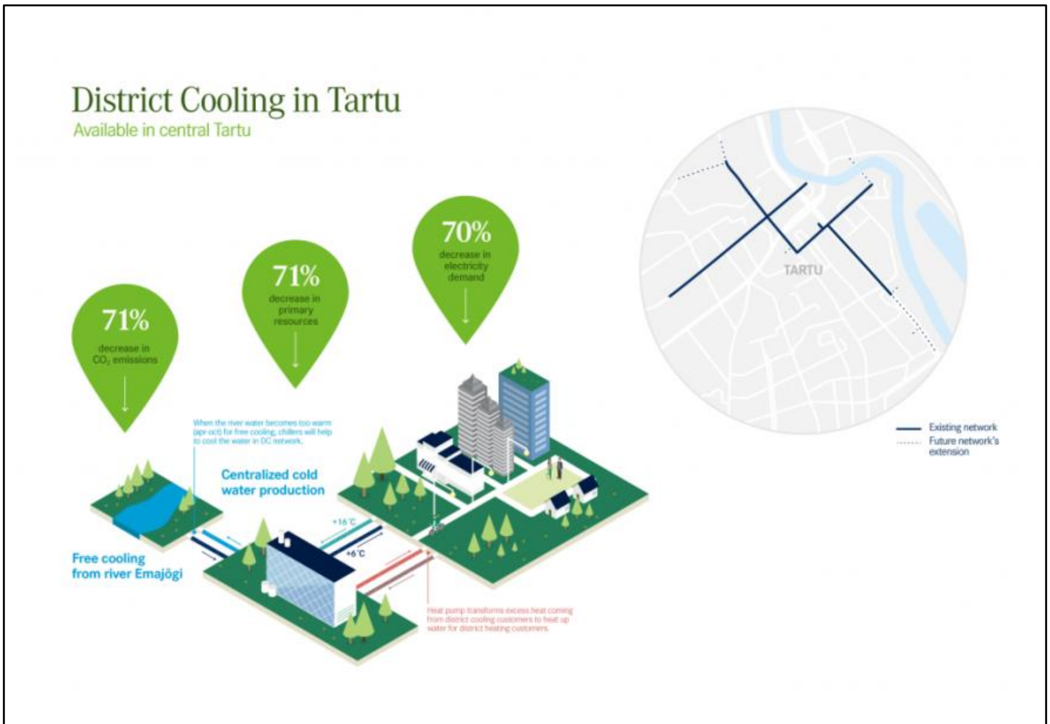


Figure 29 Tartu: the first district cooling solution in the Baltics (Source: euroheat.org)

VII. Perspectives

Both district heating and cooling networks are expected to **continue growing**. They are indeed one of the main enablers of Tartu's environmental strategy. The new Master Plan of Tartu will therefore include an extension of the district heating area.

In particular, there is a big potential for connecting **single-family houses,** which represent about 20 % of the total housing stock in Tartu. Currently, about 90 % of the apartment houses are connected to district heating while single-family-houses represent less than 5 %.

The **local strategy is in line with the national energy strategy**, which emphasises the importance of reducing dependency on imported fuels, improving the exploitation of local energy resources and increasing the decentralised and integrated energy production solutions such as CHP.

The new DH act is not expected to have a major impact on the business model of Fortum Tartu. The current price of DH is already competitive. However, the new Act should bring more flexibility and enable Fortum Tartu to better adapt its offer to the clients' needs. In particular, the company will benefit from offering a two-component tariff, having the possibility to develop its activities on a market basis if prices remain below the established reference price or to adapt its prices depending on the evolution of natural gas price.

Overall, Fortum Tartu has good perspectives and shall remain competitive in the coming years. The main question today is how far and quick will the development of district heating and cooling go. This will depend on the result of negotiations between the Municipality and the DH company, both wanting to further expand the DHC grid but the latter requiring a minimum profitability level.

VIII. Conclusion: Key Success Factors

The DHC system in Tartu is a good example of how to renovate an old and inefficient DH system to make it more efficient and sustainable. The key success factors contributing to its well-functionality can be summarised as follows:

i. **Coherent policy framework for DH.** Even if the Government admits that the DH market is currently over regulated, the roles and responsibilities of the different parties are clear and operational in the current regulatory framework. The new DH Act will set the path for a liberalised and more efficient heating market in Estonia.

ii. As a consequence of the previous point, the **price of heat is capped by law on the long term**, which brings a very high level of confidence for clients and a rather good visibility of prices to DH operators and investors. This will be still the case when the new DH Act comes into force through the introduction of a reference DH price.

iii. **Coherent urban planning, including DH zoning.** The City Council has integrated DH in its urban planning, namely through the DH zoning established by the city's urban development Master Plan. These zones are defined in cooperation with Fortum Tartu, to ensure a coherent and efficient DH zoning.

iv. **Alignment of interests between the municipality, DHC company and final users**. They are all looking for a sustainable option for energy supply, at competitive prices and a good quality service. Cooperation and frequent communication between the parties facilitate the development of a win-win relationship.

v. **Strategic fuel shift and therefore competitive prices.** Fortum Tartu has realised a solid programme of strategic investments to upgrade the DH system and build a strong business based on quality services and sustainable solutions. The choice of using local biomass and peat through a CHP plant subsidised by the Government has proved to be particularly efficient to maintain competitive and stable heat prices, independent from price fluctuations of fossil fuels. This good decision is particularly visible when comparing the evolution of Tartu's DH price to other DH companies in Estonia that did not do those strategic movements and are not competitive anymore.

vi. **Adequate size**. The previously mentioned strategic investments were also possible because of the **size of the network and sufficient volume of sales,** allowing a good return. The development of the CHP plant, and the investments in their own local fuel production were possible because a critical size was achieved.

vii. **Fortum's technical and financial backup.** The strategic investments made were technically and financially secured by Fortum, which is a historical electricity producer and brought its know-how for a successful implementation.

IX. References

- 2003, District Heating Act
- Tallinn 2013, *2013 Guidelines for the Determination of Weighted, Average Cost of Capital*, Estonian Competition Authority
- Juliane Große (UCPH), Niels Boje Groth (UCPH), Christian Fertner (UCPH), Jaanus Tamm (City of Tartu), Kaspar Alev (City of Tartu), 20 January 2015, Tartu *Urban energy planning in Tartu*

2.2.4 FRANCE: Smart District Heating and Cooling in Paris Saclay

French district heating systems have been developed mainly in the 1980's after the oil crisis. More recently, with the introduction of renewables in DHC systems and associated subsidies, their development is moving forward but DH market share remained at 6 % of the national heat demand in 2015.

Paris Saclay Smart District Heating and Cooling Network will become one of the most innovative DHC grids in Europe and is an interesting example of what could be the future of those networks. It combines renewables, low temperature exchange networks, demand management, heat storage, articulation with electrical and natural gas grids, in a district which is France's largest technology and science cluster, exclusively composed of low energy consumption buildings.

Some of the key factors contributing to the success of the DHC project include i) a **mutualisation** of operation and investment costs; ii) **secured** future energy **sales**; iii) an adequate level of **subsidies**, based on robust criteria; iv) a **political willingness** to develop the project; v) managed by a dedicated fully **empowered local authority**.

I. National context

I.I Facts and figures

Basics

The development of district heating networks in France has followed several steps, over the last seven decades:

- 1950's: development of district heating networks in big cities (Paris, Grenoble, Strasbourg)
- 1960's: growth of district heating linked to major urban development policies
- 1980's: development of geothermal energy based DH systems, mainly in the Paris region, following the 1973 and 1979 oil crisis
- 2000's: development of renewables in DH (CHP, biomass and waste).

In 2015, France had **500 district heating** networks, serving **6 %** of the French heat demand or 7 % of the citizens heat needs (in France, 35 % of residential sectors is heated by electricity, and 44 % by natural gas).

The residential sector represents **55 %** of the total French DH sales, the **services sector 39 %** and the various industrial sectors, 5 %.

Renewables

The share of renewable energy in DH supply has reached **44 % in 2014** (after correction due to climate variation), compared to 40 % in 2013, and 20 % in 2005.

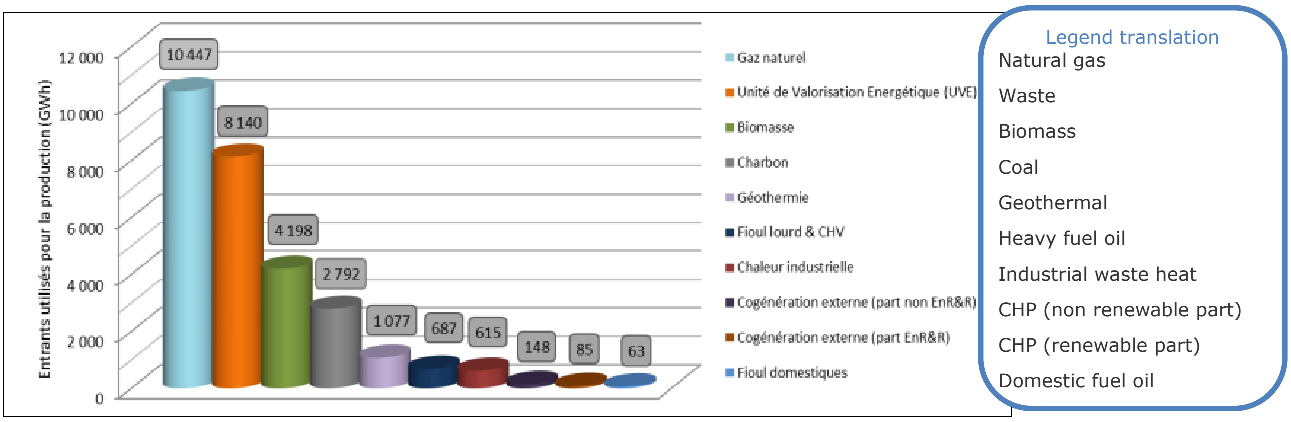


Figure 12 : Les dix principales sources d'énergie (en énergie produite)

Figure 30 French DH energy production mix in 2014 (Source: SNCU)

Operation

The charts below show the breakdown of French DH **ownership and operation modes**. The pie chart on the right, based on kWh supplied through DH grids, offers a more realistic picture. It shows that 89 % of those infrastructures are publicly owned, three quarters of which are managed under a **PPP contract**. Direct public management (*régie* in French) accounts for 5 % of the total, and 6 % of the public grids. Both the share of private grids and of direct public management rises if the breakdown is based on number of DH systems (pie chart on the left), as those two categories are much smaller, in average, than public grids managed through PPPs.

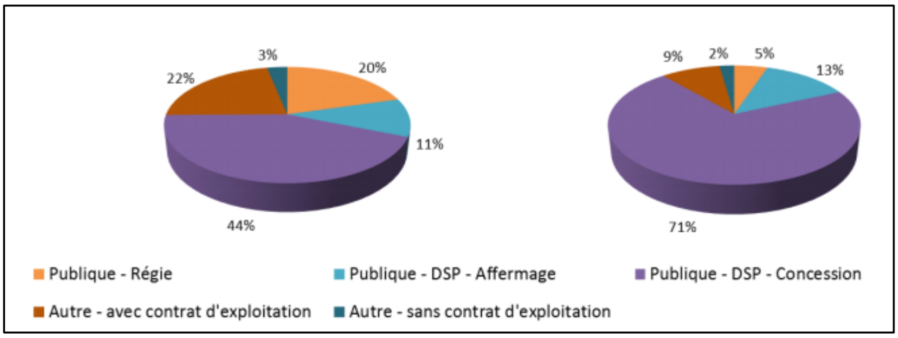


Figure 31 Management mode of French Heating networks in terms of nr. Of DH systems (left) and supplied energy (right). Source: SNCU

Price

The 2014 average price of DH in France was EUR **72.2/MWh (ex VAT)**, composed of 39.3 % fixed component (the so-called "R2" = EUR ex VAT 50.89/kW) and a variable component ("R1" = EUR ex VAT 49.86/MWh)

I.II Policy tools and incentives supporting DHC grids

The Heat Fund: "Fonds chaleur"

The Heat Fund is a public fund created in 2009. It offers a range of subsidies for renewable heat production and DH development. It is open to collective housing, cities and their cooperation structures (*intercommunalités*) and privates companies. Renewable heat production, waste heat recovery and DHC projects are usually subsidized by this fund.

From 2009 to 2013, the heat fund has delivered EUR **1.12 billion** for 3 266 projects, out of which 769 biomass projects, 342 geothermal projects, and 603 DH networks (= 1 500 km trench length).

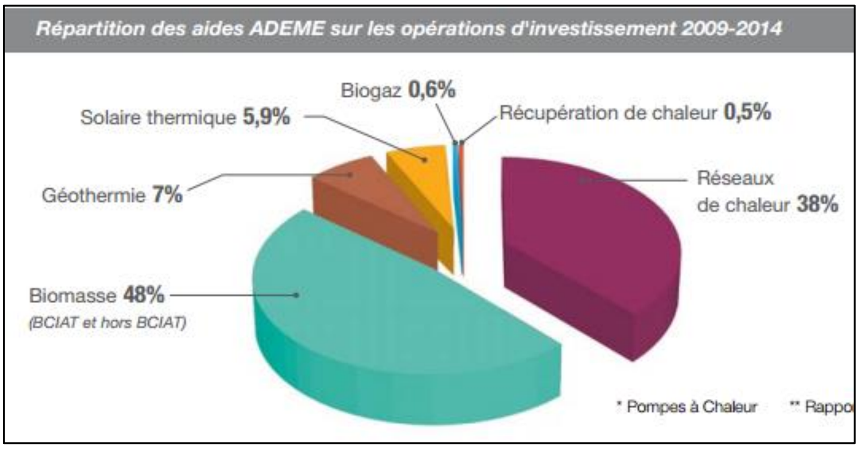


Figure 32 Distribution of Ademe subsidies from 2009 to 2014 (Source: ADEME)

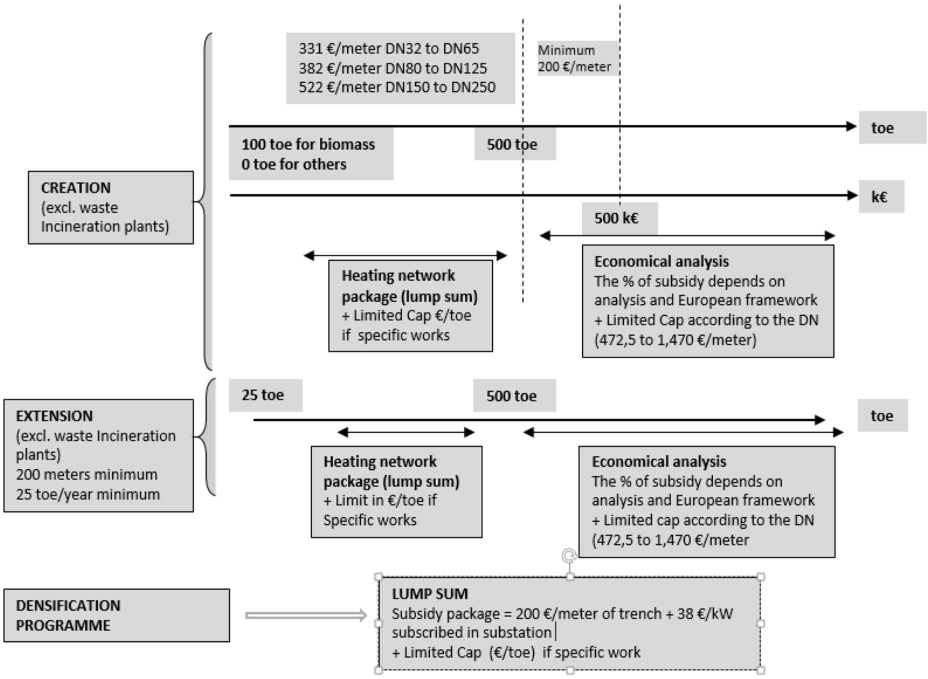
For the next period, 2015-2017, the total yearly subsidy will reach EUR 420 million/year.
Two preliminary **conditions** are required for DH projects to be granted these subsidies:

- Being supplied over 50 % by renewables, with a linear density of the network above 1.5 MWh/ meter of trench length/year; or
- 70 % renewables supply with a density comprised between 1 and 1.5 MWh/ meter trench length/year.

The **ADEME** (French Agency of the Environment and the Control of Energy, 100 % public) is in charge of analyzing the business cases and deciding on grants, considering the following factors:

- Technical performance of the DH system (efficiency, insulation level…)
- Financial balance and competitiveness of the delivered energy
- Contractual strength and risks
- Innovation
- Perspectives of development
- Sustainability

Therefore, it is not possible to predict accurately the level of the subsidy that one project can be granted, (usually between 0 and 30 % of the investment). However, the tables below indicate what can be the maximum amount for different sizes of DH projects:



SUMMARY OF SUBSIDY CALCULATION FOR NEW AND EXTENSION OF HEATING NETWORKS – FONDS CHALEUR 2016

Figure 33 Summarized scheme of subsidy - French Heat fund 2016 (Source: ADEME)

Reduced VAT rate for DH consumers: 5.5 %

A reduced VAT rate of **5.5 %** (instead of 20 %) is applicable to the variable part of the DH tariff, subject to the fulfilment of some conditions as regards the renewable origin of the heat sold through the grid.

In France, the fixed part of the tariff called "R2", is proportional to the subscribed capacity (EUR/kW) and represented 39 % of total average heat cost in 2014. This part always benefits from a reduced VAT level (5.5 %).

The variable part is called "R1" (61 % of total average heat cost, EUR/MWh).This part benefits from a reduced VAT level of 5.5 % only if more than 50 % of the heat is produced by renewables. Otherwise the VAT is 20 %.

The thermal regulation rule (RT 2012)

The thermal regulation rule (RT2012) allows a building connected to a DH grid to exceed the maximum consumption values (50 kWh Primary Energy / m² / year) if the carbon footprint of the network is below a certain threshold level.

Energy transition Act (Loi relative à la transition énergétique pour la croissance verte) (August 17th 2015)

The energy transition Act has confirmed the major role of DHC in terms of use of renewables (biomass, geothermal and solar energy) and heat recovery from waste and industrial activities. This act aims at multiplying by 5 the share of renewables in DHC: meaning over **50 % of renewable** in DH by 2030 (compared to 38 % in 2012) and **5 to 7 million** more dwellings connected to DHC systems (compared to 2.2 million in 2012).

DH zoning rule (« Procédure de classement des réseaux »)

This procedure (updated in 2012) allows local authorities to make the connection to district heating compulsory for consumers under certain conditions in a defined area, for any new or existing buildings being subject to major refurbishment and having a subscribed capacity over 30 kW (heating, cooling or domestic hot water power).

Three conditions are to be fulfilled for the district network to be classified under this legislation:

- The DH or DC grid is supplied by more than **50 % with renewables**
- An appropriate energy metering device is installed for each consumer
- A guaranteed business model balance for the heating network

Exceptions:

- Buildings proving that the connection to the DH network does not bring satisfying financial or technical conditions to the user
- Within this defined area, buildings having a subscribed capacity below 30 kW.

II. Presentation of Paris Saclay DHC system: a smart DHC concept

II.I The Paris Saclay urban development project

The Paris-Saclay project bundles scientific, economic and territorial challenges. It is located 20 km south west from Paris and represents **1 800 000 m²** to be built between **2015 and 2028,** with its associated infrastructure.

It is a cluster of excellence gathering the top French scientific, engineering and business schools (60 000 Students + 10 500 researchers), state-of-the-art research laboratories and many private companies:

- 550 000 m² education and research institutions
- 560 000 m² office space
- 380 000 m² family housing
- 168 000 m² student housing
- 86 000 m² of shopping facilities, public equipment etc.

To develop this area, a joint urban development zone called "ZAC" in French (*zone d'aménagement concertée*) of 562 hectares has been defined, in which the Paris-Saclay Development Agency is empowered (see details in section II.III).

II.II The Smart DHC system in Paris Saclay

Its main characteristics are summarised below:

Key facts and figures

DH market share	100 %
Heating & Cooling capacity	DH: 37 MW DC: 10 MW
Heat &Cold production	DH: 40 GWh/y DC: 10 GWh/y
Km network (double-pipe)	DH and DC : 10 km
CO_2 emissions (heating)	<100 kg/MWh

- **Small system**: 1 200 000 m² connected to the network in phase 1 (2015-2021), 7 municipalities
- **Production:**
  - 7 semi centralized heat pumps stations and natural gas boilers
  - two **geothermal drills** 700 m depth, temperature 30 °C
  -

The planned investment of the District Network is EUR **50 million** and its **energy mix** is presented on the right (Figure 34), dominated by geothermal energy.

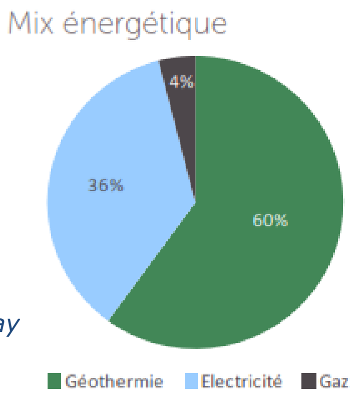


Figure 34 Energy mix of Saclay DHC system (Source: Tilia)

The DHC system is composed of 4 different sub-systems:

- one geothermal network
- one medium temperature network: 30 °C – 15 °C feeding the heat pump stations
- 7 hot water networks 63-45 °C (from the heat pump stations to the buildings)
- 7 cold water networks 6-12 °C (from the heat pump stations to the buildings)

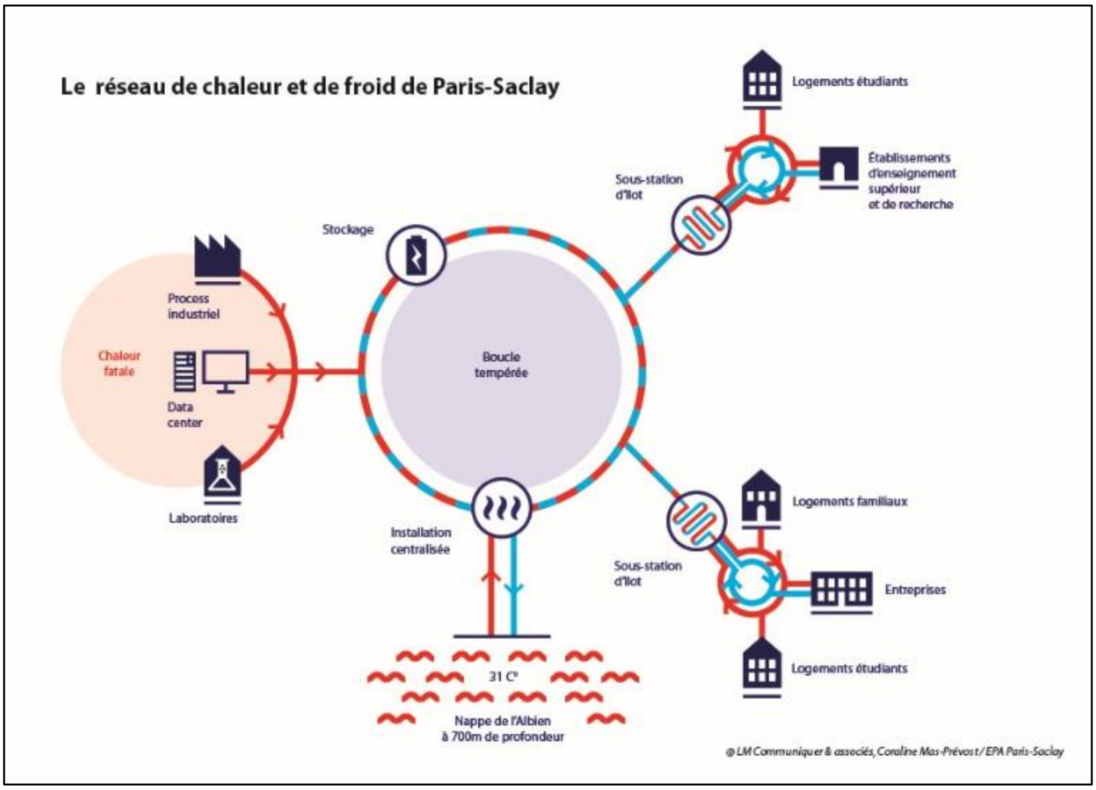


Figure 35 Simplified technical principles of Paris Saclay Smart heating and cooling district grid (Source: LM Communiquer & associés, Caroline Mas-Prévost/EPA Paris-Saclay)

Key technical characteristics of the network

- A **low carbon** emission (< 100 g CO_2/kWh) and **> 50 % renewable** energy network;
- the medium temperature network (30-15 °C) shall allow each consumer to reinject energy to the benefit of the other consumers through heat pumps;
- a complementary **mix of users** composed of residential and service buildings, as well as educational facilities shall allow the balance of the overall heating and cooling needs;
- a mix of different complementary energy sources - geothermal energy, electricity (heat pump) and natural gas (boilers) - shall allow to operate the network efficiently, considering user demand, availability and prices of energy sources;
- **electrical peak shaving** shall be possible;
- **building management systems** installed at consumers' facilities allow sending information to the centralized network operation centre and shall allow to anticipate and act on the demand side (heat energy peak shaving, for example).

II.III The Paris-Saclay Development Agency

As principal contracting authority for the urban planning and development of this area, the **Paris-Saclay Development Agency (or EPAPS[40])** is an autonomous

[40] Etablissement public d'aménagement Paris-Saclay

governmental agency, working closely with the local authorities to implement a balanced project in terms of housing, transport, amenities and services, in a living environment which benefits from the remarkable qualities of an extensive territory situated south-west of central Paris. EPAPS represents **11 municipalities** (125 000 inhabitants), for a limited life time (ca. 15 years).

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 (natural gas, electricity, heat and cooling networks).

III. Urban development and expansion of DHC

As mentioned previously, Paris-Saclay Development Agency is responsible for the entire urban development of the area and its infrastructure, including the development of the smart DHC grid of Paris Saclay.

As the local Authority granting the building parcels to real estate developers, EPAPS has the power to **impose the connection to the Smart Heating and Cooling network** to any new projects built in this area. It will therefore impose the connection of each building between now and 2028.

After 2028, when EPAPS will disappear, the mandatory connection to DHC (« *Procédure de classement des réseaux*», previously described in section I) will remain applicable.

However, there exists **some exemptions** to this mandatory connection to the grid.

i. Historical constraints:

Existing buildings are currently not connected to the DHC network, and will most probably not be. In most cases, the heating technology of the existing building is not compatible with the specifications of the DHC network, either because they rely on electrical heating, or because the temperature requirements in the secondary heating circuits of the building are too high (around 90 °C instead of 63 °C).

Some new building projects also developed standalone solutions before the DHC system was actually planned (2015), which are not compatible with the DHC grid specifications.

ii. Capacity of the DHC network:

Although the DHC network has been designed taking into account the whole development of the area, it bears its own technical limits. The main one is the limited capacity of the geothermal wells. Presently, the two wells cover approximately 25 % of the peak power demand, and 60 % of the annual energy demand. As the network shall guarantee a minimum of 50 % of renewable energy on its overall supply, it shall consider any new connections with regard to its ability to fulfil this requirement and develop incremental, additional renewal energy sources.

Although cooling needs are mostly beneficial to DH, cooling needs requirements of some specific consumers (like research centers) can also be a constraint to the full supply of the energy needs through DHC (see Figure 36 below). Some users will need a high cooling capacity for a limited time in the year. Therefore, an agreement has been found with some of those consumers to fulfil their peak needs with additional decentralized cooling devices (decentralized electric chillers) owned and operated by the consumers themselves. The main advantage is to reduce the size of the DHC equipment (pipes and heat pumps), reduce the capacity subscription of the consumer, and reduce the global cost of the solution for both parties.

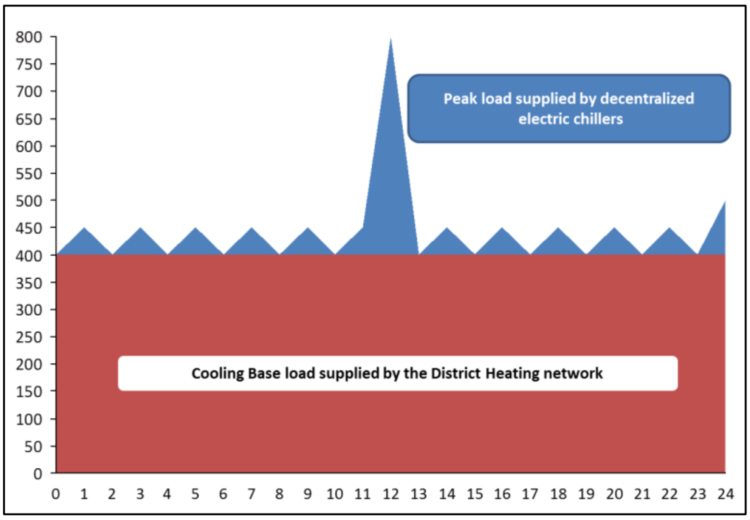


Figure 36 Illustration of cooling energy demand for specific user (Source: Tilia)

IV. Local heating and cooling markets

IV.I Demand and supply forecast, and its uncertainty

The weather conditions of the Paris region allow the development of DHC grids. The average value of Heating Degree Day over the last 5 years reached **2544** (between 2009 and 2014). The map below represents the thermal density[41] of the Paris region and its existing DH networks.

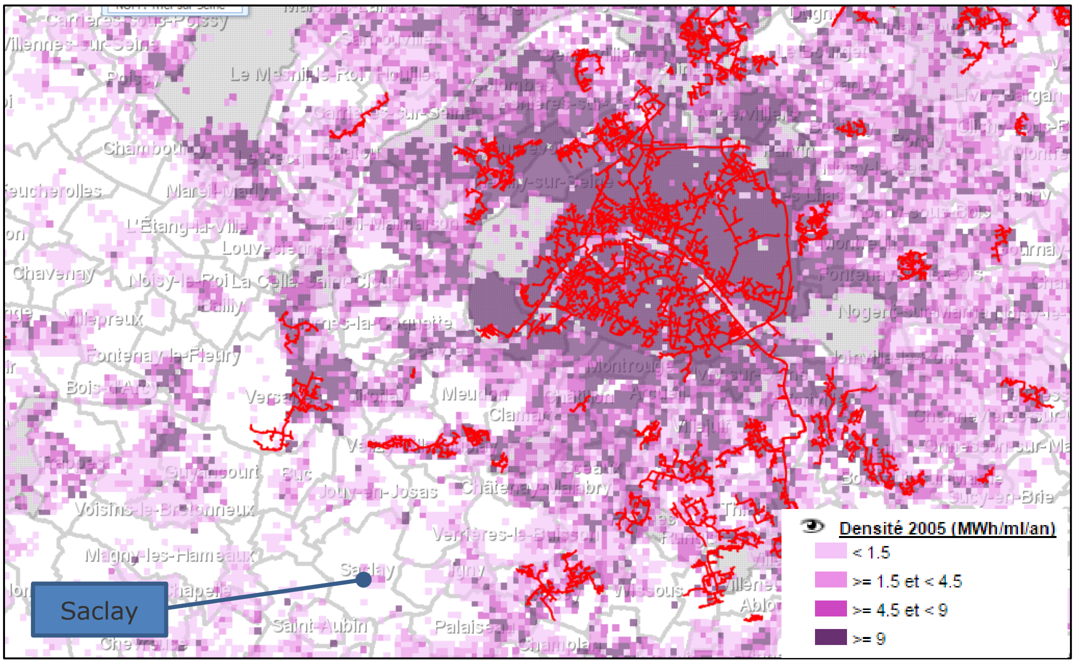


Figure 37 Thermal density and DH systems in the Paris region

Each pixel or cell of the map represents a square of 250 m X 250 m. The heat density of a cell is calculated from the heat consumption data, divided by a theoretical linear network to serve the buildings mesh. The red lines represent the existing DH networks.

Source http://carmen.developpement-durable.gouv.fr/18/densite_thermique.map

Most of the buildings that will be built on Paris Saclay area shall fulfil the national thermal regulation RT 2012 requirements with the following levels of consumption and peak demand (Figure 38).

[41] The **heat density** is heat consumption of an area, divided by a theoretical linear network to serve this area.

Typology of user	Power (W/m²)			Consumption kWh/m²/y		
	Heating	Domestic Hot water	Cooling	Heating	Domestic Hot water	Cooling
Offices	*51*	*0*	*26,4*	25	0	15
Commercial activities	75	0	80	30	0	15
Hotels	40	22	40	21	48	15
Laboratories	150	0	225	50	0	60
Family Housing	40	10	0	40	30	0
Student Housing	45	10	0	40	45	0
Restaurants	150	25	100	25	15	30

Figure 38 Expected energy consumption by type of consumers

According to the projections, the average thermal density of the network will be **4.3 MWh m linear trench / year** for the heat, for a built zone of 1 800 000 m² on a 562 ha area.

IV.II Price competitiveness

Average price for Paris Saclay smart district heating and cooling grid

The average present price of the network is a follows (average price in January 2015)

Energy	*Average price without VAT*	*Average price Including VAT*	*Percentage of variable cost / total cost*
Cooling	EUR ex VAT 97.39/ MWh	EUR incl VAT 102.74 / MWh	22 %
Domestic Hot water	EUR ex VAT 65.73 / MWh	EUR incl VAT 69.35 / MWh	50 %
Heating	EUR ex VAT 107.97 / MWh	EUR incl VAT 113.91 / MWh	31 %

Average cost of energy 2015

Remark: this average price does not include the connection costs, that shall be paid once, at the beginning of the contract between the DHC network and the consumer (420 EUR HT / kW subscribed heat and 777 EUR HT / kW Cooling).

Comparisons with other national district heating and cooling grids

The two following tables present the average price for heating and cooling of the French district heating grids[42].

DH networks: average price: EUR **79.4/MWh ex VAT** (levered average EUR 70.6)

	Heating grids
Number of grids	536
Average year of the beginning of the operation	1986
Total installed capacity	19 579 MW_{th}
Amount of consumed energy	28 340 GWh / 2 437 ktoe (1)
Total length of the grids	4 660 km
Number of delivery points	33 691
Total of thermal energy supplied	20 485 GWh
Total turnover of the grids (2)	EUR 1 484 905 thousand ex VAT
Average fixed part in the invoicing (R2)	42.1 %
Overall average price of the MWh (R1 + R2) (3)	EUR 79.4ex VAT
Weighted average price of the MWh (R1 + R2) (4)	EUR 70.6 ex VAT

(1) 1 toe = 11.63 MWh; 1 MWh = 3,600 MJ (2) Total takings (EUR) / supplied energy (MWh)
(3) Average of the heat sales prices (4) sum of turnover generated by the heat sales divided by the sum of MWh sold by the heat grids

Figure 39 General features and average cost of DH in 2014 in France (Source: SNCU)

[42] Source : *Enquête annuelle sur les réseaux de chaleur et de froid Restitution des statistiques* 2014 - SNCU

DC grids: average price: EUR ex VAT **131.8/MWh ex VAT** (levered average EUR 116.3)

	Cooling grids
Number of grids	20
Average year of the beginning of the operation	1 993
Total installed capacity	740 MW_{th}
Amount of consumed energy	211 GWh / 18 ktoe (1)
Total length of the grids	160 km
Number of delivery points	1 060
Total of thermal energy supplied	913 GWh
Total turnover of the grids (2)	EUR 106 181 thousand ex VAT
Average fixed part in the invoicing (R1)	51.8 %
Overall average price of the MWh (R1 + R2) (3)	EUR 131.8 ex VAT
Weighted average price of the MWh (R1 + R2) (4)	EUR 116.3 ex VAT

(1) 1 toe = 11.63 MWh; 1 MWh = 3 600 MJ
(2) Total takings (EUR) / supplied energy (MWh)
(3) Average of the cooling sales prices
(4) sum of turnover generated by the cooling sales divided by the sum of MWh sold by the cooling grids

Figure 40 General features and average cost of DC in 2014 in France (Source: SNCU)

Comparisons with independent, standalone solutions and their limits

The estimates that were established in 2015 in order to convince consumers to connect to the DH system presented a 20 % overall cost difference in favour of non-renewable, standalone, independent solutions for heating (natural gas boiler), mainly because the natural gas price was very low at that time.

The comparison made with renewable independent solutions presented a slight difference (2 to 8 %) in favour of standalone, independent solutions (heat pumps with vertical geothermal probes).

However some limits to these comparisons shall be taken into consideration. First, the average price of heating being partially (31 %) dependant on variable costs (50 % for domestic hot water and 22 % for cooling), the comparison between solutions depends highly on the assumptions taken into consideration for the evolution of the prices of gas and electricity over the next 20 years. Besides, predictability and stability of supply from geothermal energy has a certain value compared to instability and unpredictability of oil and gas prices and this is not taken into consideration in a strict price comparison.

Second, the level of consumption of each building is highly hypothetical, and forecasts are set at a quite low level (RT 2012). If the real consumption of the buildings is higher than expected, then it will benefit to solutions with the highest level of fixed cost (DHC).

All in all, the global cost of an integrated DHC solution against independent, standalone ones in the new, state of the art Saclay buildings is currently foreseen as a bit higher, based on current market prices for various energy fuels. But the dynamic assessment of the DHC comparative advantages has to include three crucial elements:

a) A broad spectrum of further optimisations that can only materialise at a later stage of development (see innovation and perspective sections below), in the context of real-life system operation;

b) Short term market prices are not a good indicator of the long term value for money and full life cycle costs of fossil fuels based solutions, especially not when they are benchmarked against stable and predictable solutions like geothermal energy;

c) It is also a constant return of experience that actual real consumption of buildings turns out to be higher than what has been planned and announced at conception stage, especially in housing, but also in tertiary and office buildings, in proportions which are variable, but often range between 15 % and 25 %.

V. Business model

V.I Governance and strategy

EPAPS is in charge of the development of the whole area, including the District Heating grid until 2030.

The **board of EPAPS** is composed of 20 members, including 3 state representatives, 10 local municipalities' representatives and 7 educational and economic development representatives.

In 2030 at the latest, the concerned local municipalities will take over the ownership and operational responsibility for the network, and shall decide about the contractual operation model of the DHC grid.

EPAPS decided in 2013 to build the DHC network in a **Design – Build - Operate** (DBO) mode (*Conception – Réalisation - Exploitation & Maintenance = CREM* in French) from 2015 to 2021. A new management contract is envisaged after 2021 though decisions are yet to be made about this operational framework.

A call for tenders was organized in 2014 to select a private consortium to design, build and operate the network until 2021. It was awarded to ***Idex-Egis.***

From 2013 to 2022, EPAPS relies on a dedicated expert partner (***Tilia***) to provide a comprehensive and adequate development support from the feasibility study to the implementation of the project, including tender full organisation and quality control in realisation and operation. The comprehensive nature of this contract improves the coherence between modelling and implementation at various stages of the project development.

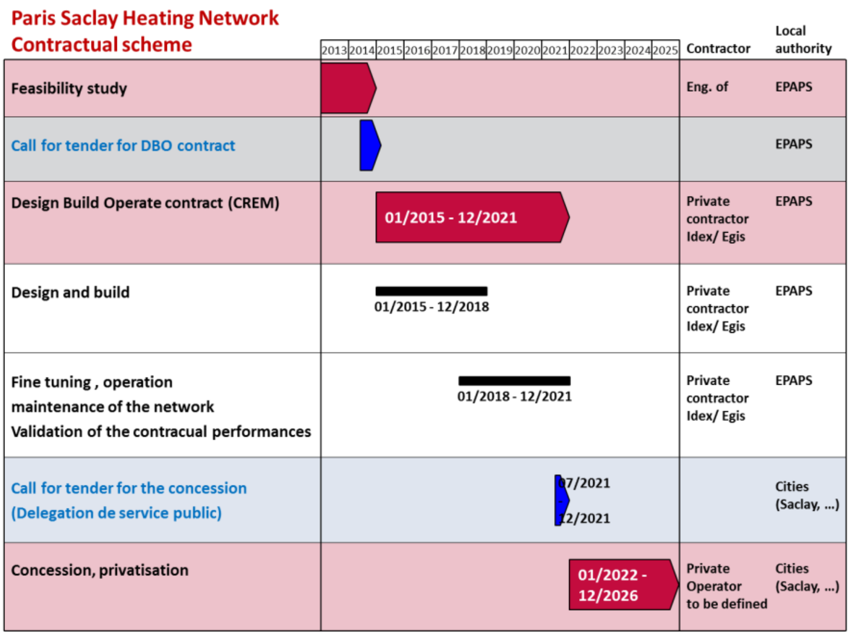


Figure 41 Paris Saclay Smart DHC grid contractual time frame (Source: Tilia)

The main differences between a DBO contract and more classical concession contracts are:

- 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 operation phase (2021).

These differences are summarised in Figure 42, where the columns on the right indicate the responsible party for each of the DHC activities listed on the first column.

-

DHC activities		Paris Saclay Smart DHC grid (DBO)	Concession mode
Strategic direction of DHC		Local authority (EPAPS)	Local authority
Management of the DHC system	Regulation of the DHC grid (tariff, quality of service)	Local authority (EPAPS)	Private Contractor
	Technical and economical optimization		
operational execution of the service	Conception	Private Contractor (Idex Egis)	
	Realization		
	Operation		
	Maintenance		
	24h technical assistance		
	Commercialization	Local authority (EPAPS)	
	Invoicing		

- *Figure 42 Contracting model or Paris Saclay Smart DHC system (Source: Tilia)*

The first **reason for choosing such a contractual scheme** was the fact that the EPAPS is in charge of the development of the area, is committed to develop buildings and attract potential clients, which has a significant influence on heating and cooling volumes needed. Asking a third party to bear this development risk through a concession agreement would have raised some concerns, and potentially increased the overall cost of the grid development, due to risk coverage charges on the private partner's side.

The second reason stems from the EPAPS will to keep in its hands on core innovation leverages. The Smart DHC network being the cornerstone of a more complete Smart grid (electrical, thermal and natural gas grid), it has been judged easier to monitor innovation and evolution towards next steps in a DBO contract than in a concession contract.

V.II Financial model

As the local authority bears the financial and commercial risks of the DHC system, it also sets up the tariff to balance the project

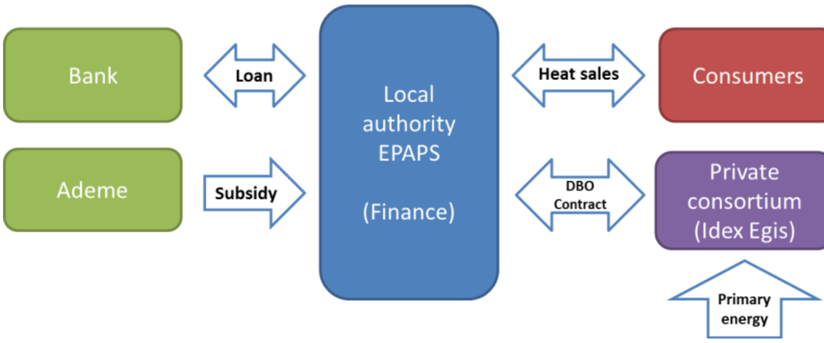


Figure 43 Paris Saclay Smart DHC system financial flows (Source: Tilia)

The **investment** level of this network is around EUR 50 million, EUR 10 million of which are provided by subsidies from Ademe. This level of subsidies is higher than the usual standards mainly due to the energy efficiency and environmental performance of the grid, and to the numerous innovative features it comprises, in a context of relative uncertainty on demand, which has been described above.

Gearing	70 % debt – 30 % equity
Interest rate	1.89 %
Debt length	20 years

Figure 44 Debt structure of Paris Saclay DHC network

Structure of the tariff

The DHC **tariff** is based on two components:

- A fixed component called "**R2**", calculated as a function of the installed capacity and equal to EUR **58/kW** ex taxes (01/2015), 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);
  - R22+R23 is the cost of operation and maintenance of the network. R21 + R22 + R23 = EUR 31/kW ex VAT;
  - R24 represents the capital pay-off for the investments in the grid and all its equipment. R24 = EUR 27/kW ex VAT.
- A variable component called "**R1**" (see table below), 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 (*hiver*), summer (*été*) and other (*mi-saison*).

Tarification du réseau de chaleur et de froid de Paris Saclay Terme R1 en € HT, valeur Janvier 2015						
Fourniture	HIVER (Du 1er décembre au 29 février)		ETE (Du 1er juillet au 31 août)		MI-SAISON (En dehors des périodes HIVER et ÉTÉ)	
	R1e €HT/MWh	R1v €HT/m3	R1e €HT/MWh	R1v €HT/m3	R1e €HT/MWh	R1v €HT/m3
FROID	0,00	0,1	32,00	0,15	12,00	0,15
CHAUD pour ECS	32,81	x	32,81	x	32,81	x
CHAUD	29,85	0,1	14,78	0,1	29,85	0,1

Figure 45 Paris Saclay Smart DHCN Variable part structure (R1). *Source: Tilia*

Additionally, the **costs of connection**, called "**R0**", are paid once to the EPAPS and are proportional to the installed capacity: EUR **777/kW$_{Cold}$ ex taxes and EUR 420/kW$_{Heat}$ ex tax** with a special discount for consumers using heat and cold.

Invoicing takes place once a month for all consumers. Tariffs are updated on an annual basis by EPAPS. R2 is **indexed** mainly on man hours and spare parts cost, R1 is indexed on primary energy unit costs (electricity and natural gas) and their respective share in the total primary energy cost.

V.III Client relationships and energy efficiency initiatives

The **structure of the variable part of the tariff** (R1), which is a kind of bonus/penalty system, shall allow two initiatives:

- the first one is the efficient **management of temperature levels on the user side**, controlled by the part of R1 cost relative to the volume of water used (expressed in EUR/m^3). Each building energy manager shall be able and incentivised to control the difference of temperature between inlet and outlet of its heat exchanger, and shall do his/her best to maximize it, and consequently reduce the volume of water that goes through the heat exchanger. The level of temperature is particularly important to maximize the efficiency of the heat pumps that produce energy (heating and cooling) and to reduce the circulation pumping energy of the network.
- Secondly, the seasonality of tariffs creates the right incentives to maximize **energy exchanges between consumers**. As can be seen on the previous table, cooling energy is free of charge in winter, price reduced by two thirds in mid-season and at its maximum price during summer. Symmetrically, the heat price is reduced by half in summer. This tariff mechanism reflects the fact that cooling production in winter is not only free of charge for the network operator but allows to produce additional renewable heat through heat pumps and medium temperature network. Conversely, heating in relatively hot conditions (mid-season) allows to produce renewable cooling energy. This tariff specification illustrates that energy exchanges between consumers are possible through the medium temperature network and benefit all consumers to reduce primary energy use.

In the energy contract signed between consumers and the network operator, **the consumers are encouraged** (but not forced) **to send information issued from their building management system to the network operator**. That information will be compiled by the network operator and shall enable improving the operation of the system and reduce the use of primary energy. Typical information that can be useful is temperature level in the rooms, operating hours of buildings and rooms, duration of reheating of the building (thermal inertia). Once the network will be in operation and sufficient data about consumers have been gathered (eg after a few years of operation), a second step will be, for wilful consumers, to receive an order or a recommendation from the network operator and act relevantly: postpone or anticipate needs, for example.

Compared to a classical network operator-consumer relationship, and because the network has been designed jointly with the buildings, parts of the **present scheme could be discussed between future consumers and the EPAPS** between 2013 and 2016, and partly designed during those discussions (regular meetings).

One of the outcomes is the structure of the tariff itself, and in particular the fact that consumers will have the possibility to **reduce their capacity** (still partly uncertain because buildings are not yet in use) after 5 years of operation for education buildings and 10 years for the others, within a limit of respectively 30% and 20% of the initial capacity.

Another outcome of this joint design of some of the key features of the project is that some specific consumers, depending of their demand profile, are allowed to subscribe a **base load capacity** to the network while their peak needs, appearing only a few days in the year, will be supplied through fully decentralised, standalone facilities (mainly electrical chillers or smaller boilers). The benefit for the consumer is to pay less fixed part to the network operator, and invest in some small local equipment, at a lower overall cost. The benefit for the network operator is to avoid upscaling the equipment (both at grid and production facility level) in order to match peak demand, and focus it's the investments on equipment that will be used more frequently, hence improving its profitability. This contractual arrangement is particularly appropriate for research centre buildings, the cooling needs of which are strongly fluctuating along erratic patterns.

VI. Framework for innovation

Paris-Saclay has developed a low carbon district heating and cooling network, vital infrastructure to harness local and renewable energies. It will increase the potential to reach optimum energy use across the region at any moment by playing on all the elements involved: thermal inertia of buildings, heat storage, the recharging of electric vehicles, the incorporation of solar panels, and many more.

The Paris-Saclay Development Agency and its energy transition institute (PS2E[43]) have signed a framework research agreement on Paris-Saclay's industrial energy systems with a view to potentially integrate them into a **broader Paris-Saclay Smart Energy project**. The initiative will cover a range of subjects: low temperature heating networks, technologies to recover waste/surplus heat, the physical storage of hot and cold energy, and the theoretical modelling of networks, among others.

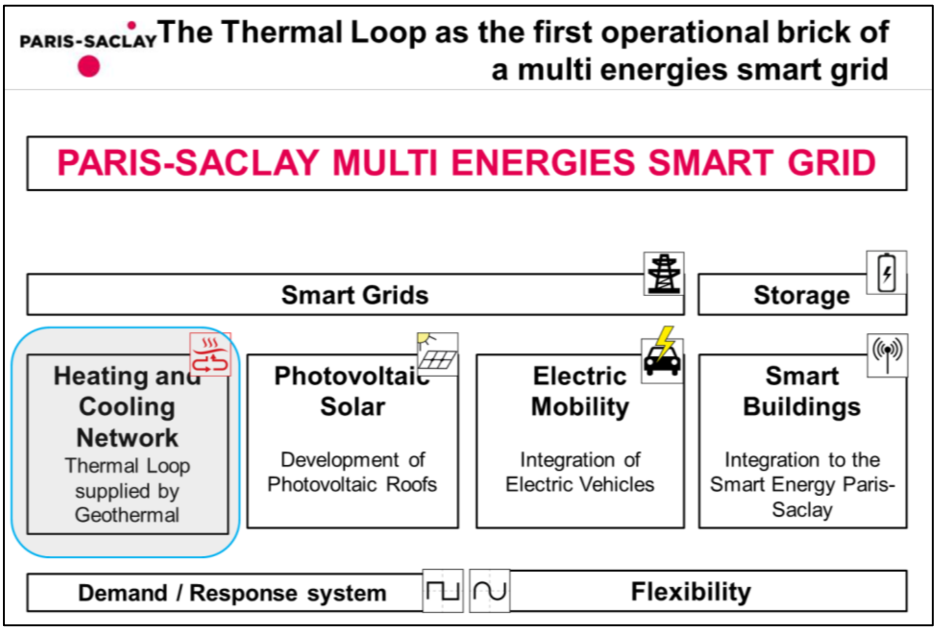


Figure 46 Paris Saclay Smart DCH system: first step of a multi energies smart grid (Source: EPAPS)

[43] *Paris-Saclay Efficacité Energétique*

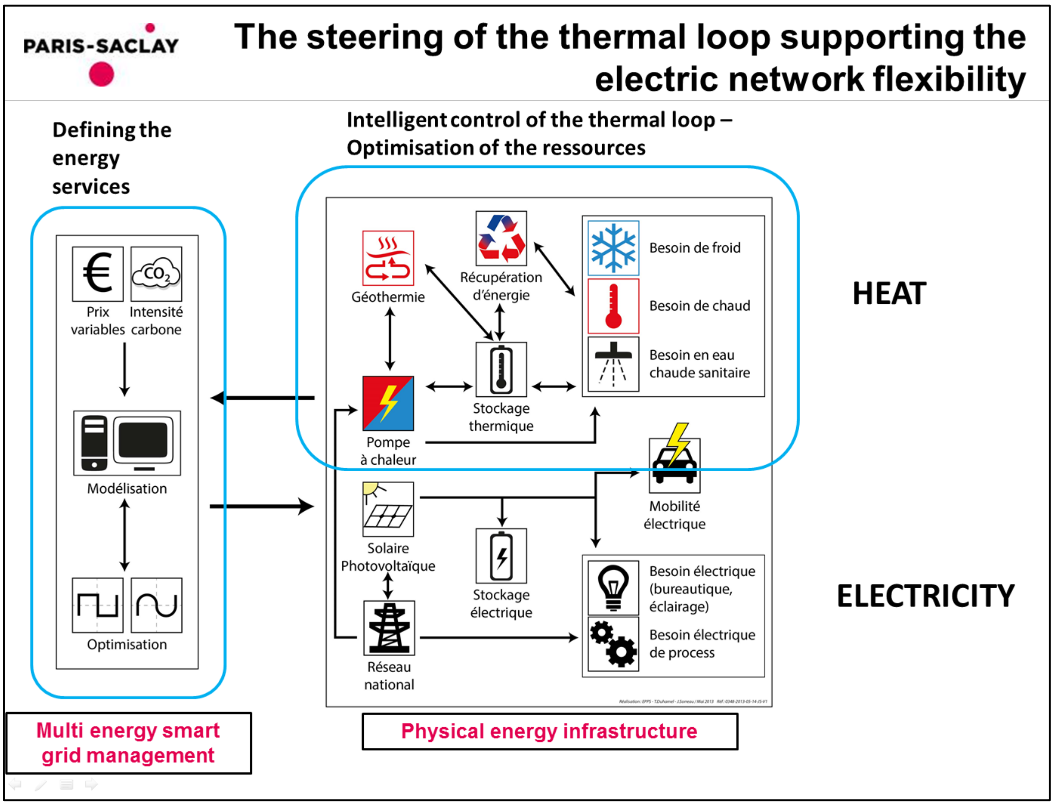


Figure 47 How Paris Saclay Smart DHC system enhances electric flexibility (Source: EPAPS)

VII. Perspectives

The EPAPS plans to connect to the network **1 200 000 m² of buildings** between **2015 and 2021 (DBO period).** The whole area of Paris Saclay represents a total **1 800 000 m²** to be built until 2028. As the Paris-Saclay DHC network is aimed at connecting the whole area, dimensioning of the system anticipates the future connections: bigger size for the pipes and bigger buildings for centralized production equipment.

The full commissioning of the DHC system is planned in 2018, and the first years of operation will give important inputs with regards to perspectives.

The additional connections may need additional renewable energy sources, like solar thermal , additional recovery heat from existing buildings (research centers Synchrotron and IDRIS, for example), in order to maintain the 50 % renewable energy target. Further optimization and innovation is due to take place based on the innovation frame mentioned in the previous section.

VIII. Conclusion: Key Success Factors

The Paris Saclay district heating and cooling system will be one of the most innovative heating and cooling networks in the world, and the cornerstone of a multi-energy network. At this stage, identified key success factors are as follows:

i. **Political willingness** to develop the Paris Saclay project and an innovative energy solution for the buildings: this has helped mainly to convince the education and research building managers of the relevance of the solution and has provided a ground for various negotiations with the numerous public stakeholders and future users of the DHC grid.

ii. **A unique public authority managing the overall development of the area and the energy / district heating and cooling design**: the local Agency (EPAPS) was responsible for both implementation of the buildings on the area and associated infrastructure like the smart DHC system. This has provided ground for a strong coherence between the DHC grid design and economic / tariff model and the tight urban planning constraints; symmetrically, some DHC-related constraints have been taken into account in the building projects.

iii. **Fairly secure energy sales**: in spite of a certain uncertainty on consumptions of each building, the project benefitted from a fairly good overall visibility on energy sales and building projects scheduled on the area, based on a mandatory connection to the DHC grid: this has been extremely helpful to secure the debt financing part of the project.

iv. **A fairly high level of subsidies, connected to the specific energy efficiency and environmental performance features of the project:** as a result, 20% of the investment cost are covered by Ademe.

v. **Low temperature heating circuits in the buildings**: all the connected consumers will use hot water at a maximum level of 60°C, which allows standardized heat pump technologies to be used, improving the overall cost/environmental efficiency of the DHC grid.

vi. **A balanced mix of consumers**, opening a broad scope for energy exchanges, based on a complementary mix of energy needs between offices, residential, education and research buildings.

vii. **Mutualisation of costs for conception and construction provides economies of scale and scope, compared to standalone solutions**: the development of one solution for all allows reducing global costs for each building or subunit (geothermal well, reduced total heating and cooling capacity installed, only one natural gas boiler for all).

viii. **Mutualisation of costs for operation, based on complementary demand profiles :** the heat demand and cooling needs partly offset each other, and can be jointly met by energy exchanges between users and optimized use of potential surplus heat.

ix. **Reasonable electricity price**: electricity cost represents 71% of the variable operation cost (25 % being natural gas cost), so a relative low price of electricity is one of the key aspects of its business model.

x. And therefore, relative **competitive energy prices for the district heating and cooling network**, compared to equivalent solutions, taking into account environmental criteria.

xi. A comprehensive **project development support**, on legal, technological and financial aspects.

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2.2.5 GERMANY: District Heating in HafenCity (Hamburg)

HafenCity is a ***new district*** *in the inner city of Hamburg, which is being converted from an old port area into a modern city quartier. The city of Hamburg integrated in its urban planning an* ***energy strategy for this new district*** *and decided to implement a low-carbon district heating system. The grid started operation in 2014 and offers a* ***cost-efficient low carbon heating solution with CO_2 emissions under 89 g/kWh****. It is being constructed progressively until 2028. At its final stage, heat will be supplied through a CHP plant fuelled by biomethane and natural gas, biomass HOBs fuelled by woodchips and a heat pump.*

Some of the key factors contributing to the efficiency and well-functionality of this DHC system include: i) The ***national policy framework*** *supporting CHP and renewable energies; ii) the strong* ***support from the city*** *of Hamburg; iii) the deep integration of* ***DH in the urban planning;*** *iii) the* ***ambitious environmental standards required by the tender****, in terms of maximum CO_2 emissions for heat supply; iv) the* ***obligation to connect*** *new buildings to the grid; and v)* ***the fruitful cooperation between the city and private operator****.*

I. National context

I.I Drivers for DH in Germany

The German system of **local public utilities** is unique. The model of the so-called "Stadtwerke" dates back to the 19th century, when municipal administrations strived to develop the comprehensive infrastructure needed to provide its citizens with affordable energy, water supply, wastewater treatment systems and public transport. These utilities used to focus their activities on the specific region where they were based.

The energy market in Germany was liberalised in 1998, which led to the reorganization and unbundling of the existing structures for energy production, transport and distribution. From this point onwards, consumers could freely choose their energy supplier and were not dependent on their local utilities anymore. On the other hand, local utilities were allowed to offer their services in not only their region, but also anywhere else in Germany. Also during the 1990's, part of the German local utilities were **partly privatized** (through a variety of PPP schemes) as many cities and regions suffered from financial difficulties. The opposite process has been occurring during the last years, where several privatized local utilities operating under a concession contract achieving expiration were **re-municipalised**.

Today, there are around 1 400 Stadtwerke operating in Germany, which are structured in different ways. In some cases they are partly owned by one of the large private utility companies (RWE, E.ON…), while in other cases the utility is still 100 % owned by the city, sometimes jointly with other public bodies.

The **district heating** sector in Germany has been affected by the historical developments of the country and its local utilities. After World War II, district heating was developed differently in West and East Germany.

- In **West Germany**, decentralised heating systems prevailed. The affordability of fossil fuels – oil and natural gas – stimulated this development in the 1950's. Some district heating systems were put in operation in new residential areas, promoted by oil companies like Shell, BP or Fina as an opportunity to sell heavy fuel. Nevertheless, district heating did not expand widely in West Germany, due to its low competitiveness against individual heating solutions and to the quick expansion of gas distribution networks.

- In **East Germany**, however, district heating expanded. DH was an attractive heating solution because of the availability of coal, and the political support to collective heating, which was part of an overall public housing policy. Indeed, individual heat supply was politically unwanted and high subsidies were provided by the Government to support new district heating investments.

In 2013, **10 %** of total heat supply in Germany was delivered via DH, as illustrated in Figure 48. The share of district heating in residential buildings was slightly higher, namely 13.5 %.

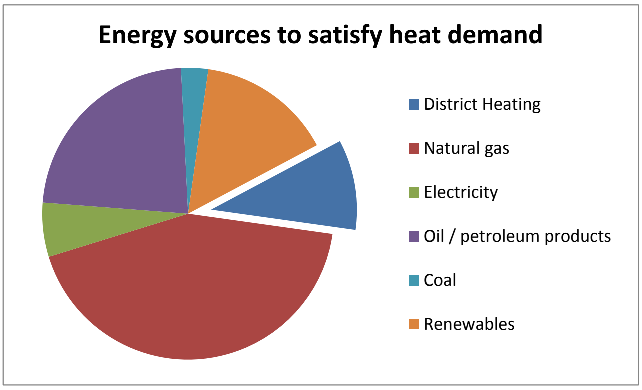

Figure 48: Energy sources to satisfy heat demand in Germany in 2013 (Source: Tilia based on data from National District Heating Association)

The **German energy transition** (Energiewende[44]) started in 2010 and has boosted the development of new district heating systems. The German Government has set ambitious energy and environmental targets, detailed in Figure 49.This policy strongly supports the expansion of **CHP**, which has had significant implications for the development of district heating grids. Indeed, CHP is being used more and more often in Germany, as it is considered a sustainable and efficient technology for electricity and heat supply. In order to provide further incentives for the construction of district heating grids, the Government supports newly built grids with **grants**.

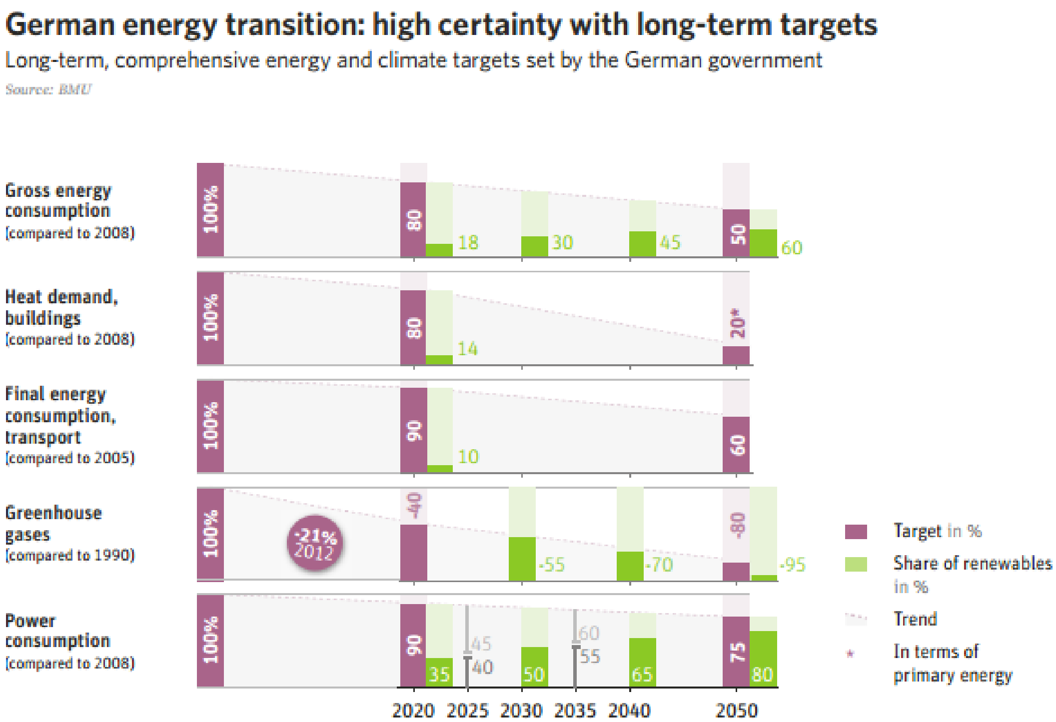

Figure 49 Energiewende targets (Source : RMU)

44 Details on the Energiewende provided on: energytransition.de/

High initial investments and the demand risk due to the inexistence of a general "DH zoning" are perceived as the main **barriers** to develop new DH projects in Germany.

- DH systems are highly **capital-intensive**. In order to be economically profitable DH needs high energy densities in terms of demand per km, as it is the case in compact cities;
- In Germany, consumers are (in general) free to choose their source of heat supply, there is not an obligation to connect to DH where available. Therefore, when a new DH system is built, the utility in charge of the service has to make the investment in the grid without knowing the exact heat consumption, taking the associated **demand risk**. Some exceptions have been made in some cities - like Hamburg - where local regulations include an obligation to connect to DH in certain areas.

I.II Policy tools and incentives supporting DH

In Germany, **district heating is not regulated** at national level. However, DH is affected by most of the laws ruling the energy sector, which have significantly evolved during the last decade. Some of these laws incentivise DH by supporting CHP, energy efficiency or RE requirements in building.

The German Energy transition came along with a set of different policy tools, such as the Cogeneration Act (*Kraft-Wärme-Kopplungs-Gesetz*), the Renewable Energy Act (*EEG*), the Renewable Heat Act (*EWärmeG*) and the energy saving ordinance (*Energieeinsparverordnung*), among others. Their impact in DH development is summarised below.

The **Combined Heat and Power Act** promotes the installation of CHP plants and the expansion of district heating systems. This act regulates the remuneration scheme for the electricity produced by CHP plants in cogeneration mode (i.e. when these are also using the heat produced for self-consumption or external use). The act obliges electricity grid operators to connect to CHP plants and to give priority dispatch to the electricity produced in these facilities, just after solar PV and wind production. Furthermore, the act regulates a premium price on top of the spot market for CHP electricity and a subsidy scheme for municipalities installing new DH systems for an amount of EUR 60/m of grid.

The **Renewable Heat Act** aims at increasing the share of renewable energy sources in heat supply and also promotes the expansion of DH. It makes it mandatory for new buildings to use a certain share of renewable sources for their heat supply. This obligation can be met if the building is connected to a DH grid where heat is produced through CHP or renewable energies.

The **Energy saving ordinance** focuses on requirements in the building sector, mainly thermal insulation, engineering systems or the heat balance of the entire building. District heating is affected indirectly by this ordinance, as it is considered as an efficient technology for heat supply and therefore a way to achieve energy efficiency requirements.

Finally, the national public **bank KfW**[45] supports investments in CHP plants and DH systems fuelled with renewable energies. This is done through its Renewable Energy programmes ("*Erneuerbare Energien – Premium*" and "*Erneuerbare Energien – Standard*"). Through these programmes, project promoters receive long-term financing at low interest rates and an investment grant funded by the Federal Ministry of economy and energy (BMWi).

[45] https://www.kfw.de

II. Presentation of HafenCity's DH system

The heat supply of the **new urban district** of HafenCity, in Hamburg, is a good example of a modern and efficient district heating grid, integrated in a larger sustainable urban development project.

The district of HafenCity is being converted from an old port area into a modern city quartier, including residential buildings, offices and shops (cf. section III). 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.

The conditions for establishing district heating were very good. The district design is compact and the city of Hamburg issued an **obligation to connect to the DH grid** for residential buildings in the entire area of HafenCity. Exceptions to this obligation can be conceded by the City of Hamburg in case it can be proven that heat generation of the building is below the established threshold for CO_2-emissions (i.e. 89 g/kWh). However, it is very unlikely that decentralised heating solutions fulfil this threshold at a lower cost than district heating, which makes DH the preferred solution for almost all building owners.

There are two district heating grids in HafenCity, and **this case study is based on the DH grid in Eastern HafenCity**, which is owned and operated by enercity Contracting Nord GmbH (eCG Nord[46]). The West of HafenCity is supplied by an older district heating grid operated by Vattenfall.

The contract for the construction and operation of the DH grid in Eastern HafenCity was awarded through a **public procurement** process organized by the city of Hamburg. The **tender** included very high environmental standards, notably maximum CO_2 emissions of 125 g/kWh. As this CO_2 target could not be achieved with fossil fuel technologies, bidders had to propose solutions based on renewable energy supply.

The tender was awarded in 2009 to eCG Nord, which proposed a heat generation with an enhanced environmental performance - namely 89 g CO_2 /kWh - achieved through a production mix using **almost exclusively renewable energies**. When finished in 2028, DH will be supplied by a CHP plant fuelled by biomethane and natural gas, a biomass heating plant and a heat pump. These technologies guarantee low CO_2 emissions and an overall high efficiency.

The main characteristics of the DH system are summarised below.

Key facts and figures (2015)

DH market share	~100 % in HafenCity
Heating capacity	7 MW (target: 48 MW)
Heat production	6 GWh/y (target: 70 GWh/y)
Km network (double-pipe)	1.5 km (target: ~16 km)
CO_2 emissions	75 kg/MWh (certified biogas)

- **Small system**: 6 GWh/y of DH (to be expanded to 70 GWh/y)
- **Private network**: owned and operated by the private company eCG Nord
- **Flexible production** (once finalised):
  - 1.6 MW_{th}/1.5 MW_e CHP plant fuelled by biogas
  - 12 MW biomass HoB (woodchips)
  - 3 MW heat pump
  - 28.4 MW peak gas boilers
  - 3 MW peak oil boilers

46 http://www.enercity-contracting.de

Figure 50 shows a map of the grid, including the existing network (in red) and the future network developments (in black). Details on the existing and future capacity are provided in Figure 51.

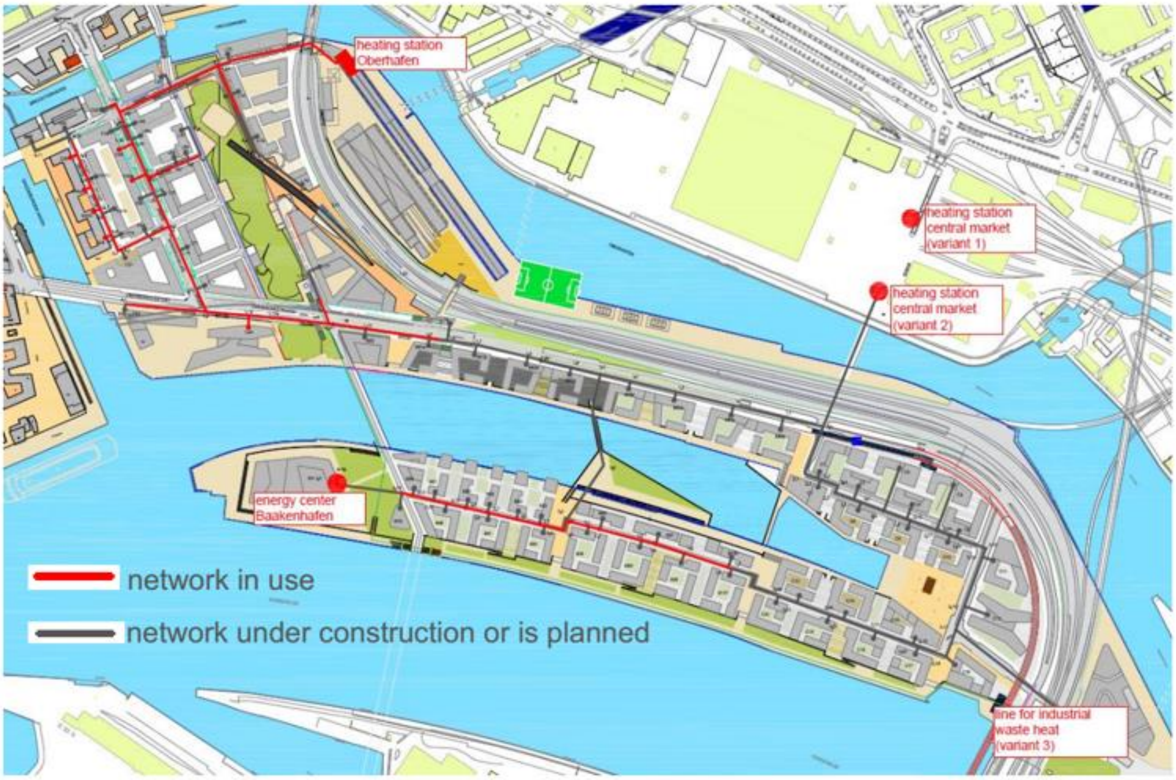

Figure 50: DH network and heat stations (red points) in Eastern HafenCity (Source: eCG Nord)

	installed capacity		production 2028		energy carrier		Deliv-ered heat
	MW_{th}	MW_{el}	GWh_{th}	GWh_{el}	GWh_{Hi}	GWh_{el}	GWh
CHP (bio-methane)*	1.6	1.5	12.8	11.4	28.9	1.6	70.1
heat generation plant (natural gas)	10.0		9.0		10.0		
	10.0						
	4.2						
	4.2						
heat generation plant (oil)	3.0		1.8		2.0		
3 heat generation plant (wood)	4.0		58.0		71.0		
	4.0						
	4.0						
heat pump (pow-ered by electric-ity)	3.0		2.8		0.8		

Figure 51 : Planned generation units of the HafenCity in 2028 (Source: eCG Nord)

III. Urban development and expansion of DH

HafenCity[47] is one of the **biggest inner-city developments in Europe,** transforming a former industrial area into a mixed-use urban neighbourhood. It is located to the north of the river Elbe and used to be a port district. After the fall of the Berlin Wall, shipping trade expanded and the harbor was not suitable for shipping big containers. Port operations were relocated to a new port to the south of the river Elbe in the beginning of the 1990's and the port ceased its operation. For over 10 years, this area of 157 ha

47 http://www.hafencity.com/

remained unused and surrounded by a custom fence. In 1997, a local company was created to develop and manage the HafenCity urban project (HafenCity Gmbh).

In 2003, the city of Hamburg decided to convert this port district into an attractive and modern city area. A **Masterplan** for a **compact and efficient district** was approved by the city in 2004 and later divided into two Masterplans: East and West HafenCity. The former integrated the urban plans for 4 150 new apartments, offices with 24 200 working places and commerce buildings to be built between 2009 and 2028. This Masterplan integrated the plans for a DH network and the obligation for buildings to connect to the grid (with the exemption described in section II).

The construction of the production facilities for East HafenCity's DH grid was **structured in 3 phases**, in order to progressively increase the heating capacity as the district grows.

1. In November **2014**, the first facility for heat and electricity generation was commissioned, the so-called *Oberhafen* heating station. It contains a biomethane-fuelled CHP unit with a capacity of 1.5 MW_e and 1.6 MW_{th} and an 8 MW_{th} heat generation plant (HOB), fuelled with oil and natural gas. The target is to increase the capacity of Oberhafen heating station to 46 MW_{th} in 2028. At this time, the expected yearly heat production will be 70 000 MWh_{th}/y. The heating station is located in a building which previously had served as a storage and handling facility for the port. Like that, the power plant maintains the traditional brick façade, fitting the maritime architecture of HafenCity.
2. A second heating station is planned for **2018** in the nearby central market. It will have three biomass HOBs fueled by sustainable woodchips with a total output of 12 MW_{th}. The boilers will start operation in 2018/2019, 2022 and 2024.
3. In **2024**, a third heating station, called *Baakenhafen*, will start operation. It will contain a heat pump with a heat output of 3 MWth.

IV. Local heat market

IV.I Hamburg's heat market

The city of Hamburg is the second largest city in Germany and has a population of 1.8 million inhabitants. It is located in the North of Germany, close to the North Sea, at the mouth of river Elbe.

Hamburg **has a high heat demand** of ca. 21.6 TWh/y, due to its high population and cold weather conditions. As the heat market has not significantly changed since 2012, the 2012-2013 figures below remain representative of the situation in 2016. Figure 52 shows how this heat demand is distributed among different consumers. In 2012, most of the heat was consumed by households (45.3 %).

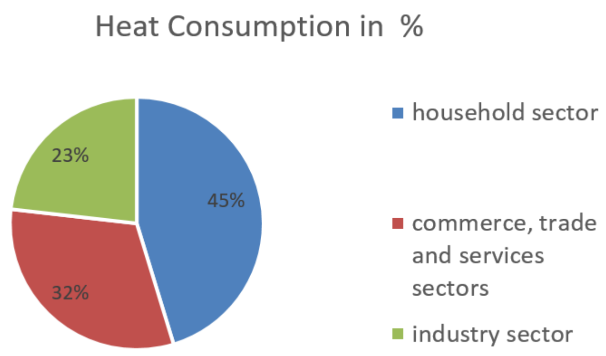

Figure 52: Heat consumption of Hamburg by consumers in 2012 (Source: City of Hamburg)

The main technology used for heat generation consist of natural gas boilers. Figure 53 illustrates how the heat demand in Hamburg is supplied. The percentage of **district heating amounted 21.5 %** in 2012.

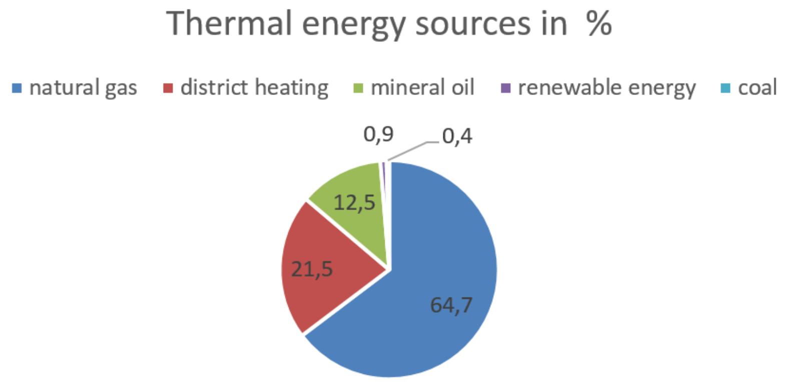

Figure 53: Energy sources for heat generation in Hamburg, 2012 (Source: City of Hamburg)

In 2013, **most of the district heating supply was produced by CHP** plants (58.2 %), followed by renewable energies (14.7 %). Most of these CHP plants are fired with **coal**, which represents a high potential for increasing the renewable energies share in district heating.

The most important district heating grids and production facilities in Hamburg are represented in Figure 54. The two big power plants called *Wedel* and *Tiefstack* are fuelled with hard coal. The rest are smaller waste-to-energy facilities, i.e. incineration plants (*MVA* in German).

This map also shows a new and innovative heat generation facility, the so-called Energy bunker (*Energiebunker Wilhelmsburg*). It is a former bunker from the World War II that is now used for energy and heat generation. It includes today one biomethane-fuelled CHP plant, a natural gas-fuelled CHP plant, two peak boilers and a solar thermal power plant. With a renewable energy share of 67 % the energy bunker is a pilot project for renewable heat generation.

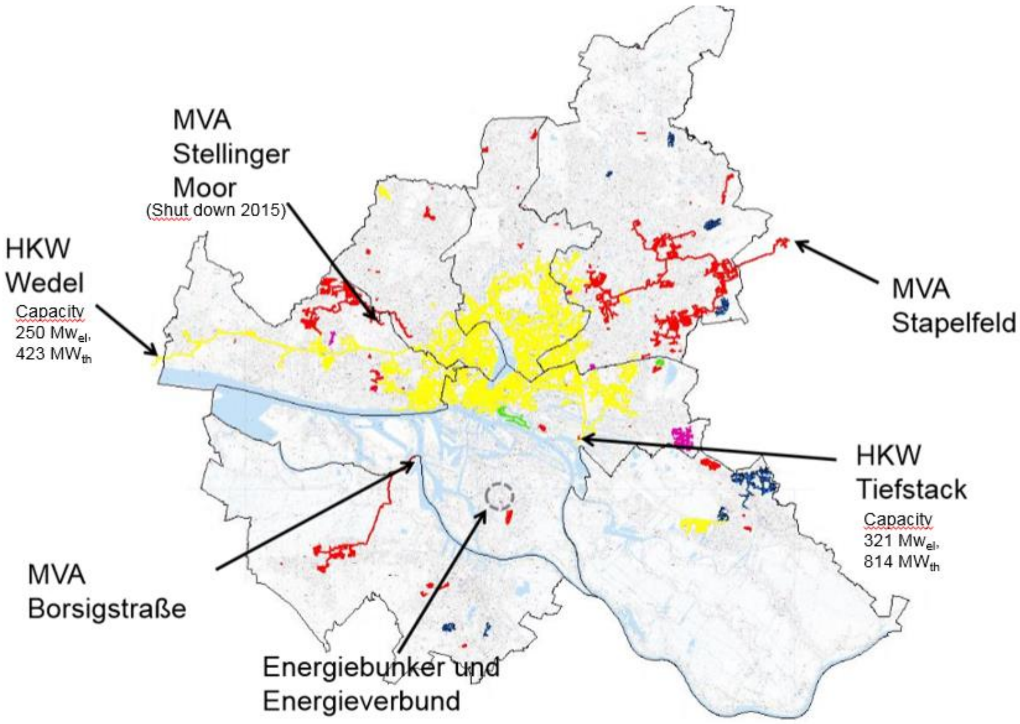

Figure 54: Main heat plants and DH networks in Hamburg (Source: City of Hamburg)

Following a referendum held in 2013, the City decided to re-**municipalise the district heating grids**. Most of the district heating grids in the city currently belong to the Swedish company Vattenfall. After the referendum, the city started the required procedures to buy Vattenfall's biggest DH grids and generation facilities. The concerning contracts are already signed and, as of January 2019, the district heating grids will be owned by the city of Hamburg again.

The City considers that the **ownership** of the district heating grid gives the city of Hamburg new opportunities to deepen its energy **transition towards a renewable district heating** supply. The City already had highlighted this objective at the time of the referendum, as part of its heating strategy. This strategy aims at achieving a sustainable and cost-efficient heat supply for the city, as detailed in Figure 55.

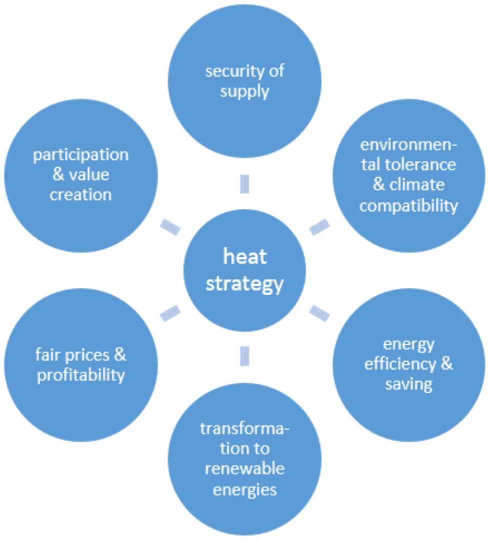

Figure 55: Heating strategy of the City of Hamburg (Source: City of Hamburg)

IV.II Demand and supply in HafenCity

The district heating sector in Hamburg benefits from its maritime climate: mildly cold and wet. The city has a heat demand of ca. **3484 heating degree-days**, which is significantly higher than Europe's average, as illustrated in Figure 56.

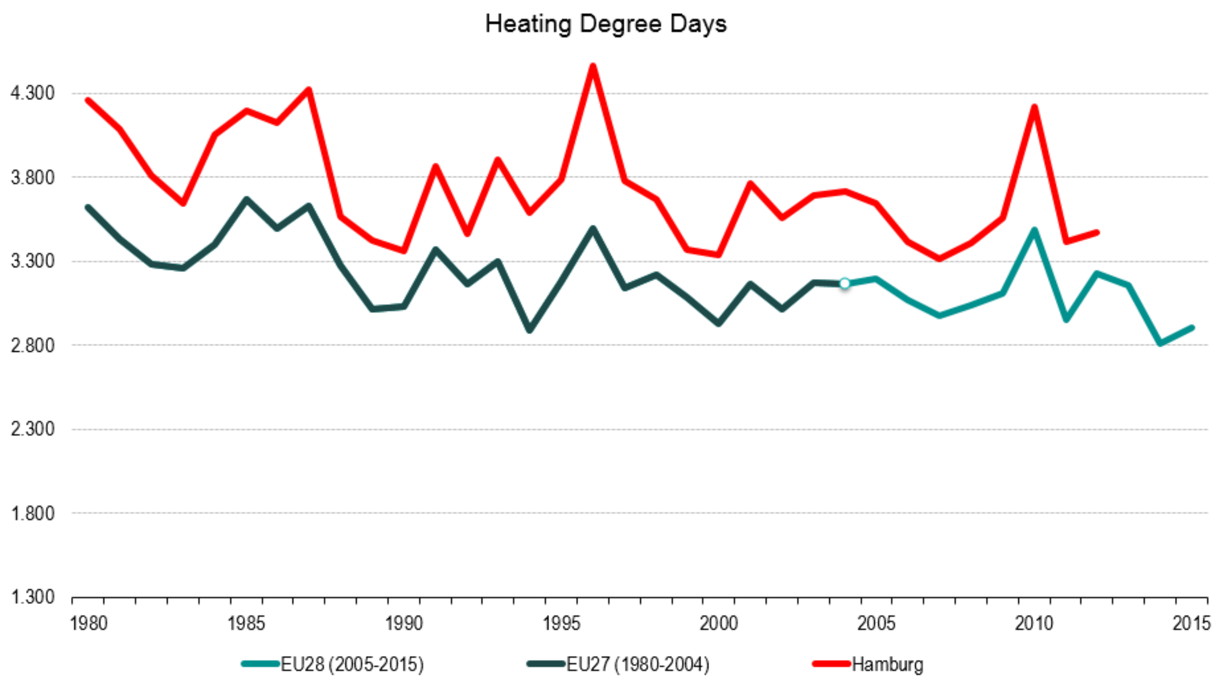

Figure 52: Heating degree days in Hamburg and Europe

The newly built **buildings in HafenCity are very efficient** due to their high insulation standards. HafenCity GmbH even developed its own "**HafenCity Ecolabel**", an energy label indicating the energy efficiency of the newly built buildings. The label has very high standards compared to other German building regulations and is often required in tenders for real estate development in HafenCity. It includes two categories: "silver" and "gold". For residential buildings, these 2 labels mean a primary energy use[48] 30 % or 45 % (respectively) lower than building code requirements under EnEV 2009. In the Eastern part of HafenCity ca. 70 % of the buildings are certified with the HafenCity Ecolabel. Indeed, the average heat demand in HafenCity in 2028 will be 28 kWh/m^2/y, which represents 18 % of the current heat demand per m² in Hamburg.

The **heat demand evolution** of East HafenCity is illustrated in Figure 57. It shows a linear increase until 2028 due to the growing population. After that, the heat demand will probably remain stable. This demand is covered with the heat generation units introduced in section II.

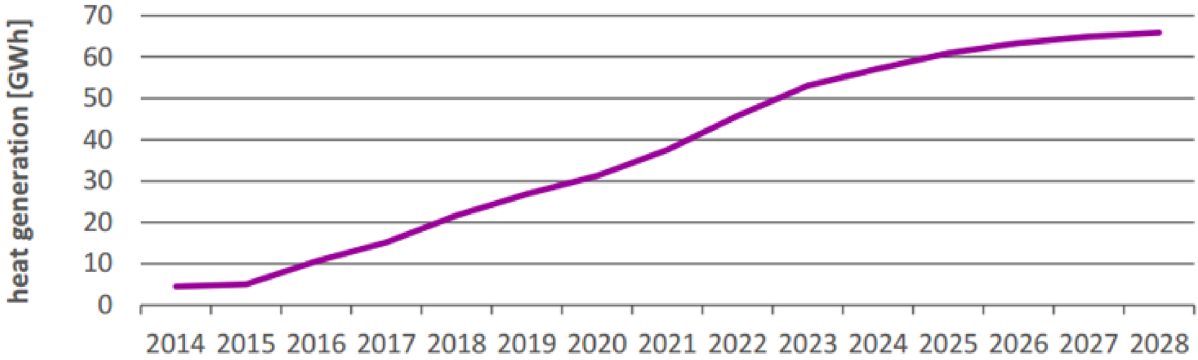

Figure 57: Heat demand of East HafenCity (Source: eCG Nord)

IV.III Price competitiveness of DH

In Germany **district heating is in general the cheapest solution** for the customer, when available. With an average price of EUR 0.90/kWh, the price for district heating is comparable to other heating technologies. As presented in Figure 58, the price per kWh for other heating fuels (pellets, gas, oil) was only slightly below the price of district heating in 2014. However, the prices of individual heating solutions represented in this graphic do not take into account neither the initial investment of individual heating solutions nor the O&M costs during their lifetime. For district heating, these costs are already included in the price.

48 This primary energy demand is measured in kWh/m^2/y and includes the energy demand for heating, domestic heat water, ventilation, cooling and lighting

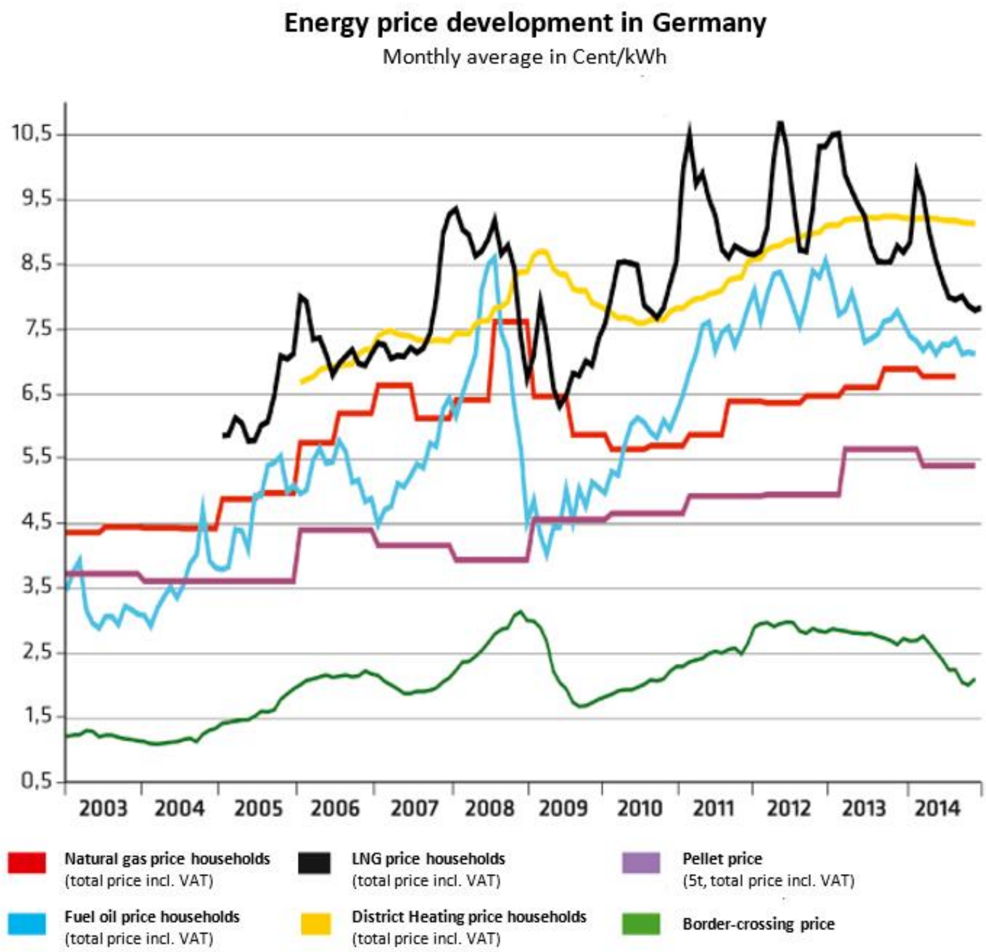

Figure 538: Energy prices evolution in Germany
(Source: energieverbraucher.de, based on data from German Federal Statistical Office)

Prices in Hafencity are competitive against individual heating solutions. However in this case the price competitiveness of DH is not crucial for its commercial viability, as there is an obligation for all buildings to connect to the DH grid.

V. Business model

V.I. Governance and strategy

In 1997 a port and location development company (GHS in German) was set up to manage the development of HafenCity. Since 2004, this company is called HafenCity Hamburg GmbH. The company is owned 100 % by the City of Hamburg.

The **board of HafenCity GmbH** consists mainly of senators of the City of Hamburg (which is both a *Land* and a *Stadt*, hence is ruled by a *Senat*). The members of the board are the Mayor of Hamburg, the senator for urban development, the senator for energy and environment, the senator of culture and the senator of finance. All relevant sectors for HafenCity are therefore represented.

The owner of the DH system of East HafenCity is **eCG Nord**, a subsidiary of enercity Contracting GmbH. The enercity Contracting GmbH itself is also a subsidiary of the group enercity GmbH, which was **originally founded by the municipality of Hannover** (a 500 000-inhabitant city in Lower Saxony, 150 km away from Hamburg). After the liberalization of the energy market the enercity holding started providing energy services at national level. It created the eCG Nord for its activities in the Northern Germany, which currently operate several DH systems in this region.

Together, HafenCity Hamburg GmbH and EcG Nord are promoting a district heating generation with low-emissions and high efficiency.

V.II Financial model

According to the tender documents, the investments for HafenCity's district heating grid and associated generation facilities had to be totally carried out by the preferred bidder. Therefore, only big corporations with sufficient financial resources could present an offer.

The heat supply in HafenCity is financed through heat sales. The average price for DH is EUR75/MWh excluding taxes. With a value added tax of 19 % in Germany, the price with taxes is ca. EUR **90/MWh**. This covers all heat generation costs (i.e. capital and operating costs).

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

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

A **connection fee** is paid for new connections. Usually a fixed price is defined, independent of the connected load. This fee is however lower than the real connection costs.

For **invoicing**, the customers either get a monthly bill based on their real consumption or make equal monthly payments based on an initial estimate, which is corrected based on the actual consumption at the end of the year.

The financial situation of HafenCity DH system has been significantly impacted by the materialization of **fuel price and demand risks**, as detailed below, preventing the company from reaching breakeven yet.

i. Prices are annually adjusted through a **formula** which is dependent on energy prices (namely oil, woodchips and electricity). The formula for price actualisation (P_{Y+1}) was proposed by eCG Nord in its bid and is as follows.

   $P_{Y+1} = P * (40\ \% * \text{oil price index} + 20\ \% * \text{woodchips price index} + 40\ \% * \text{electricity price index})$

   The price indexes are published by the Government and the weighting was based on the final production mix of the DH network (i.e. biogas, woodchips and heat pump respectively). As for biogas there is no national price index, it was decided to use the oil price index instead.

   The oil price drop during the last years has therefore impacted the revenues of the DH system, and the **prices paid by the customers have been lower than real costs**.

ii. The DH system has also suffered from the **delays in real estate developments**. In particular, the street paving was done for the whole HafenCity area before the arrival of most of the new buildings, forcing eCG Nord to invest in the distribution system before having enough clients to finance these investments through heat sales. Moreover, the uncoordinated new constructions make it challenging for the company to connect new clients if they are not located nearby, which cannot be controlled neither by eCG nor by the city.

VI. Client relationships and energy efficiency initiatives

eCG Nord provides several **energy services** to investors, urban planners and residents. These services include energy efficiency consulting, maintenance of the DH grid and facilities and management of complaints.

All services are provided by eCG Nord itself, and customers can easily contact the company. The office is located very close to the area of East HafenCity, in order to enable the staff of eCG Nord to react in real time when needed and immediately be on the site.

It also provides personal advice during planning, building and operation. The company is **cooperating with the City of Hamburg** to discuss with real estate developers about heat supply options as soon as they decide to invest in HafenCity. In particular, eCG Nord informs them about the two possible **options for heat supply** and their related costs, i.e. connection to their DH grid or installation of an individual heating solution with associated emissions lower than 89 g CO_2/MWh. Today, there is only one building that decided not to connect to the grid: the office building of Greenpeace. The energy demand of this building is very low, and is met through a combination of several fossil-free solutions (mainly 2 heat pumps fuelled by PV panels and small wind turbines and a biomass boiler as back-up). This solution is however more expensive than DH.

VII. Framework for innovation

An innovative option for heat generation in HafenCity would be to use the **industrial surplus heat** generated by a copper-producing plant at the East of HafenCity. The heat produced is now transferred to the river Elbe and lost. If this heat was used for DH, it could cover 90 % of HafenCity's demand. This solution, which is currently under development, would save about 6,000 tonnes of CO_2 per year. eCG Nord, the industrial partner and two project promoters (Tilia and the electricity distributor Hamburg energy) are exploring this option.

To carry out such a project, a DH transport line of more than 3 km, crossing the river Elbe, would need to be built between the production site and the DH grid. The industrial partner could supply an average of 18.5 MW_{th}. By doing this, 120 GWh_{th}/y would be available for DH and the heating station "Central market" would not need to be built in the inner city, resulting in important gains in air quality and energy efficiency. Within a period of 20 years this project would save approximately 123 000 ton of CO_2. In addition, the environmental impact of the industrial facility would be reduced through a decrease of the heat transfer to the Elbe river.

Several feasibility studies have been carried out for this project, demonstrating its viability. However, it has not been implemented yet because of a disagreement between eCG Nord and the industrial company regarding the heat price. Negotiations are ongoing and are expected to end by the end of 2016.

VIII. Perspectives

The district heating system of HafenCity will be one of the most efficient district heating systems in the world when finished in 2028. Until now, the district heating concept has been implemented as planned, even if the heat sales are being lower than expected, as previously explained. Today, approximately one third of the construction of the grid and the heat generating facilities are completed. Real estate developments and related connections to the DH grid are expected to continue increasing in the coming years and reach the 2028 targets.

IX. Conclusion: Key Success Factors

The key success factors which led to an ecological and efficient district heating system in HafenCity are summarised below.

<u>Key success factors at national level</u>

i. **Strict regulations to reduce CO_2 emissions.** Germany has set ambitious environmental targets in the frame of its energy transition (*Energiewende).* These targets have been translated into stricter environmental standards for heat supply, which incentivise the use of low-emission technologies such as efficient DH.

ii. **Feed-in tariffs for renewable energies and CHP plants** have also facilitated the deployment of these low-emission technologies. The deployment of decentralised CHP has particularly boosted the development of new DH systems.

iii. The **available funding through KfW loans and investment subsidies** offered by the Federal Government has also fostered DH investments, which are highly capital-intensive.

<u>Key success factors at local level</u>

iv. **Support from the City of Hamburg**. The city is the project promoter, and planned HafenCity's DH grid as part of a broader **energy strategy** aiming at reducing CO_2 emissions. HafenCity is a flagship project for Hamburg and benefits from a high political buy-in.

v. As the area of Hafencity is **owned by the City**, the latter was able to impose high environmental standards to all new buildings in the district. This can be illustrated through the creation of the Hafencity Ecolabel, required in many tenders for new constructions.

vi. **Comprehensive energy planning**. As HafenCity was a new district, a comprehensive energy concept could be planned from scratch. This was a unique opportunity to develop a new district heating grid, as no heat supply existed.

vii. The **public tender** proved to be and efficient process to promote competition while meeting **strict economic and environmental standards.** This resulted in an innovative, efficient and low-carbon DH system offering a cost efficient service in line with those high quality standards.

viii. The **obligation to connect** to the DH grid imposed by the city facilitated the investments. This allows the district heating grid to benefit from **economies of scale**, which are translated into lower costs and ultimately lower prices for final users. It is also a way to **reduce the demand risk**, if the connection forecast is reliable. Indeed, the reliability of the initial demand forecasts is critical for the financial viability of new DH systems. HafenCity case shows that mitigating the demand risk at development stage should be given higher importance.

ix. Finally, the **good cooperation between the city and the private operator** eCG Nord has been essential for developing the project. Both parties have aligned their interests to a certain extent and are working together to promote connexions and the efficient installation of energy systems in the new buildings. However, the construction works for HafenCity development could have been better coordinated with the construction of the new DH grid to avoid the current financial difficulties of the latter.

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2.2.6 ITALY: District Heating and Cooling in Brescia

Brescia is a 196 000 population town located in the region of Lombardy (Northern Italy). It was the first Italian city to develop a DH system, in the 1970's, following an integrated approach to energy and waste management.

Today ***70 % of the heat demand is covered by DH****, mainly produced from a highly efficient CHP waste-to-energy facility. Some of the key factors contributing to the successful deployment and operation of this DHC grid include: i) a* ***strong support from the Municipality****, which designed the DH system following a* ***long-term and integrated approach to energy and waste management,*** *aiming at ii) reducing the carbon footprint and fossil-fuel dependency of the City while offering* ***competitive heat prices*** *to its citizens. This is achieved mainly through the iii) use of* ***local resources*** *(waste-to-energy, surplus heat); iv) an* ***efficient public-private partnership*** *(long-term concession); and v) integrating* ***innovative technologies*** *and management modes to enhance its competitive position and the* ***quality of the service*****.**

I. National context

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 2013 represented **5.6 %**[49] **of the national market share** in terms of final users. Since 2000, DH has experienced an annual growth rate of ca. 7 % (in terms of heated space). DC developments are very recent, with a total installed capacity of 182 MW (2013).

The heating market is **not regulated** at national level. It is **not possible to enforce the connection** to a DH grid. Indeed DH activities take place in a highly competitive environment where the choice of heat supplier is principally based on prices. The main alternative to DH is the use of **natural gas boilers**, which dominate the heating market.

There are **not many national incentives to DHC**. In particular:

- There are no specific investment grants for DH, despite the long payback periods of these systems (above 20 years).
- Until 2016, DHC projects were supported through the issue of **white certificates**[50] (corresponding to the primary energy saved through the projects), that could be traded on the market. However, this support scheme has recently been changed and some DH support has been significantly reduced, which could prevent new DHC projects from being developed.
- A **reduced VAT** is applied to heat sales to residential consumers supplied with RE sources or CHP (10 % instead of 22 %).

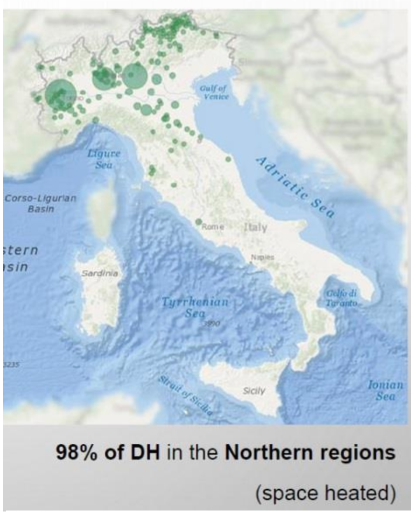

Figure 59 DH grids in Italy (Source: AIRU)

[49] Euro Heat & Power report, 2015

[50] 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.

Italy has more than **200 DH systems**, mainly located in the Northern regions, as illustrated in Figure 59. The 3 large cities supplied with DH -Brescia, Milan and Turin- represent 42 % of the total DH supply. Most of these systems were **originally publicly owned**. However, the newly developed systems are mostly privately owned and the 3 large systems mentioned before are managed under **public-private partnerships** (concessions). There are more than 120 DH operators, including a few big groups such as A2A (the DH market leader, operating Brescia's grid), IREN, HERA or EGEA.

The **energy mix** of the Italian DH systems is mostly based on fossil fuels (mainly natural gas) as illustrated in Figure 60 below.

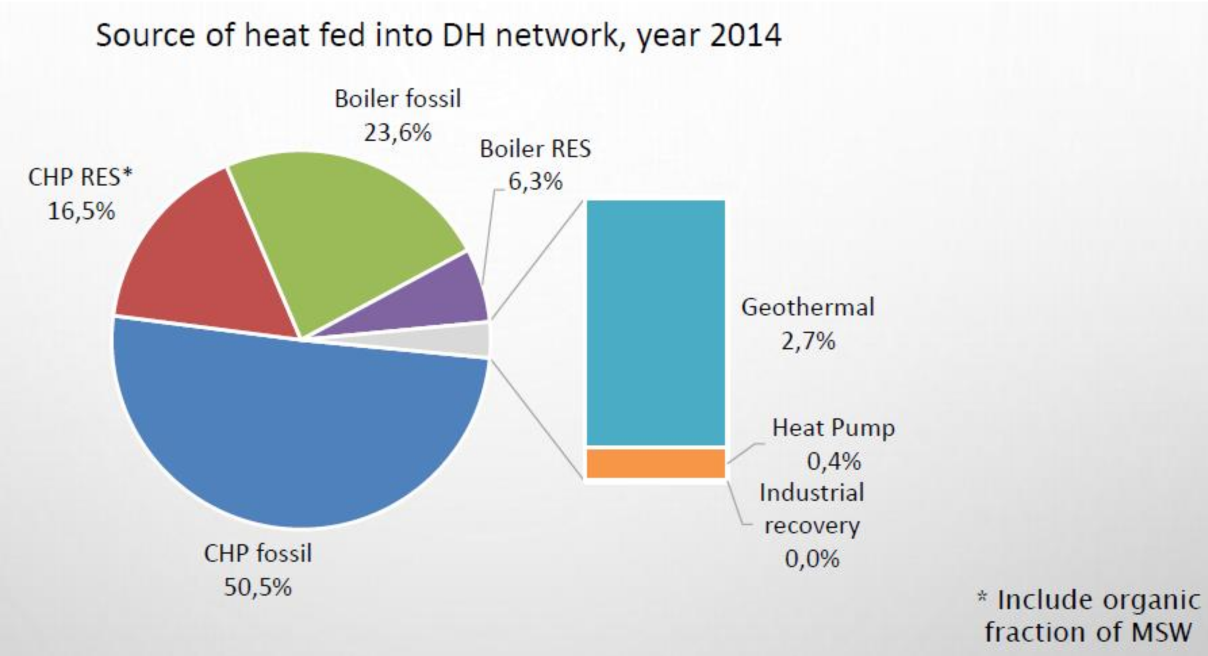

Figure 60 DH energy mix in Italy 2014 (source: AIRU)

In Italy, DH is still wrongly perceived by some people **as a rather old and inefficient technology**. This perception is slowly changing but there is a great potential for improving the awareness about the benefits of deploying efficient DHC systems. The Italian District Heating Association (AIRU[51]) is one of the key actors working on it.

II. Presentation of Brescia DHC system

II.I Overview

The DHC system of Brescia was developed in the 1970's by the local utility company of the city. Since 1996, it is owned and operated by the A2A Group, which is partially owned by the Municipality of Brescia. It supplies **70 % of the heat demand** in the city, mainly through a **waste-to-energy CHP** plant. The system's energy mix is illustrated in Figure 61.

The map below (Figure 62) represents Brescia's DH network and heat generating facilities (in yellow). The main characteristics of the DHC system are summarised below:

[51] http://www.airu.it/

Key facts and figures

DH market share	~70 %
Heating & Cooling capacity	DH: 710 MW (2015) DC: 23 MW (2015)
Heat &Cold production	DH: 1266 GWh/y (2015) DC: 33 GWh/y (2015)
Km network (double-pipe)	DH: 665 km (2015) DC: N.a.
CO_2 emissions (heat)	155 kg/MWh (2013)

- **Medium-size system**: it supplies 21 000 buildings in Brescia and 2 neighbouring municipalities (Bovezzo and Concesio)
- **Public-Private Partnership (>30y concession):** The DHC system is owned and operated by A2A Calore & Servizi SRL (A2A Group)
- **Efficient production**:
  - 180 MW_{th} waste-to-energy CHP (*Termoutillizzatore*)
  - 110 MW_{th} multi-fuel CHP (coal and gas) (*Lamarmora*)
  - 420 MW natural gas HOBs (*Centrale Nord* and *Lamarmora*)
  - 10 MW surplus heat recovery from a local steel industry (as of 2016)

The **client structure** is as follows:

- Heat demand: 80 % residential;
  20 % tertiary and industrial sectors;
- Cold demand: 100 % tertiary sector (two main clients: a hospital and the university)

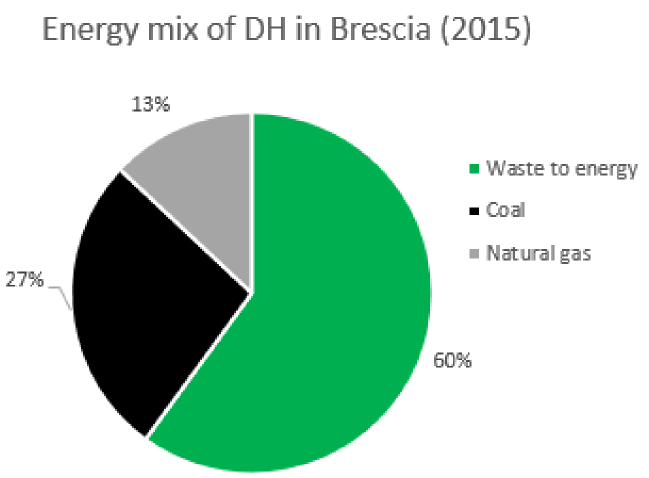

Figure 61 Energy mix of DH in Brescia 2015 (Source: A2A)

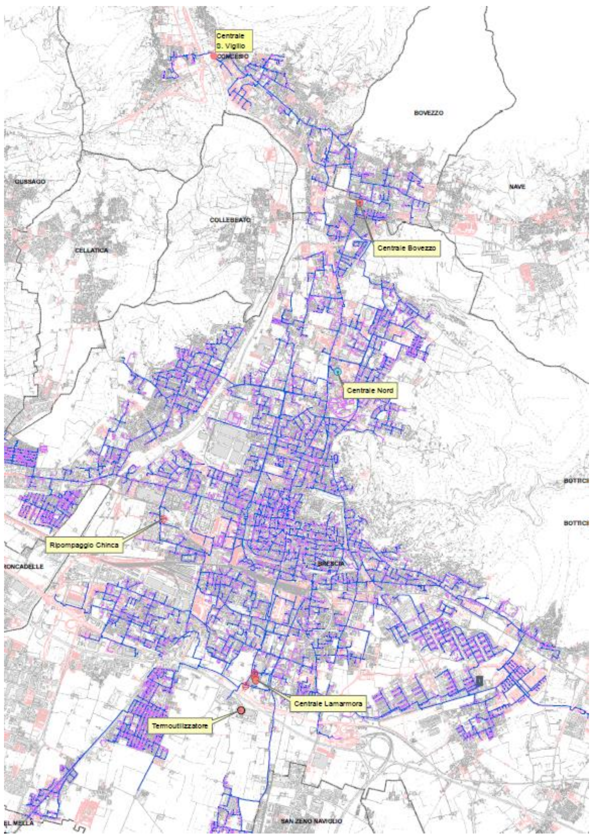

Figure 62 Map of DH network in Brescia (Source: A2A)

II.II Historical development of DH in Brescia

Brescia was the **first Italian city to develop a DH system**, in the 1970's, mainly driven by the will of the Municipality to provide public services in a coherent and integrated manner, through its municipal utility *Azienda dei Servizi Municipalizzati* (ASM). This company was founded in 1908 and was responsible for several services such as energy distribution (power and gas), water treatment and sewage, traffic lighting, street cleaning, etc.

Following the nationalisation of the electricity sector in 1962, ASM developed a project for a **new CHP plant** and a DH grid to use its heat. This project allowed ASM **to remain self-sufficient for electricity supply,** independent from the recently nationalised system.

The municipality and its local utility worked together on a long-term **comprehensive plan** for the development of DH grid and heat generating facilities, including the waste-to-energy (WtE) plant. The main historical milestones for the DH system are presented below:

- The DH system was **commissioned in 1972**, initially covering the areas close to the first generating facilities (methane-fuelled HOBs) in Centrale Lamarmora (cf. Figure 63);
- In 1978 and 1981, two **CHP** units (fuelled by natural gas and oil) were built in *Centrale Lamarmora*.
- In 1987/92 the capacity of *Centrale Lamarmora* was increased through the installation of another multi-fuel CHP unit, fuelled by natural gas, oil, coal, or a mixture of these;
- In 1998 the **waste-to-energy CHP plant** came into operation (*Termoutillizzattore*), using solid urban waste (the not recycled share) as fuel and avoiding the emission into the atmosphere of ca. 300 000 tons of CO_2;
- In 2004, the WtE plant commissioned a new (third) combustion line ;
- Finally, since January 2016 the grid is supplied with **surplus heat recovered** from a nearby steel factory.

The evolution of the connections to the DH grid is presented in Figure 64 below.

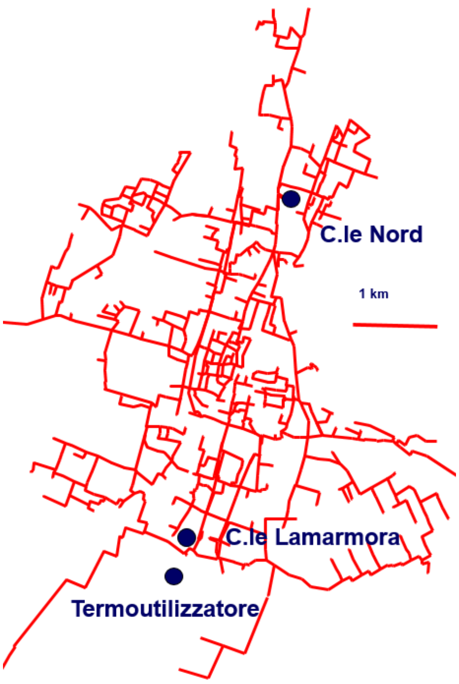

Figure 63 DH system Brescia

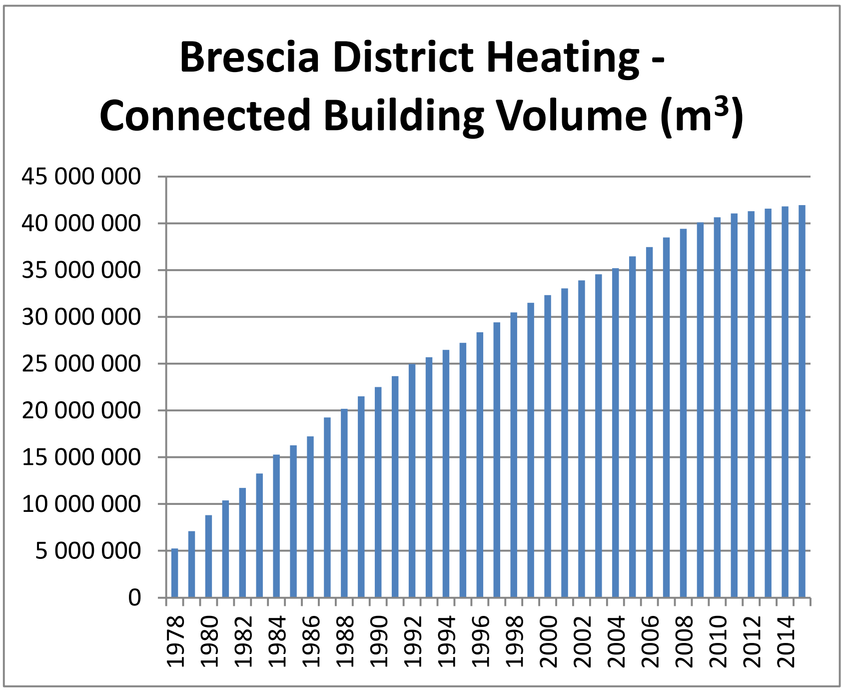

Figure 64 Evolution of connections to the DH grid in Brescia (Source: A2A)

II.III Brescia's waste-to-energy plant

Brescia's waste-to-energy plant uses state-of-the-art technology and **was ranked first in the world in 2006**[52] by Columbia University (New York). The criteria considered for this award were:

- The efficiency in the recovery of electrical and thermal energy;
- The level of emissions achieved;
- The quality in the reuse and processing of waste;
- The acceptance of the local community; and
- The aesthetic quality and architecture.

Its main **technical specifications** and operational data are summarised below:

- Type of combustion system: reverse thrust moving grate (3 combustion lines)
- Gross combustion power: 300 MW_{th}
- Net power: $180MW_{th}/80MW_{e}$
- Waste processed: 740 000 ton/y, including municipal solid waste collected mainly in the Province of Brescia
- Energy production: 652 TWh_{el}/y ; 748 TWh_{th}/y
- Primary energy saved: > 150 000 toe/y
- Avoided emissions: > 300 000 ton CO_2

The plant was commissioned in 1998 as **part of an integrated, ecological system for the management of waste, energy and local resources**. Since the 1990's, Brescia has succeeded in improving its recycling share from 15 % to 40 %, as illustrated on Figure 65. The remaining waste is send to the WtE plant. In 2016 Brescia started operating a new separate collecting programme to further increase the recycling rate.

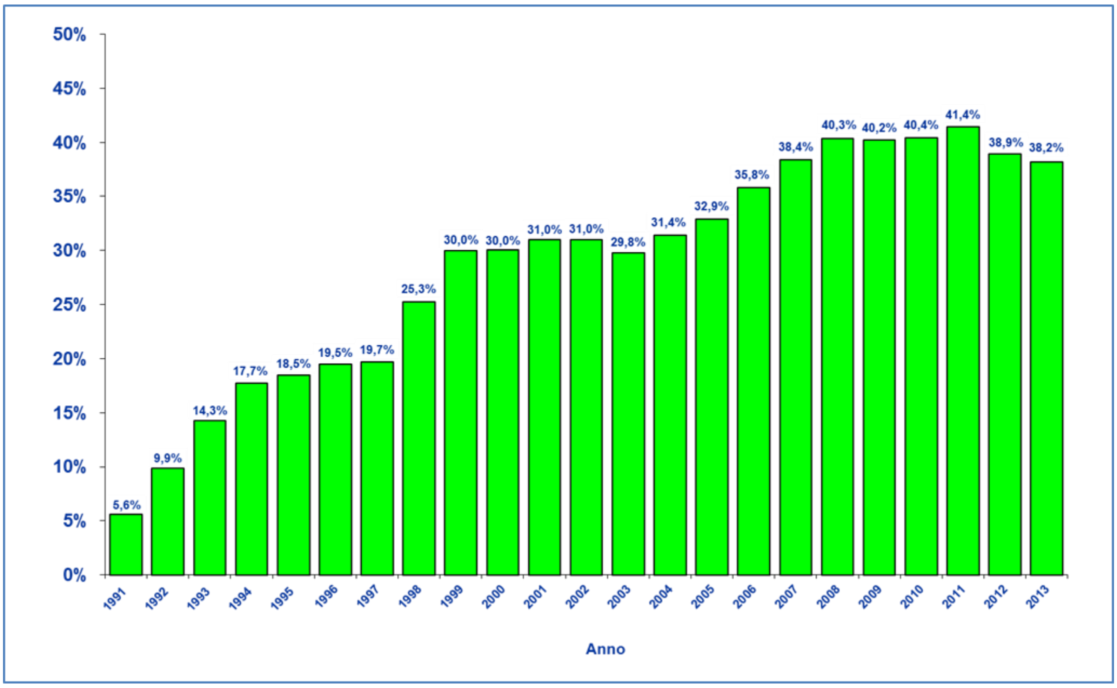

Figure 54 Evolution of the share of municipal waste recycled in Brescia (Source: A2A)

[52] "Industry award" received from the Waste-to-energy research and Technology Centre of Columbia University

III. Urban development and expansion of DH

As mentioned before, the expansion of DHC in Brescia has been **strongly supported by the Municipality**. Firstly to remain energy self-sufficient and, later on, as part of its will to reduce CO_2 emissions through an **integrated approach to energy supply and waste management**. This integrated approach was based on Scandinavian experiences linking DH and WtE.

The new grid was built in existing areas, as illustrated in the images below (Figure 66). By that time, the DH operator was still the municipal utility, which facilitated the progress of construction works. The promise of lower prices for heating users enhanced the public acceptance of the construction works.

1972 – Realization of DH network in Brescia 2 area   Early '80s – Realization of DH network in city center

Figure 66 DH works in Brescia (source: A2A)

The DH system is managed through a **long-term concession** (>30-year) between the Municipality and A2A, which is not limited to a specific time period.

IV. Local heating and cooling markets

IV.I Demand and supply

IV.I.1 Heating

Brescia has an annual heating **demand** of ca. **2500 heating degree-days**[53], mainly covered by DH. The average energy use in existing residential buildings is estimated at 195 kWh/m²/y[54] (primary energy),.while new buildings as of 2016 are near-zero-energy buildings.

The **energy mix for heat supply** in Brescia has evolved from 100 % fossil fuels in the 1950's to 40 % WtE, strongly influenced by the deployment of DH. Even if the DH grid has almost reached its maximum extension, it has still potential to reduce its carbon footprint.

Consumers are free to choose their heating solution from those available in the market (DH, gas boilers, biomass boilers, heat pumps, electric heating, etc.). The main **alternative to DH** is **natural gas**, which is in general available in the city and also offered by A2A.

[53] The calculation of day-degrees is done considering an indoor reference temperature of 20°C, in the time span 15 october – 15 april

[54] Average energy use in certificated buildings, (source PEAR Regione Lombardia - Programma Energetico Ambientale Regionale, the Energy-Environmental Regional Plan)

The daily demand load profile of the **DH grid** for a typical winter day is presented in Figure 67 below. This demand is met as follows:

- For a load lower than ~200 MW_{th}, it is met through WtE;
- between ~200 and 300 MW_{th}, through the multi fuel CHP; and
- above ~300 MW_{th}, through natural gas HOBs.

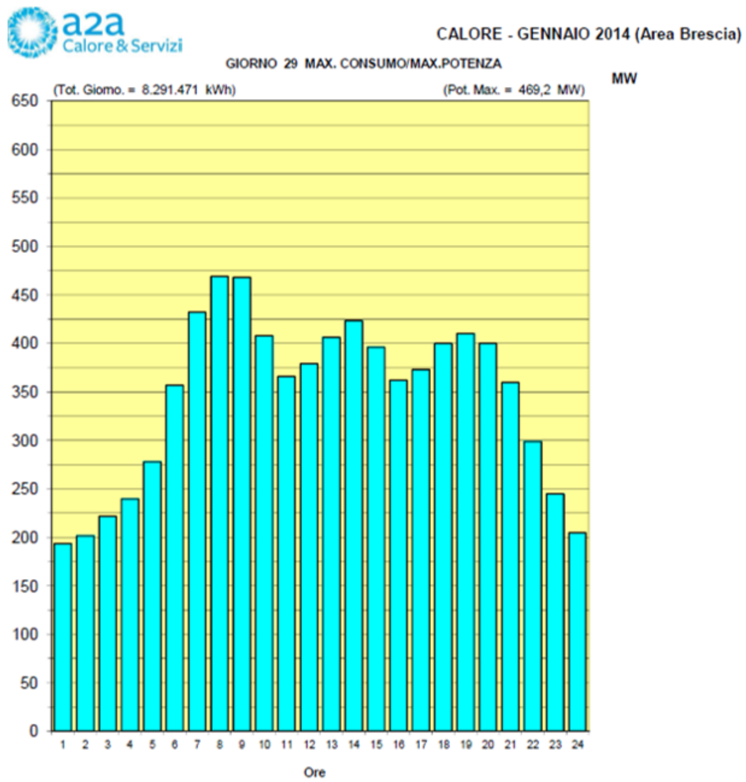

Figure 67 Typical daily load profile of DH (Source: A2A)

IV.I.2 Cooling

The first **DC grid** in Brescia was commissioned in 1999 by A2A. The evolution of its demand in the last 10 years is presented in Figure 68. The DC grid supplies 2 main clients: the University of Brescia and a hospital.

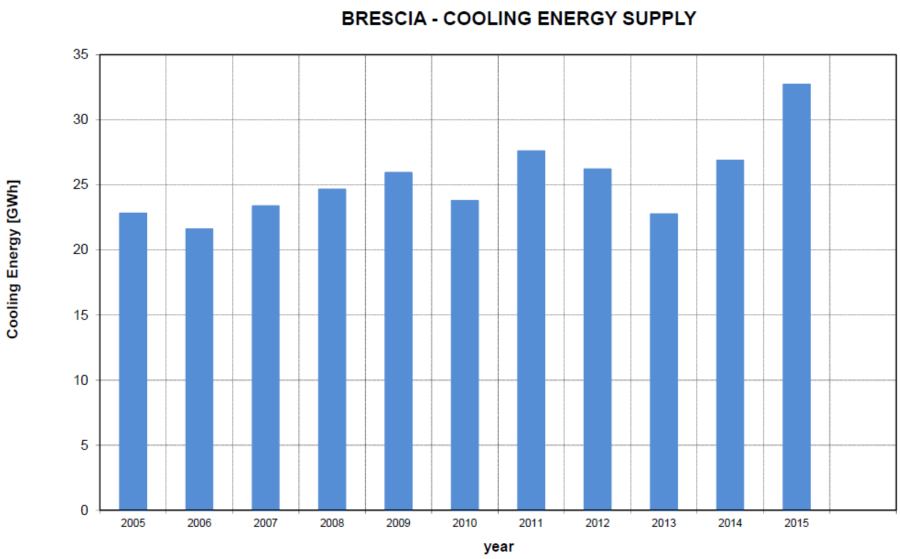

Figure 558 Evolution of DC supply in Brescia (Source: A2A)

IV.II Price competitiveness of DHC

DH is competitive against its alternatives for all connected buildings. DH prices are similar or lower than natural gas. The average price for **DH is ca. EUR 70/MWh** (excluding VAT, based on some months in 2016). The tariff structure is explained in section V.II.

DC is today mainly integrated in a larger energy supply offer (eg. together with DH, electricity, steam…) which is also competitive and attractive to consumers.

V. Business model

V.I Governance and strategy

A2A Calore & Servizi SRL is 100 % owned by the **A2A Group**, which is listed on the Milan stock exchange. The Group 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 69 below.

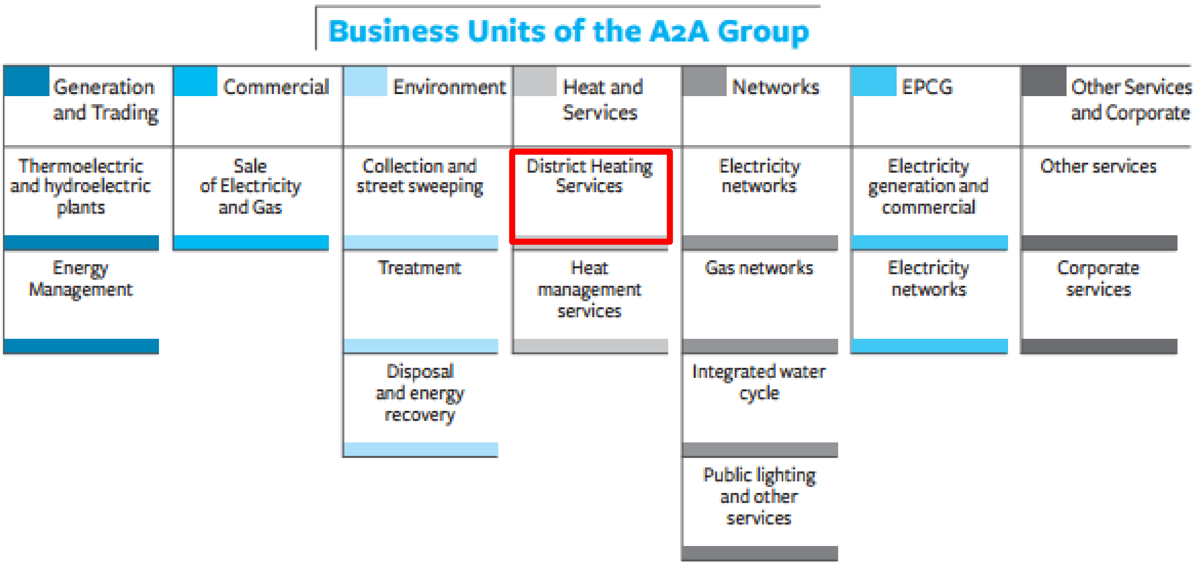

Figure 69 Business units of A2A Group (A2A Calore & Servizi highlighted in red) Source: A2A

The Group is **50 % owned by the Municipalities of Brescia and Milan** (in equal parts) since its creation in 2008, as presented in the shareholding structure below. It is the largest Italian multi-utility company and leader in DH.

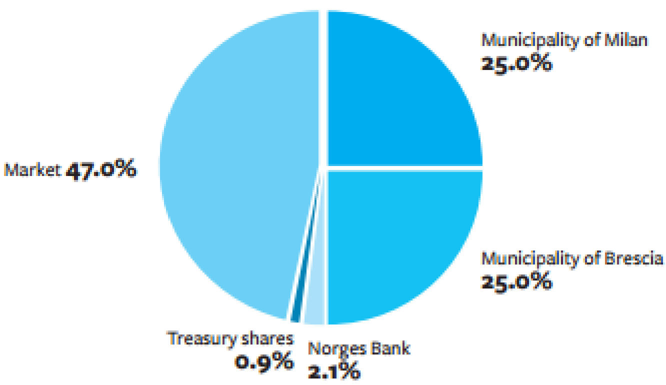

Figure 70 Shareholding structure of A2A 2015 (Source: A2A)

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.

The **DHC strategy of A2A** is focused on improving the efficiency and carbon footprint of the grid and to continue providing a high quality service.

V.II Financial model

The A2A Group has a **strong financial position**, and its DHC business is profitable and keeps growing. The payback of Brescia's DHC **investments** was ca. 15 years, already achieved. In 2015, the Group's EBITDA[55] reached EUR 1048 million, 2.3 % higher than the previous year. Its financial information is accessible on its website[56].

The **revenues** of the DHC company are mainly generated by the sales of heat, cold and electricity. **Invoicing** usually takes place every month and tariffs are updated on an annual basis.

Specific **DH tariffs[57]** are established for 3 groups or types of clients: one-family houses, residential multi-apartment buildings and tertiary buildings (including industry). These clients can choose between 2 types of **tariff structures**:

1. Unique tariff (one component): EUR 64-70/MWh_{th}
2. Two-component tariff
   i. Fixed component: calculated as a function of m^3/h of hot water (1097-2600[58] EUR/m^3/h/y);
   ii. Variable component: unit price per MWh consumed in the building or apartment (EUR 40-45 /MWh_{th});

The **DC tariff** has a two-component structure and is defined on a case-by-case basis following negotiations with the clients.

There is **no connection fee** and clients are **allowed to disconnect** from the grid without paying any fee/penalty.

Individual metering is widespread (at building level). However, in general there are **not sub-meters** in each apartment and cost allocations are based on m^2. Some apartment buildings have nevertheless recently started installing heat meters ("cost allocators") in each apartment, independently of the heat source (DH or individual gas boilers).

V.III Client relationships and energy efficiency initiatives

Clients are satisfied with the quality of the DHC service. A2A performs surveys on a regular basis to assess its customers' satisfaction (every 2-3 years). However, there is still room to **enhance the awareness about the benefits of the DHC system**. The performance of DH systems has been progressively enhanced to achieve very high standards. Despite this, some citizens still perceive DH and waste incineration as rather old and poorly performing technologies, which do not correspond to the reality. A2A works on changing this perception to make Brescia's citizens realise the benefits of their highly efficient DHC system.

A2A is very committed to improve the efficiency of its DHC systems. Energy efficiency among its clients is mainly promoted through the consumption-based tariff. The grid does not integrate smart meters yet.

55 Earnings Before Interest, Taxes, Depreciation and Amortization

56 http://www.a2a.eu/

57 Approximate prices based on the available 2016 information at the time of the site visit

58 Different prices are established to different client groups (lower to individual apartments, higher to tertiary consumers)

VI. Framework for innovation

A2A relies on innovation to keep pace with the development of new technologies and management modes, and integrates these in its DHC business. The company has several partnership agreements with **universities** (notably in Milan and Brescia) and participates in various **EU projects**, such as the following ones:

i. "Cold summer" project: Synergies between DC and DH
Since 2015, A2A is investigating the benefits of using **absorption chillers to produce cold for DC** supply from the heat available on the DH grid. During a first test phase, it was estimated that for an office building of 100 kW DC power supplied with electricity and DH from Brescia's WtE plant, 20.5 tons CO_2/y could be saved, which corresponds to 92 % less emissions than the alternative cooling option (namely electric chillers). In 2016, this DC concept was also implemented at a hospital connected to 170 kW of DC.

ii. The Stratego EU project[59], which aims at supporting local and national authorities in the EU implementing more efficient heating and cooling solutions, mainly through comprehensive **heat planning**.

iii. Brescia Smart Living project, partly funded by the Ministry of Education, University and Research. The project started in 2015 and will finalise in Q1 2018. It aims at developing a concept of **sustainable Smart City in Brescia**, integrating improved public services and governance and resulting in an enhanced quality of life for the citizens.

The main areas covered by the project include energy demand management, public lighting, analysis of air quality and noise, waste collection, social interaction, protection of vulnerable groups, security, ICT infrastructure, communication and transparency/governance.

VII. Perspectives

The main developments in the DHC system of Brescia are expected to focus on improving the efficiency of the system and increasing the awareness about the benefits of DHC among its users. In particular:

- **Surplus heat** recovered from the local steel factory is expected to represent 3 % of the total heat demand in 2016.
- A2A aims at **reducing the share of fossil fuels** in its energy mix, mainly through the integration of thermal storage systems allowing an increased use of heat from the WtE plant; and recovering heat from a nearby wastewater treatment plant.
- **DC is expected to keep growing**, probably based on absorption chillers to take advantage of the potential synergies with the DH grid.
- Further communication and **awareness raising** activities about the benefits of DHC, addressed to Brescia's citizens.

VIII. Conclusion: Key Success Factors

Brescia's DHC system is a good example of an **efficient and integrated approach to energy and waste management**. The key success factors identified in this case study are summarised below.

i. **Support from the Municipality**. Since the DH grid commissioning in 1972, the Municipality of Brescia has strongly supported its deployment. The Municipality

[59] http://stratego-project.eu/

realised since the beginning the importance of taking an integrated approach for developing the DH grid and followed the best available practices, mainly based on Scandinavian examples. DH was used as a tool to reduce CO_2 emissions and Brescia's carbon footprint and the results have exceeded the initial expectations.

ii. **Integrated approach to energy and waste management, including long-term heat planning.** The DH system was carefully designed taking a long-term approach and seeking a performant, cost-efficient and sustainable heat supply at competitive prices.

iii. **Use of local fuels**, namely waste-to-energy and surplus heat.

iv. **Successful cooperation between public and private parties (PPP).** The Municipality of Brescia holds 25 % of the shares of the DHC grid operator A2A, which is translated into a high influence on the Group's strategic decisions.

v. **Competitive prices.** The prices of Brescia's DH grid are competitive against the alternative options for heat supply (natural gas). This is mainly due to the use of efficient state-of-the-art technologies and local fuels.

vi. **Innovation.** The DHC system integrates innovative technologies and management modes to enhance its competitive position and the quality of the service.

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4.2.7 SPAIN: District Heating and Cooling in Barcelona

Barcelona was the first city in Spain to build a DHC system (in 2004) and actively promotes this type of energy supply, especially in new urban areas. ***Ecoenergies Barcelona*** *is the second DHC system in the city, based on* ***biomass*** *and* ***surplus cold recovery*** *from a liquefied natural gas (LNG) terminal. It illustrates the potential of DHC (and particularly DC) in cities with warm weather, where district energy supply is less common than in Northern countries.*

Ecoenergies network is operated through a ***public-private partnership*** *(30-year concession) and is gradually expanding in the city. Some of the key factors contributing to its efficiency and increasing deployment include: i) a strong* ***support from the local Government,*** *which was the project promoter and is highly engaged in implementing sustainable and* ***innovative*** *projects as part of its* ***smart city*** *strategy; ii)* the **fruitful cooperation between public and private parties**, which has led to high quality and environmental standards as well as **competitive prices** while **raising awareness** about the benefits of DHC among local industries and citizens; iii) *the* **flexibility** of the system, mainly due to its modular implementation, diversified and low-carbon energy mix and **smart grid** approach allowing continuous optimisation of the system's operation.

I. National context

Spanish heating and cooling markets are dominated by **individual solutions**, mainly based on natural gas and electricity, respectively. District heating represented in 2015 less than 1 % of the national market share in terms of installed capacity. This can be explained by the relatively low heating demand, lack of awareness and experience in district heating of urban planners and the widespread use of natural gas and other fossil fuels for heating.

However, the benefits of DHC are gaining visibility among decision-makers and the number of DHC networks is increasing[60]. The Spanish DHC Association (ADHAC[61]) is playing a key role in **creating awareness** about the benefits that DHC systems could bring in terms of cost and energy savings, reduction of fossil-fuel dependence and positive impact in the local economy, among others. District cooling is becoming particularly attractive to industries and tertiary buildings having a high electricity bill due to their cooling needs.

Most of the DHC installed capacity has been developed under **public-private partnerships** (PPP)[62], which allow optimising the allocation of public resources while benefiting from the expertise provided by the private sector. The main customers of DHC networks in terms of installed capacity are tertiary buildings (48 %) followed by residential (31 %) and industry (21 %)[63].

The **National Energy Efficiency Plan** 2011-2020 supports the deployment of DHC systems and national and EU funds are available for these kind of projects. Energy labelling takes into account the energy and CO_2 savings gained through DHC, which is often an additional incentive to connect to these networks. New DHC systems are expected to be created mainly in new urban areas as part of a comprehensive urban planning.

Renewable and CHP electricity production is supported at national level through a **premium tariff** scheme which is granted on top of the spot electricity market price[64].

[60] In 2016, 306 DH networks had been identified by ADHAC

[61] http://www.adhac.es/

[62] The ownership structure in terms of installed capacity is 20% public; 37% private; 43% PPP (2016, ADHAC)

[63] 2016 figures, ADHAC

[64] Royal Decree 413/2014 regarding facilities producing electricity from renewable energy sources, cogeneration and waste

The Spanish Government introduced this support scheme in 2014, substituting the former feed-in tariff scheme and significantly reducing the financial support to these technologies. The premium tariff is capped to a certain number of hours of operation per year (which depends on the technology) and the amount is updated and published every 6 months.

Local and regional authorities are playing a key role in promoting DHC. For instance, the Catalonia's authorities are strongly supporting DHC projects as part of its urban and energy strategies and are leading the Spanish DHC deployment. Today other regions are considering replicating some of the most successful projects in this region, such as the DHC network of Ecoenergies Barcelona.

II. Presentation of Ecoenergies Barcelona DHC system

II.I Overview

Ecoenergies Barcelona DHC system started its operation in 2012 and is being constructed following a **modular approach** with 3 phases:

1. PHASE 1 (construction between 2011-2012, current facilities): Biomass plant, cold production facilities (conventional and industrial chillers), gas boilers and part of the distribution network, located in the areas of "La Marina" and "Zona Franca", which are currently industrial areas which will be converted into mixed-use areas through the construction of new residential buildings (cf. Figure 72).
2. PHASE 2 (2017-2019): Surplus cold recovery from LNG regasification process, ice storage facilities and transport network for the recovered cold (Port area).
3. PHASE 3 (2017-2024): Network expansion (15 000 000 m^2 of heated floor area to be connected).

The map below (Figure 72) illustrates the areas covered by the network, where solid lines represent existing network and dotted lines represent future constructions. The main characteristics of the system are summarised below:

Key facts and figures (2015)

DH market share	N.a.
Heating & Cooling capacity	DH: 23 MW (target: 40 MW) DC: 14 MW (target: 70 MW + 36 MW ice storage)
Heat &Cold production	DH: 12 GWh/y (target: 59 GWh/y) DC: 7.6 GWh/y (target: 54 GWh)
Km network (double-pipe)	12 km (target: 36 km)
CO2 emissions	DH : 94.9 kg/MWh DC: 0 kg/MWh (net emissions, compensated with CHP electricity production)

- **Small system**: Currently 12 GWh/y of DH and 8 GWh/y of DC (once finalised, 86 GWh/y DH and 83 GWh/y DC).
- **Public-Private Partnership (30y concession):** The shareholders of the SPV are Barcelona City Council and 2 private partners. Veolia operates the network.
- Flexible production (once finalised):
  - 10 MW_{th}/2 MW_e CHP Biomass plant fuelled by garden waste biomass (30 %); and other forest biomass from the region (70 %)
  - 30 MW gas peak boilers
  - 40 MW industrial cooling and chillers
  - 30 MW surplus cold recovery from LNG terminal
  - 36 MW cold storage (5000 m^3 water tank to be converted into ice storage)
  - Will probably integrate solar thermal

The **energy mix** of Ecoenergies DHC system, once finalised, is described in Figure 71. It is expected to result in 13 400 teq CO_2 emission savings per year[65].The current mix is however different, with 100 % DC produced from electricity and **70 % of heat produce by biomass**. Gas boilers are supposed to provide peak capacity to the grid once the different parts (mainly "Marina" and "Zona Franca") are interconnected. This is however not the case today, and the Marina area is still 100 % supplied with gas.

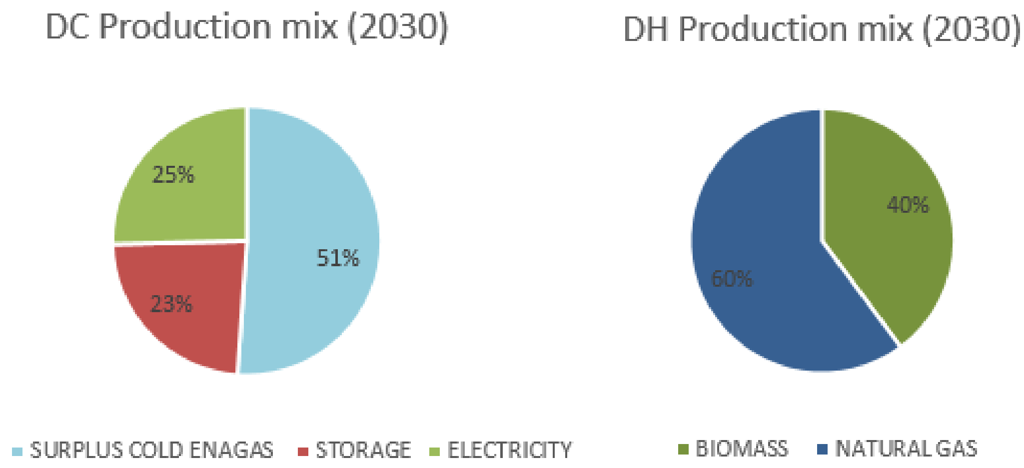

Figure 561 Fuel sources used for DH and DC in Ecoenergies Barcelona 2014 (Source: Ecoenergies)

The expected **client structure** at the end of phase 3 is as follows:

- Heat demand: 70 % residential; 30 % tertiary sector (today 100 % tertiary);
- Cold demand: 60 % tertiary sector; 40 % industry (today 100 % tertiary)

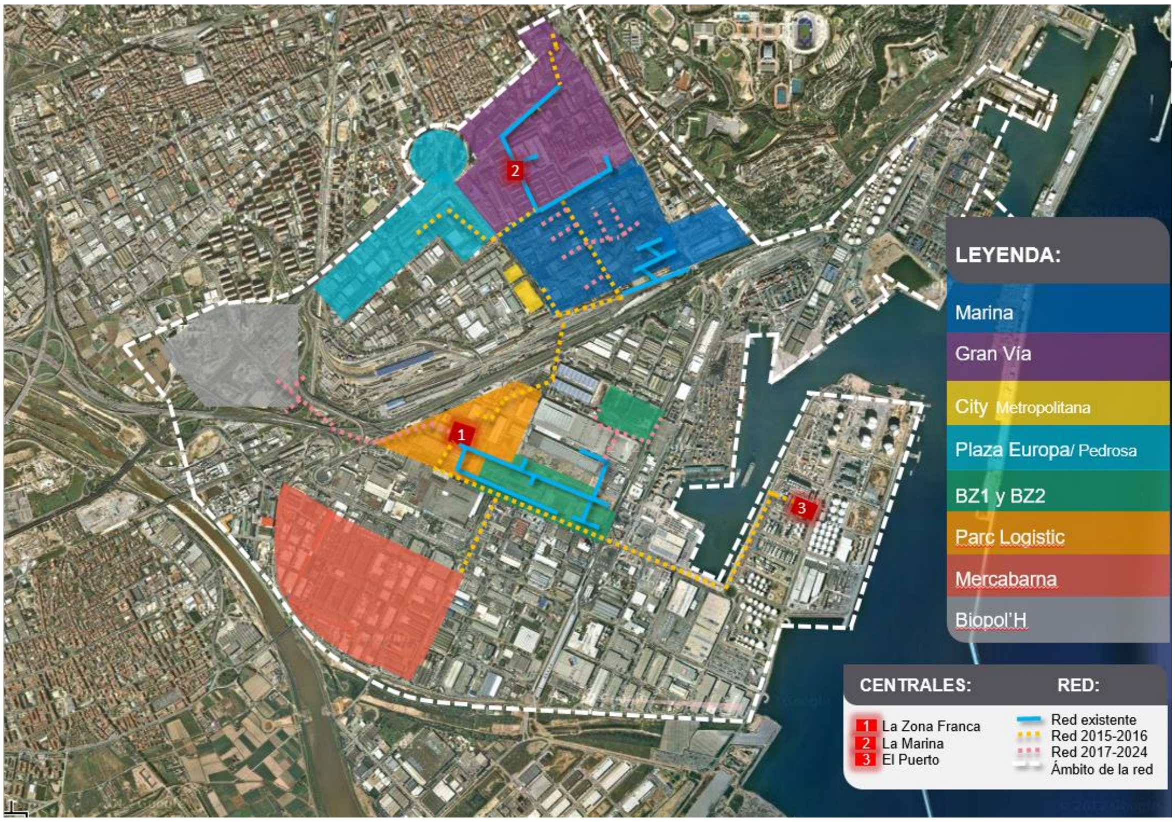

Figure 72 DHC system Ecoenergies Barcelona (Source: Ecoenergies)

65 Annual reduction compared to conventional decentralised thermal energy production

II.II Production and storage facilities

Ecoenergies DHC system has been designed to gradually expand while **adapting its energy mix and operating mode**. The main production, storage and control facilities are described below and illustrated in Figure 73.

i. A 10 MW_{th} / 2 MW_e **biomass plant** fuelled by garden waste biomass from the city and other forest biomass from the region (base load).

ii. **Gas boilers** providing peak load.

iii. **Surplus cold recovery** from the regasification process at the **LNG terminal** will supply negative cold (i.e. below 0 °C) to the DC network. This is a **first-of-a-kind** solution with big replicability potential.

Barcelona's LNG terminal is operated by one of the Spanish TSO[66], Enagás. It has six tanks with a total LNG storage capacity of 760 000 m^3 and an emission capacity of 1 950 000 m^3 (n)/h. The **regasification process** takes place in open rack vaporizers and consists in heating the LNG (which is stored at - 160 °C) with seawater to reach a temperature above 0 ºC and return it to its gaseous state. Ecoenergies' solution aims at recovering the important amount of cold that is today transferred to the seawater and therefore lost. It will use part of this surplus cold to cool liquid CO_2 in a secondary DC network and supply the food hub of Mercabarna with **-38 °C industrial cold** (which is currently being supplied through industrial chillers) as well as the free trade zone ("Zona Franca") with -10 °C.

The contractual arrangements for this heat supply are still under discussion. In principle, Enagás will provide its surplus cold for free to Ecoenergies, while the terms and conditions of the supply to final users will be agreed between the two parties.

iv. **Cold storage** facilities at "Zona Franca", with several storage tanks.

v. **A control unit** provided with an **optic-fibre SCADA[67] system** able to remotely supervise and control the operation of the system in real time (production, distribution and demand load) following a **smart grid** scheme.

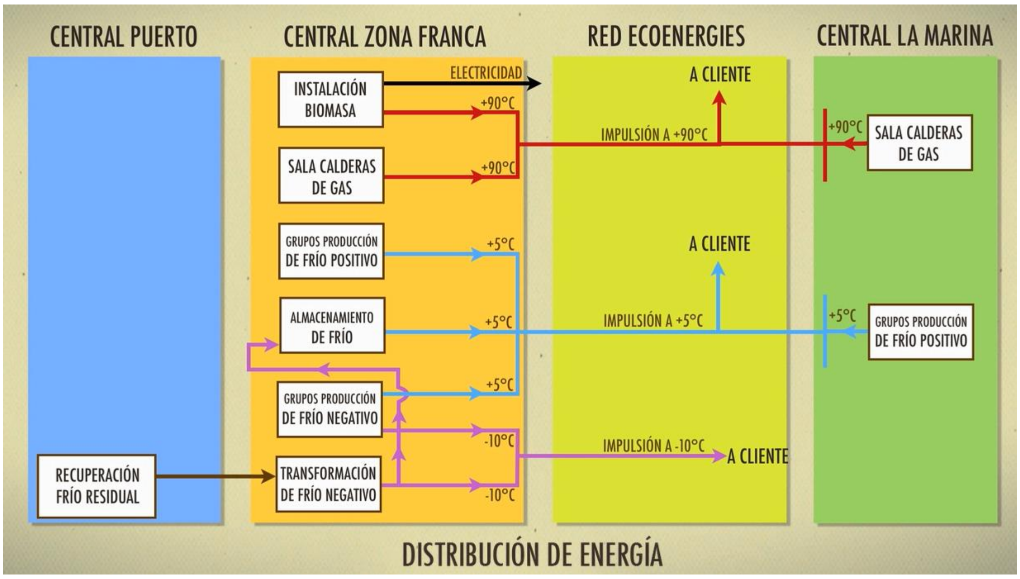

Figure 73 Ecoenergies DHC network scheme (Source: Ecoenergies)

[66] Transport System Operator
[67] Supervisory Control And Data Acquisition

III. Urban development and expansion of DHC

The City Council of Barcelona has played a key role in developing and implementing Ecoenergies DHC project. Inspired in other international experiences –mostly in Denmark- Barcelona was **the first city in Spain to integrate DHC in their urban planning** and is strongly supporting the deployment of district energy, especially in new areas.

The deployment of DHC networks is part of the **city's ambitious Energy Plan**[68], firstly established in 2002 with the objective of creating an efficient energy supply model integrating a high share of local renewable energy sources. This first plan was updated in 2010 and integrated into a broader **Smart city strategy**[69] that is being successfully translated into numerous projects and initiatives making Barcelona a European reference for innovative and sustainable urban management and development.

The first Energy Plan aimed at improving energy efficiency in the city. **Recovering surplus heat and cold** for energy supply became a priority and, as a result, the first district heating and cooling networks were conceived for two new urban developments: Districlima (recovering surplus heat from a waste incineration plant and using seawater for refrigeration); and Ecoenergies (recovering surplus cold from a LNG regasification process). The location of both networks is represented in Figure 74.

Figure 74 DHC networks in Barcelona: Districlima (2004) and Ecoenergies (2011)
Source: Barcelona City Council

Districlima[70] was the first DHC network in Spain and has been successfully operating and expanding since 2004. It was part of an urban transformation of the Forum area and the 22@ district of innovation and is operated through a PPP model (25-year concession). The private partner and network operator is Cofely (Engie group), while the 4 public partners include national, regional and local authorities. At the end of 2015, the system had a production capacity of ca. 70 MW heat and 40 MW cold, cold storage facilities (40 MWh water storage and 80 MWh ice storage) and 15.6 km of network.

Ecoenergies project could build on the successful experience of Districlima, and followed a similar approach. The City Council had undertaken several prefeasibility and feasibility studies since 2003, and developed detailed tender documents that were published in 2009 and included the main design elements and budget for the project (production facilities, network, fuel mix, buildings to be connected and associated energy load profiles, etc.). The procurement process for a 30-year concession contract was undertaken in cooperation with the municipality of Hospitalet de Llobregat -also covered

[68] The Energy Improvement Plan of 2012 was updated into the current Energy Plan 2011-2020

[69] http://smartcity.bcn.cat/en/

[70] http://www.districlima.com/en

by the DHC network- and the evaluation took into account the overall energy efficiency of the proposals, environmental performance and services offered to final users, among other criteria. This time the contract was awarded to the private operator Veolia and the public partner was Barcelona's City Council.

Unfortunately, the real estate development in the areas covered by Ecoenergies was significantly lower than expected mainly due to the financial and economic crisis, as further explained in section V.II. Both public and private parties are actively cooperating to find new clients and reach the optimal load for the network that would allow realising the missing investments and deploying all the project's benefits.

IV. Local heating and cooling markets

IV.I Demand and supply

Barcelona has a subtropical-Mediterranean climate, with **mild winters and hot summers**. Heating demand is therefore relatively low (ca. **1150 heating degree-days)**, while cooling demand is relatively high and keeps growing.

Barcelona's heating and cooling demand is mainly covered by **individual solutions** typically fuelled by natural gas and electricity, respectively. Consumers are free to choose their gas and electricity supplier. The retail market concentration is relatively moderate, with 5-6 suppliers providing 90 % of the total supply in each market.

The average **energy use** in existing residential buildings is 80 kWh/m^2/y while new buildings consume 45 kWh/m^2/y. This energy use and corresponding energy sources are presented in Figure 75 for residential buildings (2011 figures). This graphic shows how the demand for domestic hot water (SHW in the graph) is covered to a large extent by **solar thermal** systems, due to the so-called Solar Thermal Ordinance that was approved by the City Council in 1999 and makes it compulsory for new buildings in the city and those under refurbishment to incorporate solar thermal energy systems for domestic hot water supply.

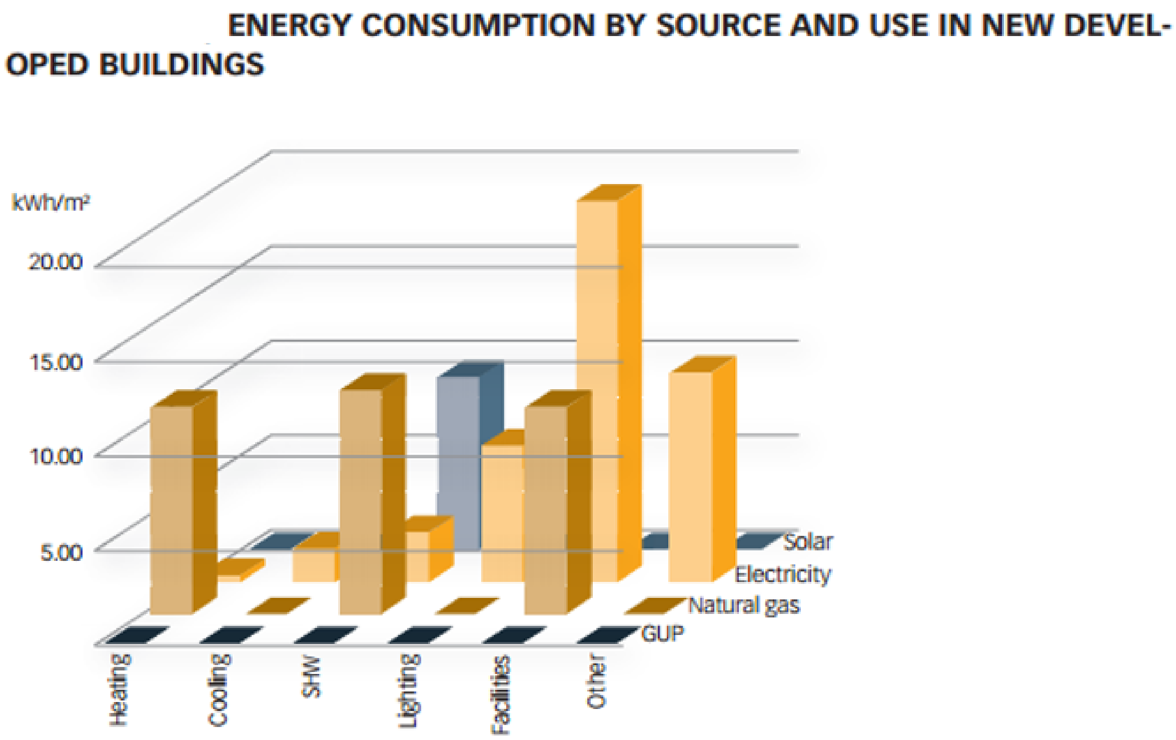

Figure 75 Barcelona's energy use in the residential sector by energy source
***Legend**: Facilities= Equipment, appliances; GUP = General Use Propane*
(Source: Energy Plan PECQ 2011-2020)

DHC is new in these markets, and its **price is regulated by the City Council** through a local public company (Tersa[71]) following the terms and conditions of the concession contracts. Similar pricing rules are applied to the two DHC networks in the city. In particular, network operators are **required to offer competitive pricing with respect to the alternative** option for energy supply of residential and tertiary buildings as well as the same level of prices in the two networks.

Tersa approves the tariffs on an annual basis and is the contract manager for both DHC concessions. It is a public company responsible for waste management in the Barcelona Metropolitan Area and owns 20 % of Districlima's SPV[72]. For its second DHC grid, Barcelona's City Council decided to build on the experience gained by Tersa when organising the public tender for Districlima and as its contract manager.

IV.II Price competitiveness of DHC

DHC is competitive against its alternative for the connected buildings. As mentioned above, the tender documents required the DHC networks to offer competitive prices against gas boilers and electricity for the residential and tertiary sectors, while business with industries follows a B2B approach and therefore needs to prove its competitiveness case by case, on a commercial basis.

The average price for DH is EUR 42/MWh (excluding 21 % VAT and cost of connection), which is around 10 % cheaper than gas supply (including equipment, O&M and fuel). The average price for DC is EUR 38/MWh, which is between 5-12 % cheaper than electricity. Tariff structure is explained in section V.II.

Ecoenergies has undertaken a large **electric measuring campaign to demonstrate the price competitiveness of DC** in Mercabarna, the city's food industry hub for fresh and frozen products. Indeed, cooling costs are often not known by consumers, as they are merged with other electricity costs. The campaign showed a potential for replacing the current electricity demand of 32 GWh/y with DC, representing 20 % savings in the electricity bill and 8730 tCO_2 potential savings.

V. Business model

V.I Governance and strategy

Ecoenergies DHC network is managed through a **SPV project company** whose shareholders are Barcelona's City Council (17.55 %) and the private partners Veolia (72.45 %) and Copisa (10 %). The **board of directors** oversees the company's activities and represents its stakeholders. There is a proportional representation of the 3 shareholders among the 16 Board members, who meet annually at least 4 times, as required by national legislation.

Public and private partners work together to implement the project's strategy of **gradually increase the connections**, DHC production capacity and network extension. Today's operating facilities (production facilities in the areas of "Zona Franca" and "La Marina") were designed to integrate in the future all the production and distribution equipment needed at the end of phase 3. Intensive **marketing and awareness raising campaigns** are being organised aiming at gaining new clients and improving the visibility of the project.

The company's **performance management** includes energy efficiency and sales objectives for its employees. For instance, company's CTO[73] has among its annual objectives achieving a global COP[74] of 3.5 (for the entire DHC system).

[71] http://www.tersa.cat/en
[72] Special Purpose Vehicle
[73] Chief Technical Officer
[74] Coefficient of Performance

V.II Financial model

Ecoenergies project represents a total **investment of ca. EUR 105 million**, from which EUR 56 million have been already realised at Phase 1. This first phase received 8 MEUR investment grant from the City Council and presents a 25:75 gearing ratio.[75]

The company **revenues** are generated by the sales of heat, cold and electricity. **Invoicing** usually takes place every month and tariffs are updated on an annual basis.

- A similar **tariff structure** is used for **DH and DC**, with two components:
  i. A fixed component based on installed capacity (in kW), which in the case of residential and tertiary sectors is the same for Districlima and Ecoenergies;
  ii. A variable component based on real consumption (MWh), where the price is established through a formula agreed among the public and private parties that takes into account real operating costs. There are currently two possible tariffs: EUR 39 /MWh and EUR 44 /MWh (depending on the level of consumption and duration of the contract)
- The **cost of connection** is paid by the consumer under the conditions established by the City Council, which are the same for Districlima and Ecoenergies (namely EUR 68.46 /kW for DH and EUR 207.29/kW for DC).
- The **renewable electricity** produced by the biomass plant receives a **premium tariff** from the Spanish Government on top of the spot market price, which is capped at 6500 h/y of operation. The amount of this premium is updated and published every 6 months (with no visibility on the future premium tariffs) and was significantly reduced (by ca. 20-23 %) in 2014 when the Spanish Government reviewed its support schemes for renewable electricity generation and CHP, having a negative impact on Ecoenergies business.

The financial viability of new DHC systems in new urban areas is highly **dependent on the reliability of the initial demand forecasts**, which in the case of Ecoenergies proved to be low. During its first years of operation, the project's **demand risk** materialised, which had a high impact on the company's financial situation. Indeed, new real estate developments did not follow the initial forecasts made by the city - as illustrated on Figure 76 - mainly due to the financial and economic crisis. On top of that, the last winters have been particularly mild, resulting in a decrease in heat sales[76]. To remediate the demand risk, Ecoenergies had to change its strategy and focus on existing building, showing a **high capacity of reaction**. Despite all the efforts, the project has not reached breakeven yet (which was initially expected by 2015 and has an estimated delay of 2 years).

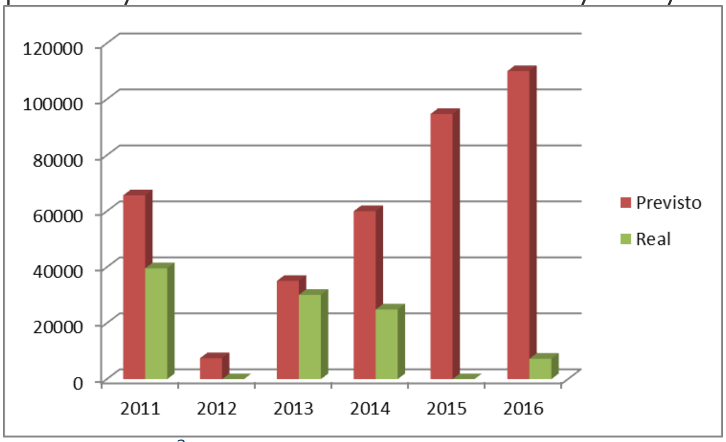

Figure 76 Connected buildings (m^2): Reality (green) Vs. Initial forecast (red). Source: Ecoenergies

[75] 25% Equity, 75% debt funding

[76] In 2015 Barcelona registered its warmest winter in of a 40-year period

Ecoenergies **turnover** in 2016 is expected to reach ca. EUR 4 million and continue increasing. Remediating measures including marketing campaigns are resulting in new connections and the awareness about benefits of DHC is being progressively risen among local industries and buildings.

V.III Client relationships and energy efficiency initiatives

Client satisfaction and rising awareness about DHC were a priority for the City Council when it conceived Ecoenergies project. This was translated into specific requirements on the tender documents and these subjects were integrated among the evaluation criteria. As a result, Ecoenergies pays particular attention to the **quality of the service**, energy efficiency and raising awareness about climate change and the role of DHC in the energy transition towards a low-carbon economy. The network has experienced neither delivery defaults nor incidents since its commissioning and consumers are in general very satisfied. Client satisfaction is directly assessed following a B2B approach, and will be addressed through client satisfaction surveys when residential buildings will be connected to the network.

To encourage energy efficiency and public knowledge of DHC, Ecoenergies has put in place a number of measures and initiatives that are summarised below:

- **Energy bills** are based on real consumption and include 13-months energy consumption records (via an online platform) as well as information on the network development, CO_2 emissions saved and energy efficiency tips. This was encouraged by the tender documents and aims at showing consumers how they are contributing to the project and to the city's energy transition strategy.
- **Smart meters** deployed in every building allow consumers to access their real time consumption (MW and MWh) and provide an enhanced **flexibility** to the network operation.
- **Climate and DHC awareness raising** is done through the company's website, public visits targeting the general public as well as local schools and universities.
- Continuous efforts from the technical department to improve **the energy performance of the network**, with a particular focus on increasing the temperature difference (ΔT) between the supply and return line at connecting points.

VI. Framework for innovation

Ecoenergies is a **highly innovative** project, both in its overall approach and specific technology used.

The City Council's support to innovation is at the core of Ecoenergies project and one of the main reasons for its success. In 2014 Barcelona was awarded with the **European Capital of Innovation** prize by the European Commission for introducing the use of new technologies to bring the city closer to citizens and foster local economy and welfare. The city has implemented several **sustainable growth initiatives** on smart lighting, mobility, waste management, residual energy, social innovation and open data, among others.

The use of surplus cold recovered from a LNG terminal to supply a DC network is a **first-of-a-kind** solution. The network will be the first in the world to implement this concept that could be replicated in many other cities.

The **smart grid** approach of the network allows a **real time management and optimisation** of its operation. Connected buildings are in continuous communication with the control unit through the SCADA system and smart meters.

VII. Perspectives

DHC is new in the local market, and the two operating networks are setting the path for a **larger deployment of district energy** supply in the city. With the support of the City Council and its private partners, it is expected that DHC **awareness** will keep raising among Barcelona's citizens and businesses and result in **increasing connexion rates**.

The energy efficiency and renewable energy share of the system are expected to progressively improve, notably through the activities listed below.

- The implementation of phases 2 and 3 will allow achieving all the energy efficiency potential, mainly through the **recovery of surplus cold** from the LNG terminal and the connection of new areas (especially in "La Marina").
- The **interconnection of the existing networks** (expected by 2018) will improve the efficiency and flexibility of the DHC system, which today is composed of 3 isolated networks as presented in Figure 72.
- Ecoenergies plans to integrate additional renewable capacity, namely **solar thermal**. As explained before, all new buildings in Barcelona are required to install solar thermal panels to provide domestic hot water. The exceeding capacity could be supplied in commercial terms to the network, turning consumers into **prosumers** and improving the overall efficiency of the system.

VIII. Conclusion: Key Success Factors

Ecoenergies DHC system is a good example of **public-private partnership** can bring innovative and efficient solutions for heat and cold supply. The identified key success factors are summarised below.

i. **Support from the City Council and prioritisation of the project**. The City Council is the project promoter, and conceived Ecoenergies DHC network as part of a broader **energy strategy** focused in improving energy efficiency, valorising local resources and boosting the local economy. Ecoenergies is integrated today in a broader **smart city** strategy as one of its flagship projects and has been allocated an important amount of resources, illustrating the city's involvement and support to innovation and energy transition.

ii. **Coherent urban planning, including heat mapping.** During the project preparation phase, the City Council integrated for the first time DHC in the urban planning of a new urban area ("La Marina"). However, the estimations of DHC demand proved to be significantly lower than the forecasts and the announced new buildings will only arrive 5 years later than expected. The **reliability of the initial demand forecasts** is indeed critical for the financial viability of new DHC systems and mitigating the demand risk at development stage should be given higher importance.

iii. **Successful cooperation between public and private parties (PPP).** The concession model chosen by the City Council allowed leveraging public resources while benefiting from the expertise and funding provided by the private sector. The **public procurement** process proved to be and efficient tool to promote competition and implement a low-carbon DHC system providing a quality service, using local resources and creating climate awareness among its end-users.

iv. **Competitive prices.** The prices of Ecoenergies are competitive against the alternative option for heat or cold supply. Otherwise, the project would not be financially viable. The use of efficient state-of-the-art technologies, cheap or free fuels (i.e. biomass, surplus cold) and the deployment of the network in energy dense areas contribute to its competitiveness. Moreover, price fluctuations of gas and electricity constitute an opportunity for DHC deployment.

v. **Flexibility in the system's implementation and operation.** The network was designed to have a progressive extension following a **modulated approach**, which partly mitigates the demand risk and reduces the initial investment costs. Its operation is completely automatized and continuously optimised through a SCADA system, which provides a sound visibility of the system and the possibility to rapidly react if needed. Once finalised, Ecoenergies system will reach all its potential in terms of operational flexibility, mainly based on a **diversified energy mix** based in biomass-CHP and surplus cold, **interconnected distribution networks** and ice **storage**.

vi. **Dynamic and engaged team.** Both public and private partners have shown a high degree of engagement, flexibility and **capacity of reaction** to overcome the difficulties of the network's first years of operation. As the demand risk materialised, the company adapted its strategy and developed a remediation plan focused in finding new clients among existing buildings, while the private partner Veolia increased its capital share on the SPV. The marketing efforts are already seeing results, and sales and connections are expected to continue increasing in the coming years.

vii. **Innovation.** The project is highly innovative, not only for the **technology** used (i.e. smart grid concept, fist-of-a-kind surplus cold recovery from a LNG terminal, distributed renewable generation, etc.) but also for its role in **creating climate awareness** among local businesses and citizens while **demonstrating the economic and environmental benefits of DHC**. The city's support to innovation and sustainable urban initiatives has positively influenced the project's development and implementation.

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4.2.8 SWEDEN: Integrated District Heating and Cooling in Greater Stockholm

*Sweden aims at becoming **carbon neutral by 2045** and has identified DHC as one of the key enablers to reach this target. The large DHC system of Greater Stockholm illustrates how these systems can support the energy transition by providing a low-carbon heat and cold supply.*

*This case study is focused on Stockholm's main DHC operator, **Fortum Värme**, which is 50 % owned by the city of Stockholm and 50 % by Fortum Corporation. Fortum Värme has a heat market share of 80 % in the city. Some of the key factors contributing to the overall efficiency of its low-carbon system include: i) a national and local **policy framework** supporting the introduction of renewable electricity production, inter alia bio-based CHP; ii) a national CO_2-taxation scheme comprising the sectors not included in the ETS system ; iii) a **market-based DH** sector, with a soft regulation to protect consumers; iv) the implementation of a **comprehensive urban planning**, including heat supply planning; v) the **flexibility of the DHC system,** with a diversified energy mix and an integrated approach gained through the interconnection and common heat dispatch with neighbouring DH grids; vi) the use of local resources (i.e. biomass, waste, surplus heat, free cooling from water bodies, etc.); and vii) the company's continuous efforts to offer **competitive prices** through a **sustainable** energy mix and to satisfy its **clients.***

I. National context

I.I Overview and drivers for DHC in Sweden

Sweden has a long tradition in district heating and has found in DHC systems an efficient way to achieve its ambitious **environmental targets**. The country has opted for a **deregulated model**, where market competition leads to improvements in energy efficiency and to lower costs.

The regulatory framework and **ownership structure** of DH in Sweden has experienced important changes throughout its history. The first DH systems in Sweden appeared in the 1940's and were owned and operated by municipalities, which were also responsible for the supply of gas and electricity to its citizens through municipal utilities. During the 1980's, many DH networks were built and in the 1990's almost all cities and municipalities had their own DH system. In 1996, a new law deregulating the electricity market came into force, covering also district heating and allowing the DH sector to function on a market basis. New private actors entered into the market and the private ownership of DH systems increased from 2 % in 1990 to 25 % in 1998 and 35 % in 2011.

Sweden aims at becoming **carbon neutral by 2045** and has identified DH as a key enabler to reach this target. DH has already played a key role in **decarbonising the heat supply** in the country, as it allowed switching to more efficient and sustainable fuels such as local biomass (mainly through CHP plants), waste-to-energy, surplus heat or renewable electricity (through heat pumps or electric boilers). In the early 1970's, 100 % of DH was supplied through fossil fuels (mainly oil) while today these represent only 6 % (mainly natural gas). The transition and conversion from fossil fuels started after the first oil crisis, but has significantly sped up during the last decade. The evolution of the fuel mix in DH between 2003 and 2013 is presented in Figure 77, which also shows the significant decrease in the CO_2 emissions associated to DH.

FUEL USE FOR DISTRICT HEATING OVER THE LAST TEN YEARS

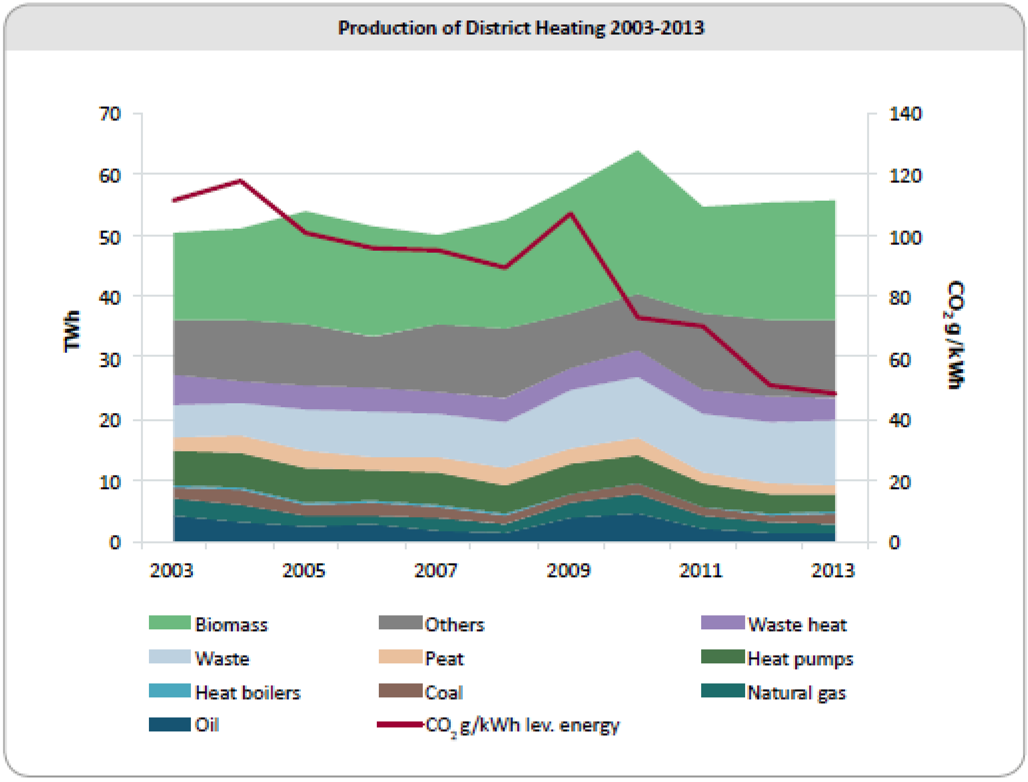


Figure 77 Evolution of fuel use for district heating in Sweden (Source: Euroheat & Power)

District heating has a dominant market position in Sweden, with 57 % overall market share and 93 % market share for multi-family apartments[77]. The demand decrease due to energy efficiency improvements in buildings is being compensated with new connections. Today's **main alternative** to DH consists in **individual heat pumps**, due to low electricity prices[78]. The intense competition between different heating sources is leading the DH sector towards a more efficient and integrated operation.

At the same time, **district cooling is rapidly growing** in the country, at a growth rate around 20 %. The fist DC network in Sweden was commissioned in 1992 in Västerås and since then DC supply has been significantly growing, as illustrated in Figure 78. This trend is expected to continue, due to the increasing cooling demand to meet higher comfort standards and the interest of big cold consumers in reducing their cooling costs. Many of the existing DC networks use **free cooling** from seawater and lakes and its main clients are office buildings, data centres and supermarkets.

[77] Source: Swedish DH Association
[78] Around EUR 20-30/MWh in 2016

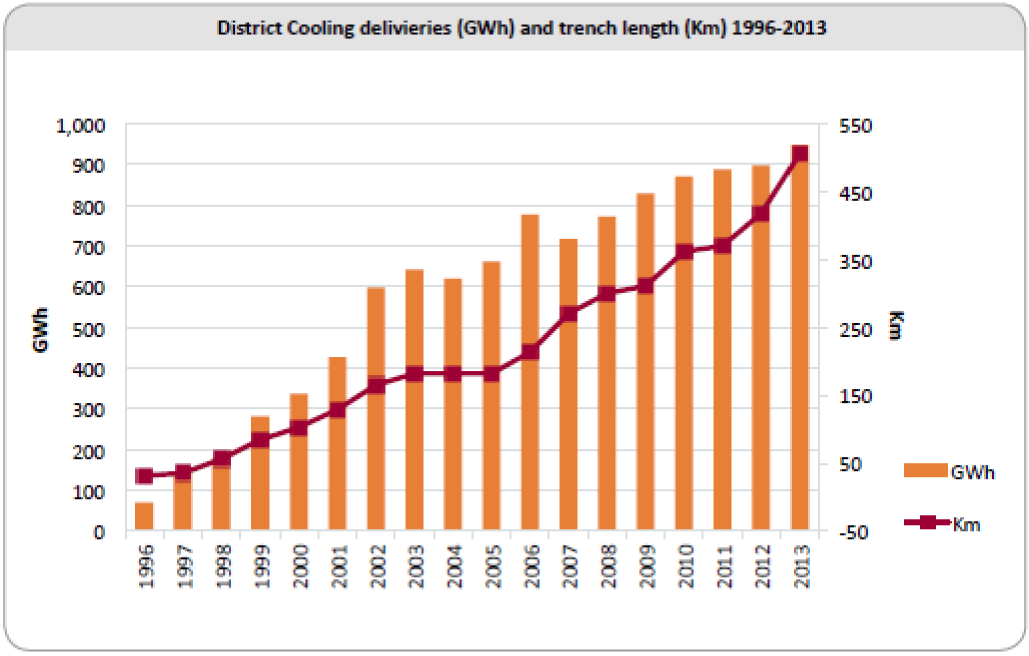


Figure 78 District cooling development in Sweden (Source: Euroheat & Power)

I.II Policy tools and incentives supporting DHC

Sweden has developed a comprehensive package of policy tools and incentives aiming at supporting a **sustainable and market-based** heat supply:

District Heating Act

In 2008, the Swedish Government introduced a new legislation to **protect consumers** and **increase transparency** in the DH sector: the DH Act. The main elements of this Act are summarised below:

- It provides a general framework for DH contracts (content, termination, compensation…);
- It requires DH companies to provide information on prices to its customers and to the general public.
- It requires DH companies to negotiate future prices and heat supply conditions with its consumers. In case of disagreement, customers can apply for mediation to the National District Heating Board.
- It regulates unilateral changes in the DH contract as well as discontinuing district heat supply.
- It obliges DH companies to inform a supervisory authority (the Swedish Energy Markets Inspectorate- SEMI) about its business and operations on an annual basis to ensure the compliance with this law.

The DH Act was amended in 2011 to integrate further requirements regarding **metering and billing**. Following this amendment, DH companies have the obligation to meter their customers' energy use and communicate the results on a monthly basis. It also established that billing is to be performed at least four times a year, unless otherwise agreed between the parties. The DH act was also amended in August 2014, introducing a set of rules aimed at facilitating industries to provide surplus heat under certain conditions to DH networks.

National benchmarking of DH prices and Price Dialogue initiative

There is a **high level of transparency in DH prices**. Apart from the price data collection undertaken by the SEMI, an annual survey of the costs for energy supply - including district heating - is performed and published by the Nils Holgersson consulting group. This survey is based on numbers reported by the DH companies on a voluntary basis.

A major voluntary market initiative, *Prisdialogen*[79] ("**Price Dialogue**"), also supports the transparency and predictability regarding DH pricing. This initiative was established in 2011 jointly by the Swedish District Heating Association and two of the major real estate organisations in the country, i.e. Riksbyggen and the Swedish Association of Municipal Housing Companies. The aim is to strengthen the customers' position with respect to DH companies in order to achieve a fair, predictable and stable price change model and to increase confidence in the DH suppliers' pricing. On a voluntary basis, DH suppliers can request to join the initiative following the 4 steps illustrated in Figure 79 below. After a first dialogue with its clients about the price evolution model, it is submitted to the *Prisdialogen* Office to be reviewed and decide whether it becomes (or continues to be) a member of the initiative. This membership proves that the DH supplier has completed a price dialogue with its customers in a good way and that the price change model meets the requirements established by the initiative.

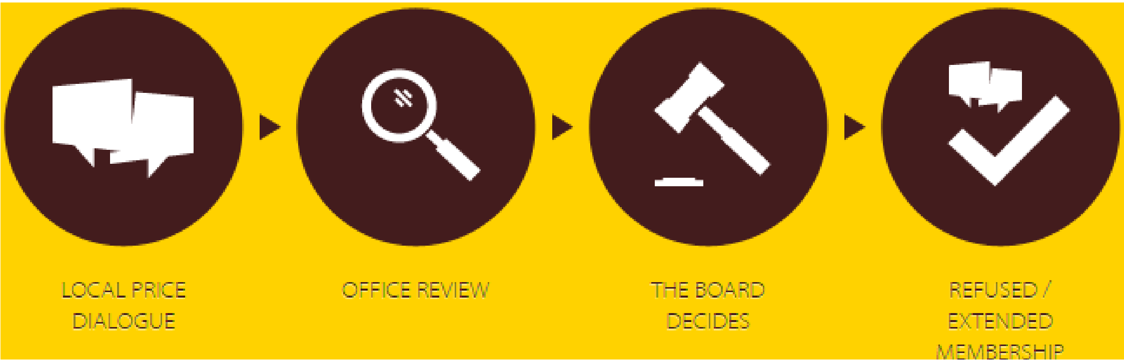


Figure 79 Price Dialogue phases (Source : Prisdialogen)

Energy taxation, subsidies and fees80

Taxation and subsidies have strongly promoted the development of renewable energy, DHC and CHP production in Sweden. The most relevant taxes and subsidies promoting renewable energy-fuelled DHC systems are summarised below:

- **CO_2 and energy taxes[81].** Renewable energy sources are exempt from both taxes, which are levied on the supply, import and production of fossil fuels for heating (and electricity use). In Sweden, **CO_2 taxation** on fuels was introduced in 1991 and has been the main policy instrument to decrease fossil fuel consumption. It has been gradually increased, from 29 EUR in 1991 to ca. EUR 120/ton in 2016 for households and services (lower for industries, forestry sector and CHP). The tax is coordinated with the EU Emissions Trading Scheme (EU ETS), which was adopted in 2005 (i.e. industrial installations covered by the EU ETS are not subject to the CO_2 tax, however heat only boilers within ETS still have to pay 80 % of full CO_2-tax). **Energy tax** is paid on fossil fuels, which represented in 2015 6 % of total DH production in Sweden.

- **Sulphur tax**. The sulphur tax is applied on heavy fuel oils, coal and peat. If sulphur is removed from the exhaust gases, the tax is refunded at the same rate for each kg of sulphur removed.

79 http://www.prisdialogen.se/
80 http://www.res-legal.eu/
81 Energy, carbon dioxide and sulphur taxes are regulated in the Energy Tax Act (1994:1776).

The energy, CO_2 and sulphur taxes for fuels (other than transport) and electricity are presented in Figure 80 below.

General energy and carbon dioxide taxes from 1 January 2015, excluding VAT

	Energy tax	CO_2 tax	Sulphur tax	Total tax	Tax öre/kWh
Fuels					
Fuel oil 1, SEK/m³ (<0.05 % sulphur)	850	3,218	-	4,068	**40.9**
Fuel oil 5, SEK/m³ (<0.4 % sulphur)	850	3,218	108	4,176	**39.5**
Coal, SEK/tonne (0.5 % sulphur)	646	2,800	150	3,596	**46.7**
LPG, SEK/tonne	1,048	3,385	-	4,477	**35.0**
Natural gas, SEK/1,000 m³	939	2,409	-	3,348	**30.3**
Raw tall oil, SEK/m³	4,068	-	-	4,068	**41.5**
Peat, SEK/tonne, 45 % moisture content (0.3 % sulphur)	-	-	50	50	**1.8**
Electricity use					
Electricity, northern Sweden, öre/kWh	19.4	-	-	19.4	**19.4**
Electricity, rest of Sweden, öre/kWh	29.4	-	-	29.4	**29.4**
Electricity use, industrial processes, öre/kWh	0.5	-	-	0.5	**0.5**

Figure 80 General energy and CO_2 taxes in Sweden, 2015 (source: Swedish Energy Agency)

- **Tax reductions for households.** Act No. 2009:194 sets rules for the tax-deduction of the installation works in one-family-houses. It is applicable to all kind of works, including the installation of renewable energy devices and the replacement of conventional heating sources with renewable ones or DH. The labour costs for the installation (i.e. not the material costs) may be deducted from the income tax.
- **Subsidies for conversion from oil and direct electricity** for heating were available between 2006 and 2010, leading to an increase in DH connections, as illustrated in Figure 81. There was also a similar scheme in the period 1998-2002 for conversion from direct electricity heating as part of an energy policy programme related to the closure of the Barsebäck nuclear power plant, in southern Sweden.

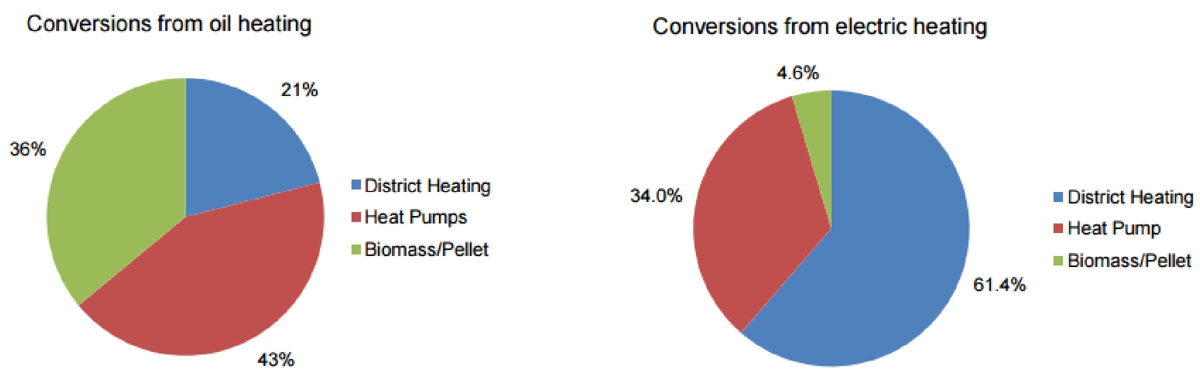


Figure 81 Conversion programme from oil and electric boilers between 2006-2010 (Source: Swedish Energy Agency)

- **NOx fee.** There is a refunding mechanism with payback to plants with lower NO_X-emissions than average. The producers of heat from boilers, stationary combustion engines and gas turbines with a useful energy production of at least 25 GWh/y are obliged to pay a fee according to their nitrogen oxide emissions. Heat producers using renewable energy sources are exempt from this obligation. The fee is SEK 50 (ca. EUR 5) per full kilogram of nitrogen oxides.

Incentives to CHP

Sweden has supported CHP since the 1990's and has progressively adapted its support towards schemes promoting CHP plants connected to DH systems and fuelled by renewable energy sources (mainly biomass).

The first important CHP developments in Sweden were mainly supported through **subsidies**. These were introduced in 1991 through programmes providing investment grants for the development of efficient electricity and energy technologies (ca. EUR 116 million in the period 1991-1998). Between 1998 and 2004 the investment grants became only accessible to CHP fuelled by biofuels, for a maximum of SEK 4000/kW (EUR 415 /kW) and 25 % of the investment cost. Grants were also available for the conversion of heat plants into CHP plants.

The national policy tools supporting DH and renewable electricity production described in this section have also positively influenced the development of CHP plants fuelled by biomass.

Electricity certificate scheme82

In particular, biomass-fuelled CHP plants have benefited from the Electricity Certificate Scheme that came into force in 2003 aiming at increasing the production of renewable electricity. For every MWh of electricity produced by an approved facility from a renewable energy source[83], the owner of the facility receives an electricity certificate from the Government that can be sold in the market and is valid for a period of 15 years after commissioning.

This mechanism also introduced a **quota obligation** for electricity suppliers and certain electricity users who are obliged to buy a proportion (quota) of electricity certificates in relation to their electricity sales or electricity use. The quotas are calculated every year based on the expected increase of renewable electricity generation, expected electricity sales and electricity used by the organisations with quota obligations. In 2015, the quota was 14.3 %. The overall Swedish goal in the green electricity certificate scheme was recently increased to 30 TWh new renewable electricity until 2020 with respect to 2002. On top of this, the 5 main political parties of the country have recently agreed on a new goal of 18 TWh additional renewable electricity by 2030.

The electricity certificate system has proved to be an **efficient policy tool to promote renewable energies** in Sweden. Figure 82 shows the increase of RE production subject to this certification scheme since it came into force[84]. The increasing offer of certificates has affected its price, which in general has decreased since 2003. In 2015 the average price was EUR 16 /certificate.

[82] See Act on Electricity certificates: Act No. 2011:1200 and Regulation on Electricity certificates – Regulation No. 2011:1480

[83] Eligible RE sources: Hydro, wind, biomass, geothermal, solar and peat (if used for CHP)

[84] The decrease in 2013 is due to the phase-out of some old hydro and biomass power plants that achieved their end of their period of grant of electricity certificates (15 years)

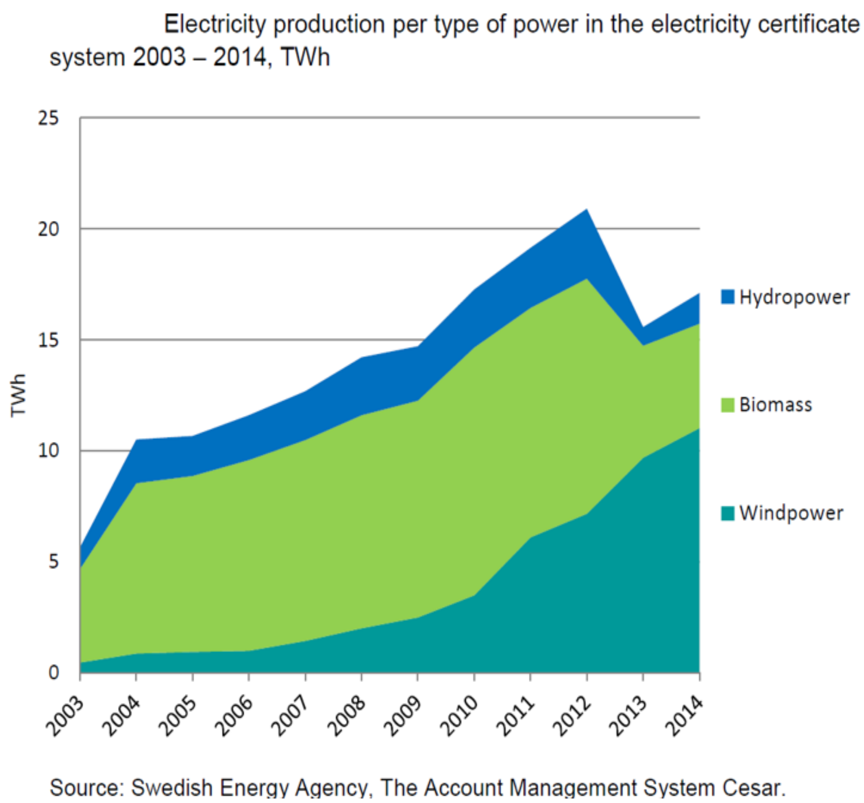


Figure 572 Evolution of electricity production subject to the Electricity certificate market by source of energy (2003-2014)

In 2012, a **common electricity certificate market** between Sweden and **Norway** was introduced. The joint market allows trading in both Swedish and Norwegian certificates, and receiving certificates for renewable electricity production in either country.

II. Presentation of Stockholm DHC system

The DHC system in Greater Stockholm is one of the largest and successful in the world, and keeps growing. This case study focuses on the DHC system of its main operator, Fortum Värme's, whose main characteristics are summarised below:

Key facts and figures

DH market share	~80 % (in the area covered by DH)
Heating & Cooling capacity	DH: ~3 600 MW DC: 220 MW
Heat &Cold production (last 6y)	DH: 7.4-10.8 TWh/y DC: 380-440 GWh/y
Km network (double-pipe)	DH: 1 330 km DC: 200 km
CO_2 emissions (2015)	DH: 0.136 kg/MWh DC: 0 kg/MWh (certified renewable electricity)*

*If we took instead Sweden's grid factor for electricity, CO_2 emissions of DC would be 11g/kWh (EIB carbon footprint methodology v10.1)

- **Large system**: Average 8 TWh/y, ~10 000 clients, direct supply to 6 municipalities
- **Public-private partnership:** The DHC system is owned and operated by Fortum Värme AB (50 % City of Stockholm, 50 % Fortum Heat & Power)
- **Flexible and optimised DH production**:
  - 7 CHP plants (fuelled by biofuels, waste or fossil fuels)
  - Heat pumps
  - Electric boilers
  - Several HOBs (fuelled by bio oils or fossil oils)
- **District Cooling**: One major system in the city centre, and several smaller ones around.
  - Above 50 % of sales produced through free cooling from the sea and other water bodies

Figure 83 below presents the areas covered by Fortum Värme's **DH system** (in green), as well as their main production facilities. The energy mix of the system is presented in Figure 84.

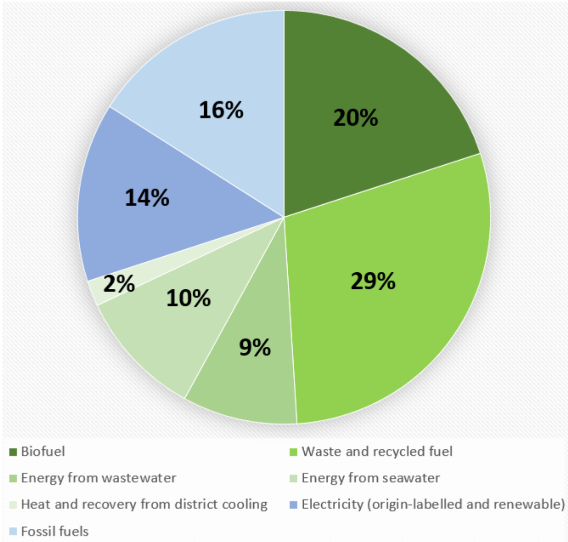


Figure 83 Fortum Värme DH network *Figure 84 Energy mix of the DH system* (2015)
Source: Fortum Värme

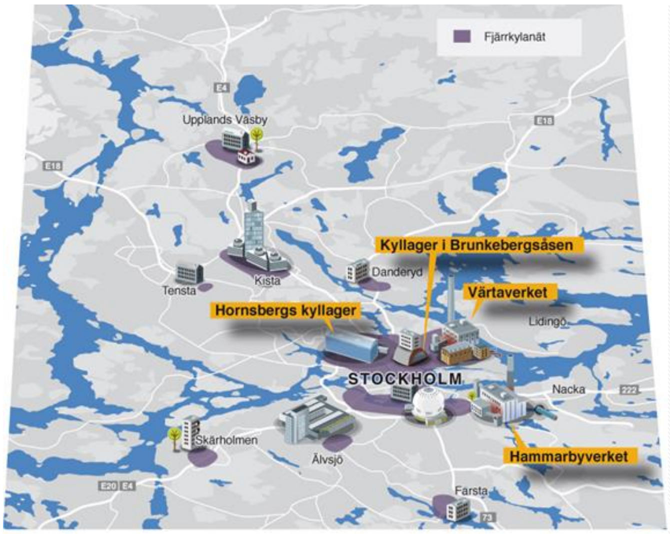
It supplies mainly the **residential and tertiary sectors** (69 % and 29 % respectively, with the remaining 2 % supplied to industries) principally through CHP facilities.

Figure 85 provides further details on the production capacity of Fortum Värme's DH system.

Net	Site	Plant	MW heat	MW electricity	Fuel(s)
City	Värtan	CHP1	350	190	Bio oil/Fossil oil
		CHP6	300	135	Coal/Olive stones
		Heatpumps	230		Electricity/Sea water
		Electric boilers	230		Electricity
	Various	HOB:s	615		Bio oil/Fossil oil
Southern	Högdalen	CHP	265	60	Waste/Refuse
		P5	75		Bio oil/Fossil oil
	Hammarby	Heatpumps	240		Electricity/Sewage water
		HOB	200		Biooil
		Electric boilers	80		Electricity
	Various	HOB:s	90		Bio oil
		HOB:s	145		Fossil oil
North western	Brista	CHP1	110	40	Wood chips
		CHP2	80	25	Waste
	Hässelby	CHP	210	65	Wood chips
	Various	HOB:s	240		Bio oil
		Heatpumps	25		Electricity/Sea water
		HOB:s	150		Fossil oil
Under commissioning					
City	Värtan	CHP8	450	130	Wood chips

Figure 85 Heat production in Fortum Värme DH system 2016 (source: Fortum Värme)

The areas supplied by Fortum Värme's **DC system** are provided by Figure 86 (in purple), while Figures 87 provides its energy mix.



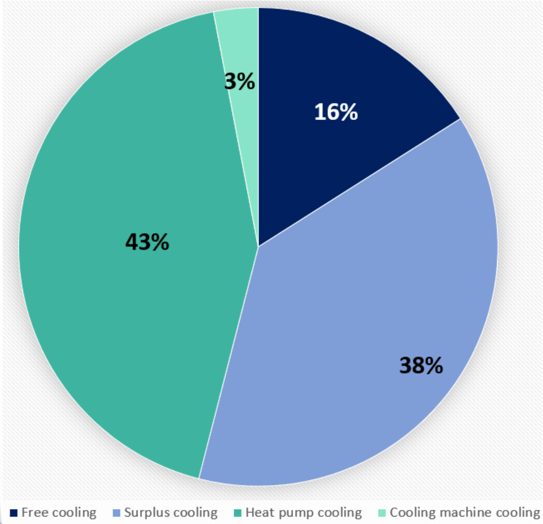


Figure 86 Energy mix of Fortum Värme's DC *Figure 87 Fortum Värme's DC system (2015)*
Source: Fortum Värme

All the clients are tertiary buildings, including IT and data centres and food storage facilities.

III. Urban development and expansion of DHC

The city of Stockholm aims at becoming **fossil-free by 2040,** and the upgrade and expansion of its DHC systems will play a key role in achieving it. This target has been integrated in Fortum Värme's strategy, which aims at reaching 100 % renewable or recycled fuels by 2030.

Indeed, Stockholm has a long tradition of ambitious environmental targets. Its first climate plan was established in 1998 and currently the climate plan 2016-2019 is under development. In 2010, Stockholm became the first **European Green Capital**[85] due to its "outstanding, long historical track record of integrated urban management, also confirmed by its ongoing credible green credentials". The award also highlighted the ambitious plans for the future, which demonstrate the continuity of the city's efforts on sustainable urban development.

Sustainability is an integrated part of all strategies and city planning. Stockholm is a fast-growing city, which has experienced growing rates above 10 % per decade since 1990. The city has managed to successfully implement a comprehensive urban planning, which aims at developing **compact new districts** with energy-efficient buildings being constructed close to public services and green areas. These new districts have generally opted for connections to the city's DHC system. **World-class "eco-districts"** such as Hammarby Sjöstad or Stockholm Royal Seaport (cf. section VII) showcase the sustainable model that the city aims to achieve in the long-term. Stockholm also supports the **renovation of existing buildings** to reach high environmental standards.

The **expansion of DH** has been one of the most important reasons for the reduction of greenhouse gases in the city (i.e. 500 000 tonnes reduced between 1990 and 2010 according to the city's action plan for climate and energy 2012-2015). The implementation of the current climate plan will be facilitated by the expansion of DHC grids and the transition towards fossil-free fuels. However, the grid expansion is done

85 Award granted by the European Commission to a cities that: i) Have a consistent record of achieving high environmental standards; ii) are committed to ongoing and ambitious goals for further environmental improvement and sustainable development; iii) Can act as a role model to inspire other cities and promote best practices to other European cities.

under **market conditions**, i.e. there is **not an obligation to connect** buildings to the grid.

Moreover, the DHC sector has indirectly benefited from the support of the city to **innovation** and to the creation of **climate awareness**. Stockholm is an internationally recognised **smart city**, which has implemented successful smart solutions in the fields of transport, energy, waste management, water supply and governance. The city organises numerous activities to inform and **engage citizens** in its climate-related actions.

IV. Local heating and cooling markets

IV.I Heating market

The heating market in Stockholm is **dominated by district heating** (80 % of market share in the city). The main alternative to DH is the use of individual heat pumps.

This area has developed a **flexible, sustainable and cost-efficient** model for DH supply, aiming at meeting the demand at the lowest cost for the system and making continuous efforts to offer attractive prices to its customers in a **highly competitive market**.

IV.I.1 Demand and supply

The weather conditions and urban density of Greater Stockholm are suitable for district heating. The city has an annual heating demand of ca. **3500 heating degree-days**, mainly supplied through district heating (sales of ca. 12500 MWh/y). Consumers include most of the tertiary buildings and residential buildings as well as some industries.

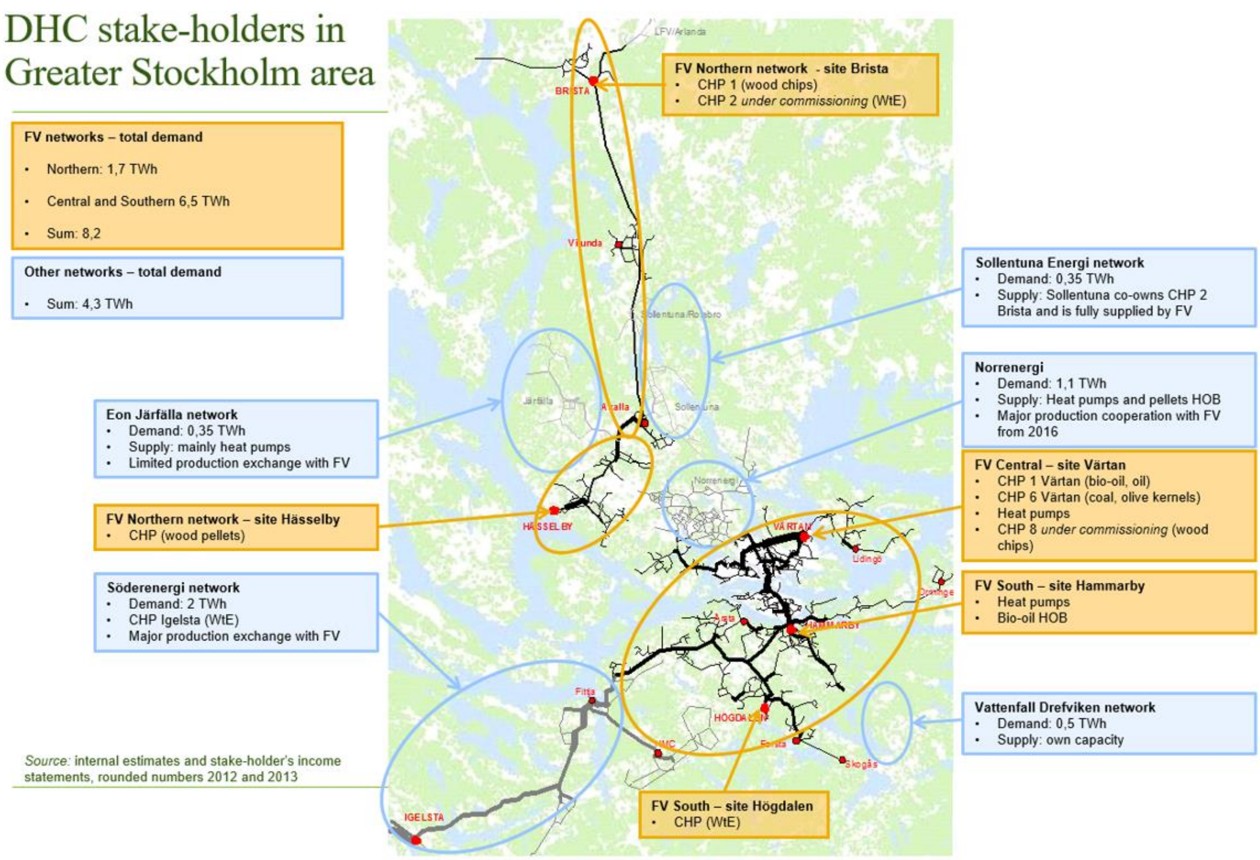


Figure 88 DH system in Greater Stockholm (Fortum Värme's system in orange)
Source: Fortum Värme

The main **DH networks** in Greater Stockholm are presented in Figure 88 above, as well as their production and main generating facilities. Fortum Värme's (FV) is the main DH supplier (highlighted in orange in the map). Its system is composed of 3 sub-systems: Northern, Central and Southern, where the 2 latter are **interconnected** since 2008.

Collaboration between DH networks has become essential to remain competitive against individual heat pumps. As further explained in section IV.I.2, heat pumps have become direct competitors of DH and forced DH companies to keep looking for further optimisation potentials in order to decrease their costs through an enhanced and efficient operation. The main collaborative initiatives undertaken in this sense are described below and have a twofold purpose: i) minimise the production costs as well as price and volume risks; and ii) minimise the investments:

- **Connection of neighbouring DH grids.** Fortum Värme has a heat exchange agreement with Söderenergi (its neighbouring grid to the South of FV South grid) and Norrenergi (its neighbouring grid to the North of FV Central grid).
- **Common heat dispatch.** Fortum Värme, Söderenergi and Norrenergi have agreed to implement a common heat dispatch in order to lower their operational costs. It was commissioned in April 2016 and allows a dynamic **optimisation of the production and supply** of DH, taking into account electricity prices, heat demand and production and distribution costs.

Energy use in buildings is decreasing due to energy efficiency measures. Existing buildings have an average consumption of 180 $kWh/m^2/y$ (incl. heating and domestic hot water) while new buildings consume 55 $kWh/m^2/y$ (final energy). This demand decrease is being compensated mainly through the grid's expansion and **new connections**.

The production mix of the system provides a **high degree of flexibility** and allows optimising production costs. The **heat load curves** for a typical year of the integrated DH system of Fortum Värme, Norrenergi and Söderenergi are presented in Figure 89. It includes the new biomass CHP plant that was commissioned in 2016 and represents how the demand will be covered on an annual and monthly basis. Base load will be mainly covered through CHP plants, where the merit order of preference is waste-to-energy, bio-fuels and coal. Heat pumps and biomass HOBs will cover mainly intermediate load, but could replace coal CHP depending on coal and electricity prices. Peak capacity is mainly provided through HOBs, fuelled by pellets, bio-oils and fossil oil (in this order of merit), but also through maximising CHP heat production and minimising electricity production in CHP plants (pink area in the figure).

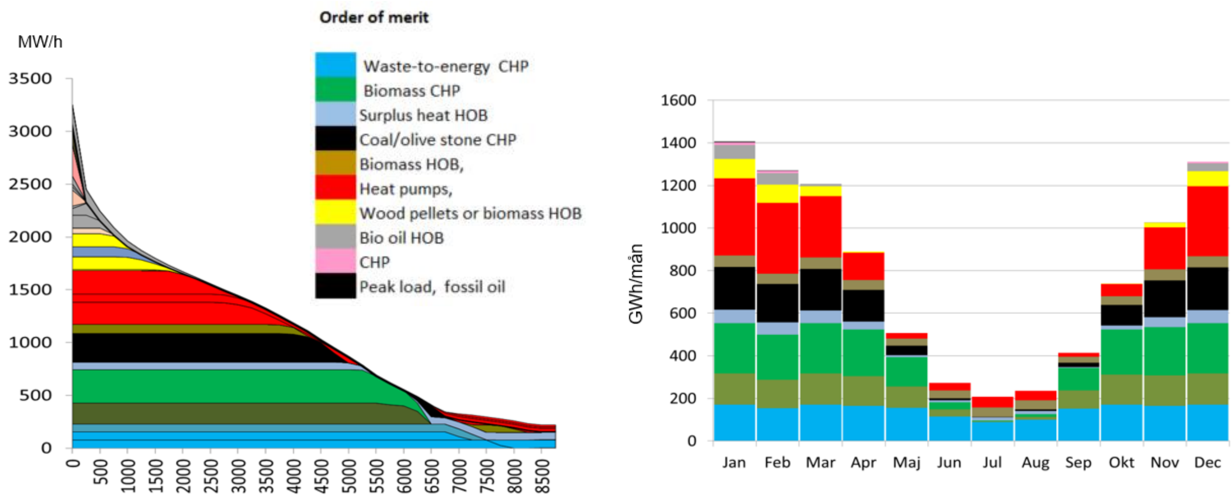


Figure 89 Heat load curves of Fortum Värme's DH system for a typical year (source: Fortum Värme)

The system has a high level of **security of supply**. It is fuelled mainly by **available local resources** such as waste and bio-fuels (i.e. biomass and bio-oils). Fortum Värme **owns its production** facilities and the interconnection with neighbouring DH grids increases even more its security of supply. It also **secures its bio-fuel supply** through the diversification of its supply (i.e. long–term and short-term agreements with several suppliers) and the storage of biofuels.

IV.I.2 Price competitiveness

Today, individual heat pumps are highly competitive due to the low electricity prices in Sweden (EUR 20-30 /MWh) and to low interest rates. **Price competition is severe**, especially between the years 2014 and 2016. However, DH prices are expected to remain competitive.

The average price for DH is **EUR 73 /MWh** excluding taxes (25 % VAT), which is below the average in Sweden (around 80 EUR/MWh). Tariff structure is explained in section V.II. As required by the DH Act, these prices are negotiated with clients (mainly housing associations) on an annual basis. As a result of these negotiations, the prices for the next year are established as well as a forecast for the following 2 years.

IV.II. Cooling market

Stockholm has **one of the largest district cooling networks** in the world. District cooling has been **rapidly growing** in the city and surrounding areas since the 1990's, at annual growing rates between 5-15 % (10-20 MW/y in the last 5 years). Where available, it is a competitive alternative to other cooling options such as individual heat pumps or chillers.

Cooling demand in Stockholm is increasing, mainly due to the increasing demand for comfort in buildings and the large number of IT and data centres with high cooling needs. The main cooling consumers consist of **tertiary buildings** (hotels, shopping centres, offices, etc.), including IT centres and supermarkets or food-related facilities.

Most of the DH companies in Greater Stockholm are also offering DC or planning to include this business in their portfolio. **DC** is a B2B activity, which is perceived as an attractive cold supply option mainly due to:

- its sustainability (low-carbon and efficient supply);
- high reliability (more reliable than the alternatives, with 99.9 % average availability ratio);
- simplicity (it's a turnkey solution, including O&M); and
- the small space needed for the main equipment, providing an opportunity to free up expensive space.

Fortum Värme has the largest DC system in Greater Stockholm area. **Free and surplus (waste) cold** cover most of its demand (54 %), as presented before in Figure 87. It supplies around 600 buildings with its **efficient production** mix, which has a high average COP of 6.9.

The average **price** of the cold provided through this system is **EUR 70 /MWh**. Tariff structure is explained in section V.II. Unlike DH, the costs for the alternative option for cooling vary a lot depending on the building and how the cooling is used.

V. Business model

V.I Governance and strategy

"AB Fortum Värme Holding samägt med Stockholms stad (publ)" is a Swedish **public company** created in 1996. The company's certificate programme is listed on the Stockholm Stock Exchange (Nasdaq OMX). It is jointly owned by the City of Stockholm and Fortum Power & Heat[86] (50 % shares and voting rights each). Its legal structure is presented in Figure 90.

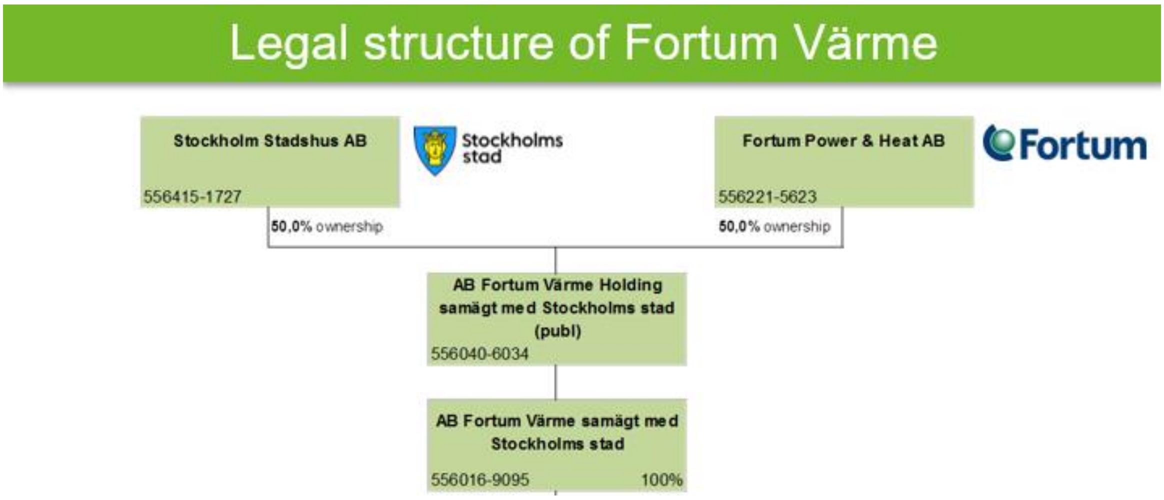


Figure 90 Legal structure of Fortum Värme (Source: Fortum Värme)

Its **board of directors** oversees the company's activities and represents its stakeholders. It is also responsible for appointing the company's CEO. There are 10 board members who are nominated at the Annual General Meeting (8 members representing the shareholders and 2 employee representatives).

Its long-term **strategy** aims at offering the most resource-efficient and sustainable energy solutions. It aims at achieving **a fully climate neutral and resource neutral business by 2030** at the latest, while continuing offering competitive solutions to its customers, good returns to its shareholders and supporting innovation.

[86] Fortum Power & Heat AB has been renamed Fortum Sverige AB in 2016

V.II Financial model

Fortum Värme has a **strong financial position**. During the last 5 years, the company has experienced a stable development of its sales margin and EBIT[87], mainly due the flexibility of its production mix and price structure. It has also implemented numerous investments aiming at increasing its competitiveness and reducing the climate impact of its activities. Its financial information is accessible on its website[88].

The company's **revenues** are generated by the sales of heat, cold and electricity. **Invoicing** usually takes place every month and tariffs are updated on an annual basis.

The **tariff structure** for DH and DC has four components, as follows:

i. <u>Fixed component</u>: calculated as a function of installed capacity (MW);
ii. <u>Variable component</u>: unit price per MWh consumed in the building;
iii. <u>Volume Discount </u>: Big customers of heat receive a volume discount;
iv. <u>Return temperature bonus / malus</u>**:** This tariff component seeks to incentivise the system's efficiency by increasing the temperature difference between the supply and return (the so-called ΔT). For instance, in DH there is a reward for lower return temperature and a penalty if the return temperature is above the established limit.

In general there is **no connection fee** and clients are **allowed to disconnect** from the grid without paying any fee (after providing a 3-month notice).

Individual metering is widespread (at building level). However, in Sweden (in general) there are **not sub-meters** in each apartment, and this is also the case in Fortum Värme's DH system. It has been traditionally accepted by housing associations to implement heat cost allocations based on m^2.

V.III Client relationships and energy efficiency initiatives

Consumers are in general **very satisfied** with the quality of the service. Fortum Värme has a dedicated team to support their clients. The level of **transparency** of the prices and strategy is very high, and customer satisfaction surveys are performed on an annual basis. The churn rate[89] is and has always been low.

The graphs below show the evolution of the **customer satisfaction index** of corporate clients (on the left) and private clients (right) for the main DH operators in Stockholm. Fortum Värme customer satisfaction (dark green) has increased among corporate clients and remained stable for private clients.

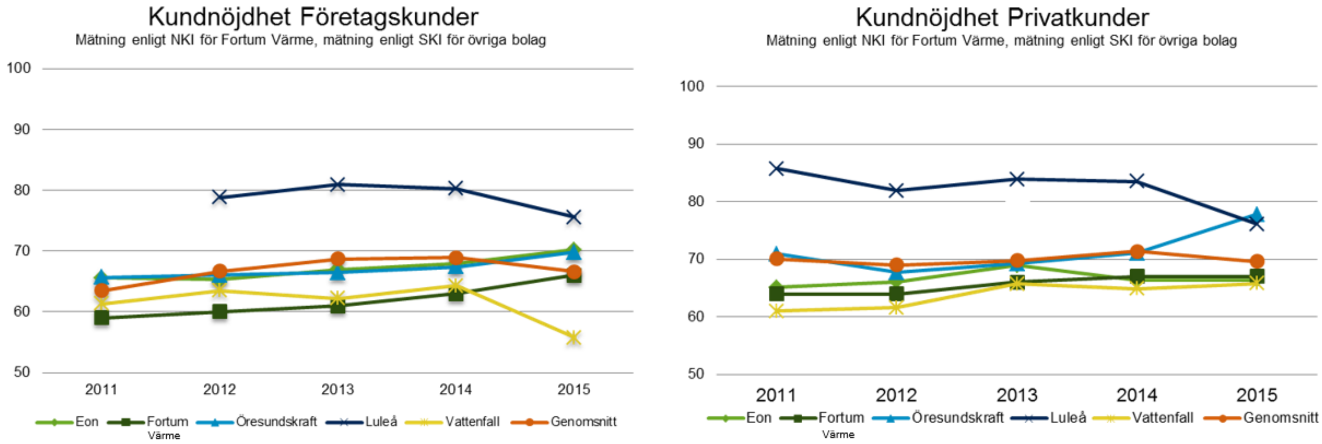


Figure 91 Client Satisfaction Index of main DH companies in Stockholm (Source: Fortum Värme)

87 Earnings before interest and taxes
88 http://arsredovisning.fortumVärme.se/
89 Percentage of subscribers who discontinue their subscriptions to DHC service within a given time period

As mentioned before, Fortum Värme **encourages energy efficiency** among its clients through its tariff (incentivising a high ΔT) and also creates **climate awareness** through efficient communication about its activities, related environmental impact and continuous efforts to reduce CO_2 emissions.

VI. Framework for innovation

Fortum Värme actively supports innovation. It is involved in several **RDI projects**, in cooperation with universities, consultants and manufacturing industries (among others). Some examples of these projects are presented below.

Open district heating[90]

Fortum Värme has implemented several pilot projects within the framework of its Open District Heating initiative. This new business model consists in connecting data centres and other local businesses in the city to the DHC network, supplying them with an efficient cooling and using their surplus heat (and cold if available) to fuel the DH (and DC) grid, as illustrated in Figure 92.

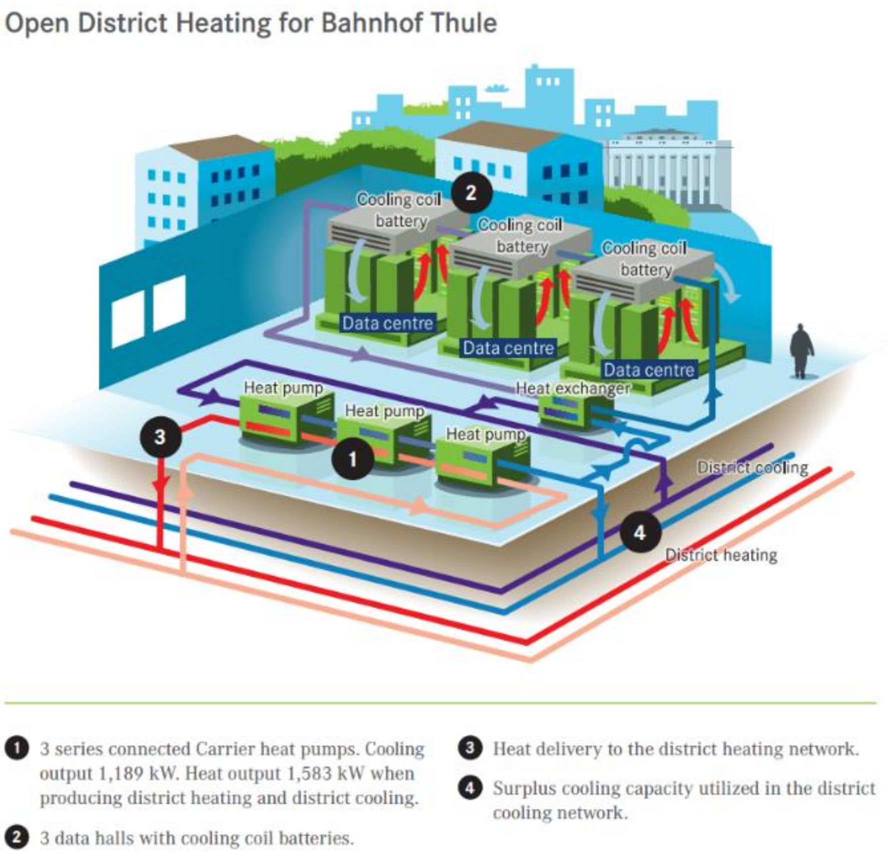


Figure 92 Example of Open District Heating project (Source: Open District Heating®)

Eco city districts

Fortum Värme is present in some of Stockholm's most innovative eco-districts, namely Hammarby Sjöstad and Stockholm Royal Seaport.

Hammarby Sjöstad[91] was the first eco-district in Stockholm and is one of its flagship urban projects. The initial idea was developed in 1990 and most of the district is now completed. Once fully built, in 2017, Hammarby Sjöstad will be able to accommodate 25 000 people in 11 000 apartments. The project aimed at reducing the environmental

90 http://www.opendistrictheating.com/

91 http://hammarbysjostad.se/

impact of the district by 50 % compared to conventional standards. Its urban model is based on circular economy, where energy consumption and waste are minimised and recycling is done whenever possible. The real estate developers in the district almost unanimously opted for Fortum Värme's DH.

Now one of the next generation eco-districts – the **Stockholm Royal Seaport**[92] – is being developed in a former industrial and port area. Plans are under way for 12000 new apartments and 35 000 workplaces that will be combined with modern port operations. The area has even higher environmental requirements than Hammarby Sjöstad and Fortum Värme has been again chosen as DH supplier. By 2020, people living there are supposed to emit no more than 1.5 ton CO_2 per person (compared to the 4.5 tons emitted by the average Swedish citizen today) and the target is to be fossil-fuel free by 2030. The City of Stockholm has decided to make it a hub for the development of Swedish environmental technology. Fortum Värme is participating in a research project called "Smart Energy", aiming at developing a smart grid in this district.

VII. Perspectives

Fortum Värme will continue investing in efficient and sustainable infrastructure to achieve its target of **a fully climate neutral and resource neutral business by 2030** at the latest. To achieve this, a number of initiatives are planned for the coming years.

- The new biofuel CHP plant in Värtan (commissioned in 2016) will significantly decrease the carbon footprint of its heat supply.
- The system's **flexibility is expected to be enhanced,** mainly through new interconnections of DH grids (i.e. its Northern and Central grids and also with neighbouring DH grids).
- The company will continue looking for opportunities to decarbonise its energy mix, notably by integrating new **surplus heat and cold** and increasing its renewable **CHP** production.
- **DHC connections are expected to keep growing**, boosted by the population growth in Stockholm and the integrated urban planning being implemented in new districts.
- **RDI** efforts will continue to support the development of efficient, flexible and sustainable options for energy supply.

VIII. Conclusion: Key Success Factors

The DHC system in Greater Stockholm is one of the most successful in the world. The key success factors contributing to this can be summarised as follows:

i. The **ambitious environmental targets** set at national and local levels. The use of DHC has proved to be an efficient way to reduce CO_2 emissions in Stockholm and other Swedish cities and is strongly supported by the Government of Sweden and its local authorities.

ii. **Relevant tax incentives:** High taxes on fossil fuels have played a key role in supporting the expansion of efficient and low-carbon DHC systems in the country.

iii. A **liberalised DH market with slight regulation.** This national choice encourages competition between different heat suppliers while providing a legal framework to protect consumers and an enhanced transparency in the sector, notably through the DH Act. **Transparency and predictability regarding pricing** is also achieved through a major voluntary market initiative, the Price Dialogue ("Prisdialogen"), established jointly by the

[92] http://www.stockholmroyalseaport.com/

Swedish District Heating Association and two of the major real estate organisations in the country.

iv. **Comprehensive urban planning, with high sustainability standards and including heat supply.** Stockholm is internationally recognised for implementing an integrated urban planning with high sustainability standards. Moreover, the development of **compact districts** facilitates the viability of DHC projects, which can benefit from high energy demand densities.

v. **Successful cooperation between public and private parties**. The City of Stockholm and its private partner Fortum Heat & Power have developed a long-term and efficient collaboration through Fortum Värme. Both shareholders have the same level of ownership and voting rights. They have managed to **align their interests** in order to provide a quality service and a cost-efficient and sustainable energy supply to Stockholmers.

vi. **Large-scale and growing system.** The large size of the grid allows benefiting from **economies of scale.** The demand decrease due to energy efficiency measures in buildings is being compensated with **new connections** as the city and surrounding municipalities grow.

vii. **High flexibility in the system's operation.** Its integrated approach, with interconnected DH networks, a diversified energy mix based on CHP and the daily optimisation of the heat and electricity production makes Fortum Värme's DHC system very flexible and cost-efficient.

viii. **Collaboration between DH companies** has been essential to start building an **integrated DH system** in Greater Stockholm, ultimately improving the efficiency of the overall DH system and reducing its costs. This collaboration has been particularly boosted by the severe competition with the alternative heating solution. The new common heat dispatch and the interconnection with neighbouring DH grids has improved the competitive position of Fortum Värme's against heat pumps.

ix. **Use of local resources to improve security of supply.** The energy mix of the DHC system is dominated by local biomass, waste and surplus heat and cold (from local industries, water bodies and wastewater treatment plants).

x. **Competitive prices.** All the above measures allow Fortum Värme to provide a DHC supply at competitive prices. The high **transparency** of prices - supported e.g. by national benchmarks realised by the Swedish DH association and Nils Holgersson consulting group – and clear **visibility on future prices** also influence the client's choice of DHC.

xi. **Innovation.** The system uses state-of-the-art technology and operational modes and relies on RDI activities to keep improving its economic and environmental performance.

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4.3 Cross-case study synthesis

4.3.1 Key Success Factors in DHC systems

The case study analyses presented before have identified **9 Key Success Factors** (KSF) leading to a high quality, efficient and sustainable DHC service. These are listed and defined below, indicating also the case studies where the KSF resulted critical to its success.

		Key Success Factors	Description
external	1	**Adequate national policy and regulatory environment**	The national energy policy and regulatory environment provide adequate ground and incentives for the development of DHC systems (e.g. by setting ambitious CO_2 targets, establishing specific fiscal measures promoting the use of renewable energy, etc.). *Case studies: Copenhagen, Gram, Hafencity, Saclay, Stockholm*
external	2	**Direct/indirect financial support**	DHC projects benefit from existing direct/indirect subsidies (e.g. investment grants, support schemes to CHP and RE, fossil fuel taxes...) and/or dedicated financial instruments (such as those offered by the "Kommunebank" in Denmark or KfW in Germany). *Case studies: Copenhagen, Gram, Hafencity, Saclay, Stockholm, Tartu*
external	3	**Focused local policy and coherence with urban planning**	Local authorities promote DHC as part of their energy supply and climate strategy and integrate heat planning 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, promoting compact and mixed-use new districts, etc.). *Case studies: All cases*
external	4	**Alignment of interests / Cooperation maturity**	Public authorities at national and local level, regulating bodies, end users, the DHC company 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 cases*
internal	5	**Availability and relevance of local resources**	The DHC system relies to a large extent on available local resources such as renewable energy sources (e.g. biomass, solar, geothermal), waste-to-energy or surplus heat/cold. *Case studies: Barcelona, Brescia, Copenhagen, Gram, Saclay, Stockholm, Tartu*
internal	6	**Comprehensive project development**	The DHC system was conceived, developed and implemented following a comprehensive, seamless approach aimed at achieving a high quality, cost-efficient and sustainable heat/cold supply. *Case studies: All cases*
internal	7	**Price competitiveness against alternative energy solutions**	DHC prices are competitive against the alternative energy solutions available in the market. This price competitiveness can be enhanced through an optimised system design, through competitive procedures for the market or by allowing competition between different heat/cold supply solutions. *Case studies: Barcelona, Brescia, Copenhagen, Gram, Hafencity, Stockholm, Tartu*
internal	8	**Flexible heat and cold production**	A flexible production allows better cost-efficiencies, mainly through a dynamic optimisation of the supply. This can be achieved through a diversified and complementary energy mix, the use of CHP and enhanced ramp-up/cycling practices, connecting the electricity and heating markets, etc. *Case studies: Barcelona, Copenhagen, Gram, Saclay, Stockholm*
internal	9	**Combining technical and non-technical innovation**	The DHC system embraces and cross-fertilizes innovation at all levels: from the use of state-of-the-art technologies to new governance modes, keeping a long-term approach when making strategic decisions. *Case studies: All cases*

The level of **influence of the KSF on the success of the analysed case studies** has been assessed and is presented in the table below, where "+++" represents the strongest influence.

Case studies	Influence of the KSF on the success of the analysed case studies								
	Adequate national policy and regulatory environment	Direct/indirect financial support	Focused local policy and coherence with urban planning	Alignment of interests / Cooperation maturity	Availability and relevance of local resources	Comprehensive project development	Price competitiveness against alternative energy solutions	Flexible heat and cold production	Combining technical and non-technical innovation
DE -Hafencity	+++	++	+++	+++	+	++	++	+	++
DK - Copenhagen	+++	+++	+++	+++	++	+++	+++	+++	+++
DK - Gram	+++	+++	+++	+++	++	+++	+++	+++	+++
ES - Barcelona	+	+	++	++	+++	+++	++	++	+++
EST - Tartu	+	+++	++	++	+++	++	++	+	++
FR - Saclay	++	+++	+++	+++	+++	+++	+	+++	++
IT - Brescia	+	+	+++	++	+++	+++	+++	+	++
SE - Stockholm	+++	+++	++	+++	++	++	+++	+++	+++

Legend + Moderate influence
++ Significant influence
+++ Strong influence

Other **secondary (or non-key) success factors** have also been identified as having a positive impact on the success of some of the analysed DHC systems but being, however, not critical.

	Secondary (non-key) success factors	Description
1	**Size**	The large size of the grid provides scope for economies of scale. *Case studies: Copenhagen, Stockholm*
2	**Customer empowerment**	Customers are at the core of the DHC business and its main stakeholders. *Case studies: Copenhagen, Gram*
3	**Long-term secured prices (visibility)**	Investors have a clear long-term visibility on DH prices *Case study: Tartu, Saclay*
4	**Climate conditions**	Cold climate conditions improve the business case for DH *Case studies: Copenhagen, Gram, Hafencity, Stockholm, Tartu*

4.3.2 Influence of the identified KSF in the performance of DHC systems

The case study analyses have also provided a better understanding on the main **indicators allowing identifying well-functioning and efficient DHC systems**, characterised by its high quality service, overall efficiency and sustainability.

To define these indicators, the consultant firstly tested if the initial indicators identified at the first phase of the study (i.e. selection criteria described in section 3.1.2) were applicable to the analysed case studies, to keep only those who proved to be relevant. This preliminary list was then adjusted and completed as relevant. The **6 resulting indicators** are presented in the table below.

	Indicators for identifying efficient DHC systems	Description
1	Economic viability of the DHC grid	The DHC business case is economically viable
2	Affordable prices of heating and cooling	The heating and cooling services are delivered at an affordable price
3	Stable and resilient supply	Prices are stable and resilient to fuel price fluctuations
4	Quality of service	The system offers a high overall quality service to its clients
5	Mid to long-term adaptability of the service	The design, management and resource scheme of the DHC system allows adapting it to future needs and potential technology developments
6	Low CO_2 emissions and global environmental footprint	The DHC system has a low-carbon energy mix, achieved through the use of renewable energy sources and surplus heat/cold, and the other environmental parameters are well monitored

The above **well-performance indicators result mainly from the existence or implementation of the identified key success factors**. While the indicators are proposed as the main elements constituting a high quality, efficient and sustainable DHC service, the KSF are critical enablers to be integrated during the design, construction and operation of a successful DHC system. KSF are therefore the main areas where policy makers, cities (or other project promoters), DHC operators and other relevant stakeholders could work to foster the deployment of efficient DHC systems.

Finally, the level of **influence of the KSF on each performance indicator** has been assessed and is presented in the table below, where "+++" represents the strongest influence.

Indicators for identifying well-performing DHC systems	**Impact of KSF on the indicators**								
	Adequate national policy and regulatory environment	Direct/indirect financial support	Focused local policy and coherence with urban planning	Alignment of interests / Cooperation maturity	Availability and relevance of local resources	Comprehensive project development	Price competitiveness against alternative energy solutions	Flexible heat and cold production	Combining technical and non-technical innovation
Economic viability of the DHC grid	++	++	+++	++	++	++	++	++	++
Affordable prices of heating and cooling	+	+++	++	+	++	++	++	+	++
Stable and resilient supply	+		++	++	+++	++	+	+++	++
Quality of service	+	+	+	++	+	+++	++	+++	++
Mid to long-term adaptability of the servic	+	+	+++	+++	+++	+++	+	+++	++
Low CO2 emissions and global environmental footprint	+++	+++	+++	+++	+++	++	+	+++	++

Legend	+	Moderate influence
	++	Significant influence
	+++	Strong influence

5. Replicability potential in other Member States

District heating and cooling is a local business. The analysis of the eight case studies shows that different models are being successfully implemented across Europe to develop high quality, efficient and low-carbon DHC systems. Indeed the design of a successful DHC project should be tailor-made, **based on a multi-criteria analysis** taking into account not only techno-economic indicators, but also the interests of local authorities and consumers -including environmental and social aspects- as well as the local heating and cooling markets.

These **modern DHC systems** have proved to be an efficient way to **reduce CO_2 emissions** while contributing to a more **resilient and cost-efficient energy supply.** Many European cities and communities have already assessed the multiple benefits of DHC systems and integrated them in their energy strategies. However, the potential for deployment of DHC systems in the EU remains very high and further efforts are needed to increase the awareness on their benefits in less mature markets and to facilitate new investments.

The **policy framework for DHC investments** has a strong influence in their financial feasibility. While technical solutions, and DHC equipment are in general easier to replicate, the business model for efficient DHC systems is highly dependent on available support schemes for **CHP, renewable energies** and **energy efficiency**. These may take different forms such as investment subsidies, feed-in premiums, tax incentives or adapted financial instruments. They contribute to make DHC more attractive to investors, while improving its competitiveness against alternative options for energy supply.

This section provides an analysis of the **replicability potential in the EU of the key success factors** (KSF) identified in this study, including the main conditions for replicability and some recommendations. 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 DHC systems in the EU.

KSF 1: Adequate national policy and regulatory environment
(Target audience: Policy makers)

Energy and environmental policies can trigger (or hamper) the development of sustainable energy supply systems. Several EU countries have established a **coherent and integrated approach to support the energy transition** towards a low-carbon economy. Most of these countries have established **ambitious environmental targets** together with a set of policy tools to **support the investments** in energy efficiency and renewable energies needed to achieve those targets, including DHC.

Among the key enablers for a higher deployment of modern DHC systems, one can highlight **relevant tax incentives and support schemes for CHP**. Environmental taxes have played an essential role in supporting the expansion of efficient and low-carbon DHC systems in Denmark and Sweden (among others), where DH systems are mainly supplied though efficient and low-carbon CHP plants. Indeed, high efficient CHP plants allow realising significant primary energy savings and can bring broader systemic benefits such as balancing to the electricity market.

It is in general recommended to support DHC systems when these prove to be the most economical (cost-efficient) option for heat or cold supply, based on a specific **long-term**

cost-benefit analysis taking into account externalities (environmental benefits, balancing…). This approach is already applied in some EU countries (e.g. Denmark or Estonia), where a national methodology is applied and adapted to specific DHC systems, and is often required by EU institutions as a condition for their financial support. Significant progress in energy optimisation modelling at local scale is ongoing in several specialised innovative firms in the EU: they will bring a very valuable market contribution to this holistic planning.

Regarding the **national regulatory framework** for DH, this study evidences three main models.

- **Most DHC markets are only regulated through local contractual arrangements, without any central regulation.**

  These can be a concession or other PPP contracts, when the development and/or management of the service are delegated to a private operator, or through internal public sector conventions or other target-setting patterns, when the service in managed in-house by a municipality or another local public body. Some smaller DHC systems are also, in some cases, developed and managed on a purely private, commercial basis. In this case, national energy regulators that were created in the aftermath of the electricity and gas unbundling have no competencies with respect to district heating, which remains mainly local, with contractual patterns quite similar to those of water as regards price formulas, and some other contract features (metering, billing, civil works…) though of course numerous specificities differentiate both sectors.

  This situation prevails in Italy, France, Germany or Spain. Some national regulations can apply, such as the ones setting the conditions under which connections can be made mandatory in a given area. But the bulk of economic regulation remains in the hands of local bodies. It is hard to assess those systems form an overall national standpoint, as they reveal a quite heterogeneous range of practices, ranging from modern, efficiency and performance oriented contractual arrangements, providing a relevant ground for steering those systems towards innovation and constantly renewed energy sources, to very loose arrangements, insufficiently regulating the operation and development of the grid, and giving no specific goals to the operator. As this study focused on efficient systems, the ones which were reviewed fall, to a various extent, in the first category, and evidence the potentialities and relevance of efficient local regulation.

- **At the other end of the spectrum, some markets are centrally regulated, like those of Denmark and Estonia.**

  As DHC systems develop as a whole, in connection with urban planning, part of the specificity of this regulation, compared to gas or electricity, stems from its upstream, holistic focus: the regulation aims at benchmarking the DHC choice as such, and as a whole, against alternative heating and cooling supply solutions, in terms of value for money to end users and other public benefits, such as environmental compliance. Regulators also assess and emulate, in a more classical fashion, quite similar to what they do in electricity and gas, the relative performance and overall OPEX/CAPEX efficiency of each local system in comparison with a standard efficient operator, the features of which are designed from the regulator’s knowledge of the sector’s best practices.

  This “full fledge” central regulation is tied, in Denmark, to the non-profit nature of the services as such, which is, as explained in the Copenhagen case, a national rule. This requires specific provisions and controls as regards the use of economic benefits from the activity, which have to be either transferred to the consumers or directly reinvested into the system. The regulation in Denmark seems well accepted as part of a system which is globally efficient, properly and transparently steered within a pattern of strong public control, focused on transparency and innovation. The rather high average price of electricity and other energy supply solutions throughout the country gives a competitive edge to DHC systems and makes their development compatible with this holistic benchmarking.

In Estonia, the inconveniencies of centralised regulation of district heating are more obvious: the heterogeneous nature of local factors and systems design solutions make comparisons difficult: it is challenging to build benchmarks and standards which are agreed throughout the industry. The ambition to use those holistic benchmarking of DHC grids against overall systemic alternatives, aimed at getting rid of inefficient inherited DHC grids which have not been sufficiently modernised, is difficult to implement. Failure to reach consensus and its driving principles could lead the country to switch to decentralised regulation in the near future.

- **The third national solution appears as a hybrid of the above described systems. Among cases and countries reviewed in this report, it is mainly used in Sweden.**

  Although the system primarily relies on local control of either private or public operation, the latter through a variety of concession type PPP patterns, a central regulatory body provides local authorities and the industry with guidelines and benchmarks, aimed at securing transparency to consumers and relevant control and steering of operators. Contractual frameworks designed from the industry's best practices are also provided by the Regulator, who overlooks their implementation. The system is well accepted and appears as hitting a good balance between the autonomy left to cities and communities in making their structuring choices as regards local energy supply, designing their systems and building the right local alliances and partnerships in and around their DHC services, on the one hand, and a relevant central input of benchmarking, good practices and sector guidelines, which can only stem from centralised, comparative work. Some private consulting firms also play a central role in feeding the system.

Though it is irrelevant to draw one-size-fits-all conclusions from the study as regards regulatory patterns, this third solution might appear as combining the best of both worlds. There are indeed very strong arguments to steer and control DHC systems at the local level of cities, communities and other local bodies, due to their local roots, links to urban planning, local monopoly features and numerous local factors, which makes each system a case of its own. But as we mentioned, the absence of central regulatory steering and overview can result in quite heterogeneous situations. Old, very dense systems inherited from the 1970's and 1980s, often managed through long term contractual arrangements, sometimes providing comfortable rents and windfalls to incumbent operators, and insufficient openness to challenging existing energy supplies. In this respect, it should nevertheless be mentioned that in some countries, large national associations, linking cities and operators, like *Amorce* in France provide a fair amount of soft benchmarking which, to a certain though limited extent, can be regarded as a substitute to lacking central regulation.

KSF 2: Direct/indirect financial support
(Target audience: Policy makers, funding institutions and donors)

DHC investments are **highly capital-intensive** and, even when they prove to be economically viable (taking into account externalities), they usually need financial support to be financially profitable. As previously mentioned, this support can take different forms:

- **Direct financial support**, such as i) revenue support schemes to renewable energies and CHP (usually feed-in premiums); ii) investment subsidies from EU or national funds (incl. regional and local funds); iii) adapted (long-term) debt funding, which can be offered by national banks like the Danish Kommune bank or KfW in Germany, but also from EU institutions like the European Investment Bank.
- **Indirect financial support**, in particular **relevant tax incentives** such as environmental taxes or reduced VAT to final users of low-carbon DHC services.

The development of an adapted offer of financial support to DHC where needed will bring new investments to the EU and accelerate the deployment of these systems. A financial instrument allowing to transfer CAPEX into OPEX (eg. through a contribution to the initial investment that could be paid back through a fee on supplied MWh) could be relevant to decrease the demand risk for new grids in new urban areas.

KSF 3: Focused local policy and coherence with urban planning
(Target audience: Local authorities, housing and urban development agencies)

The study demonstrates the pertinence of taking an **integrated long-term approach for urban planning, including energy supply** as well as waste management, water supply, transport and other public services. This is already being implemented by several local authorities in the EU, resulting in sustainable models for urban development.

New compact districts with high environmental standards are particularly adapted to efficient DHC systems. A balanced mix of consumers -mainly residential and tertiary buildings- and high energy densities facilitate the viability of DHC investments. However, the development of DHC grids in these new districts frequently subject to a demand risk that, if materialised, can threaten the financial viability of the grid. The **reliability of the initial heat/cold demand forecasts** is indeed critical and some of the studied cases show that mitigating the demand risk at development stage should be given higher importance.

In **existing districts**, the deployment of DHC systems can be encouraged through urban **densification** and/or coordination with the **energy refurbishment of buildings**. An energy labelling of buildings based on primary energy demand and building codes and standards promoting integrated low-temperature heating and high-temperature HVAC systems (that can be supplied through DHC) may also encourage further connections to low-carbon and efficient DHC grids.

In some cases, the establishment of a DH zoning with **mandatory connection** to the DH grid can be relevant, as it reduces the demand risk and facilitates the access to debt funding. However, the DH system should maintain incentives for a competitive energy supply over the time.

KSF 4: Alignment of interests / Cooperation maturity
(Target audience: Policy makers, local authorities, housing and urban development agencies, DHC operators, citizens, DH associations…)

The **alignment of interests** between the **municipality, the DHC company and final users** becomes particularly important at the development stage. In this sense, citizen empowerment can play a key role and enhance the acceptance of the project. In all the analysed case studies, the local actors succeeded in cooperating to provide a quality DHC service and a cost-efficient and sustainable energy supply.

Political buy-in stands out as one of the key enablers to develop efficient DHC systems. Apart from the policies and financial schemes mentioned above, local, regional and national authorities can support DHC projects through the **connection of public buildings** to the grid and **creating awareness** about the benefits of DHC systems.

Collaboration between DH companies is increasing and becoming very relevant in more mature DH markets. Greater Copenhagen and Greater Stockholm have already applied an **integrated approach to DH** in their regions, ultimately improving the efficiency of the overall DH system and reducing its costs. In both cases, a **common heat dispatch** and the **interconnection with neighbouring DH grids** have improved the competitive position of DH against the alternative options for heat supply and resulted in lower prices for consumers.

KSF 5: Availability and relevance of local resources
(Target audience: Local authorities, DHC operators and suppliers)

The use of local resources can **foster the local economy** while **improving the financial and environmental performance of the DHC system,** reducing its exposure to fluctuations of fossil fuel prices. In particular, DHC systems can create (and maintain) local employment and integrate the following local energy sources:

- **Renewable energy** sources, when available (e.g. geothermal, biomass, biogas, solar, renewable electricity, etc.). The use of biomass for heating can also support the development of a local supply chain.
- **Waste-to-energy** facilities, powering a circular economy.
- **Surplus / waste heat and free cooling** from local industries, water bodies, wastewater treatment plants…

KSF 6: Comprehensive project development
(Target audience: Local authorities, DHC operators, other project promoters and consulting firms)

In order to design and implement new DHC projects, the promoter (typically a DH company or a city/ community) needs to have the appropriate **techno-economical and operational expertise** to **build a robust business model**. This implies more than traditional EPC or engineering competencies: the iterative nature of the new DHC systems' development requires an early though robust assessment of demand, and a constant adjustment of models and technical solutions to actual energy needs. It is therefore extremely important that authorities in charge and developers manage to cooperate in a way that allows **continuity and coherence along a rather long period**

of time. Too often, external expertise is sought by local bodies in a discontinuous way, on a limited scope, which can hamper the strategic thinking and step by step optimisation, linking construction and operation, which an efficient DHC system requires. Most of the successful projects reviewed, especially as regards new areas, have relied on a stable cooperation between controlling authorities, developers and advisors, all of which have been positioned as partners to the project considered as a whole, and not as case-by-case expertise providers.

Moreover, this continuous and comprehensive development has to follow a **well-integrated approach**, covering both the grid development (new clients, links to city planning, etc.) and H&C production. In all the studied cases this was the case, as the DHC operators were whether fully integrated (i.e. in charge of the H&C production and distribution) or, where unbundled (in the Copenhagen case), all parties of the value chain where closely and efficiently cooperating.

KSF 7: Price competitiveness against alternative energy solutions
(Target audience: Local authorities, DHC operators, other project promoters and consulting firms)

The energy supply from DHC systems has to be **competitive against the alternative source for heat/cold** supply. In particular:

- DH prices have to be competitive against individual energy systems. **High demand density** (MWh/km grid), **cheap energy fuels** (e.g. industrial surplus heat, local RE sources, renewable electricity at low market prices) and supportive policies and taxation for DH and renewable energy sources can improve the competitiveness of DH with respect to individual (fossil-fuelled) heat boilers or heat pumps. The same principles are applicable to DC, which can also benefit from high demand densities and cheap energy sources (notably free cooling from water bodies or industrial processes). However, cooling costs are frequently unknown to consumers and DC promoters may have to carry out a metering campaign to demonstrate the business case for DC.

- The **transparency of prices** - supported e.g. by national benchmarks – and a clear **visibility on future prices** (less vulnerable to price fluctuations in the fossil fuel and electricity markets) also influence the client's choice of DHC.

- **Complementary demand profiles** and the **dynamic optimisation** of the DHC system's operation (further explained below) allow the mutualisation and reduction of operational costs.

KSF 8: Flexible heat and cold production
(Target audience: Local authorities, DHC operators, other project promoters and consulting firms)

Most of the analysed case studies incorporate a high degree of **flexibility in the production**, which results in an optimal operation of the DHC grid and a higher use of RE and surplus / waste energy. This flexibility can be achieved through a **diversified and complementary energy mix**, the use of **CHP** and **thermal storage** systems and the **continuous (dynamic) optimisation** of the DH system's operation. It allows the system to benefit from fluctuating electricity prices to establish an optimised merit order, reducing the costs in heat production.

Seasonal thermal storage pits such as the one in Gram are particularly interesting in a context of increasing share of **intermittent RE electricity** production, as they can provide **balancing** services to the EU electricity markets and a decarbonised heat to consumers at a **relatively low investment cost** (of ca. EUR 500 /MWh of storage capacity[93], while the cost of electric batteries is currently around EUR 450-500 /kWh[94]). The evolution of electricity prices will influence the volume of future storage pits. Indeed, more fluctuating prices make high-volume storage pits more cost-efficient, the effects of which can be combined with economies of scale.

For **new DHC systems in new districts,** flexibility in the production can also take the form of a **modulated/ phased construction**, which partly mitigates the demand risk and reduces the initial investment costs while allowing the system to adapt its generation in the future, if needed.

KSF 9: Combining technical and non-technical innovation
(Target audience: Policy makers, DHC operators, research centres)

Finally, most of the DHC systems analysed in this study have benefitted from the **support of the city and DHC operator to innovation**, and often represent flagship projects within a broader energy or smart city strategy.

RDI investments have supported the development of modern DHC systems and will be crucial to keep improving their economic and environmental performance. These RDI activities are often realised through partnerships with universities, research centres or other EU actors (e.g. through EU funded projects).

Some of the **innovative technologies** seen in the analysed case studies have a big potential for replicability, notably seasonal heat storage pit and the first-of-a-kind cold recovery from GNL terminal, and could be specifically supported at national and EU level.

Public tenders have been efficiently used by several EU cities and communities to promote competition while meeting **certain technical and environmental standards.** In the case of Ecoenergies Barcelona, the City Council integrated in the tender documents a requirement to **create awareness** on DHC among its citizens and DHC consumers through a website, public visits and information on the energy bill about the DHC system development, CO_2 emissions saved and energy efficiency tips.

Innovative governance modes or social initiatives to improve climate awareness are indeed relevant for a higher deployment of DHC systems, in particular when they foster citizen participation.

[93] National average in Denmark for seasonal storage pits of 100000-200000 m3 (Source: Ramboll)
[94] Average prices in France for large batteries

6. Conclusion: Lessons learnt and potential policy guidelines

Studying, in-depth, the models and patterns of some important and successful DHC cases in Europe, suggests that each of them has a distinctive architecture, has relied, throughout its development, on primarily local dynamics, and combines partly replicable success factors in various ways.

It might therefore seem quite challenging to draw adequate policy guidelines from such an empirical analysis. This should neither hamper the proper understanding of the role which DHC systems can play in energy transitions, nor deter the design of policy guidelines to support the development of efficient, open DHC grids.

Actually, strong trends, which deserve specific attention from a policy making standpoint, do appear when one considers the role of those DHC grids at the heart of both local energy systems and energy efficiency policies, from a holistic perspective. They provide, in many respects, a flexible backbone for coherent local strategies, mainly due to the fact that they enable local authorities to combine a variety of energy efficiency and decarbonisation leverages.

6.1. Efficient DHC systems often provide an evolutive backbone to balanced energy transitions

Most of the DHC systems reviewed in the current study are powerful, cost efficient enablers to reach ambitious carbon targets, and convert local energy systems from fossils fuels to renewable energies.

a) At one end, **DHC grids can be supplied by a very broad range of renewable or recycled energies.**

They range from various biomass fuels to geothermal energy, but also include biogas from waste or sludge, often through cogeneration, and other potential sources. Surplus heat and cold from industry, data centres or other sources, and other recycled energies can also be used. As DHC grids develop, they provide a large offtake base for those local energies, and stimulate their development: wood from biomass, and the structuring of dedicated forestry or agricultural activities and certifications they require, or surplus heat from local industries, for example, often remain untapped until a local demand stems from a DHC grid, which provides the right incentives to study, assess, organise and use those new energy supply sources.

In and around some of the cities or areas that were studied, figures evidence that those renewable or recycled energies, developed in connection with the DHC grids they supply, have played a more important role in leveraging the overall substitution of fossil fuels by renewable energies, than renewable electricity production, and complementary to it.

b) Efficient **DHC grids are also linked, at the other end, to energy efficiency policies in buildings**, both as regards new construction and renovations.

Reduced energy consumption in buildings might, at one point, narrow the economic scope for DH grids, or threaten their economic balance and question their business model. Though this is a generally accepted idea, this study suggests that, in most cases, the economic downside of reduced consumption can be offset through new connections and by the benefits from increasing the system's flexibility, introduced mainly by new systems that facilitate an enhanced local intelligence as regards energy sourcing.

Those field cases actually evidence that improved building performances do not undermine the relevance of developing or densifying efficient DHC networks, though they certainly influence the technical models and pricing structures that underpin their development. DHC grids and efficient buildings can be part of a joint energy efficiency strategy, whereby more flexible supply, often including heat exchanges within the system, especially if cold is included to it, is conceived, dimensioned, and periodically re-engineered through a constant dialogue with end users, and a gradually activated demand side.

As a consequence of that, the business model of district heating and cooling operators also involves more service, and tariff structures can be adjusted in a way that better values the availability and flexibility of the energy provided by the grid, integrating a fixed tariff component that partly covers fixed costs and incentivising the contribution of end users to the overall efficiency of the grid (for example through a bonus-malus tariff component based on the return temperature, as in Stockholm, Saclay or Copenhagen).

This combination of fuel decarbonisation and optimized consumption is a powerful, cost-efficient leverage to deep local decarbonisation. It also stimulates local economic activity and paves the way to more balanced, resilient energy systems.

c) Other factors will allow further energy optimization to occur within those DHC grids.

The first one is related to the numerous possibilities for energy recycling and exchanges which those grids make possible. **In those cases, the grid is not only conveying energy from primary sources to end users, but can be used as a complex exchange, storage and optimization system**, connecting various energy profiles at different points of their cycles, in order to optimize their combination, and multiply secondary energy sources within the grid itself. Remote control and smart metering devices create a range of new possibilities in those grids, together with the use of storage. Such solutions ca be developed and encouraged in all three identified regulatory patterns, as case studies in Saclay, Copenhagen and Stockholm respectively evidence.

The second one builds on possibilities to connect those “smart” heating and cooling grids with electricity grids. This will gradually enable real time arbitration between multiple energy sources to supply specific local needs. But it will also help managing the costs and addressing the technical challenges of the instability linked to the increased share of intermittent renewables in electricity grids. The reason for this is that **heating and cooling grids can integrate key devices such as heat pumps, electric boilers, small CHP facilities or cheap centralised or decentralised thermal storage, which, when properly positioned and combined with local electrical systems, can help to efficiently manage intermittency from wind and solar generation, at an affordable cost.**

A country like Denmark provides an example of this successful strategy. The installed renewable capacity (mainly wind) now roughly equals peak power demand: a large part of the resulting intermittency is managed through small, decentralized, power driven CHP facilities. Those small CHP facilities provide, in average, 50 % of Denmark’s electricity, and they are connected to various DHC grids, and to thermal storages. They were consciously designed and gradually developed from the 1980’s onwards as a key component of optimised systems enabling the country to develop its renewable power capacity well beyond the points that were for long regarded as thresholds beyond which local electricity grids would become unmanageable, or unaffordable. The Gram case illustrates how the use of seasonal storage pits can turn DH grids into balancing service providers, turning intermittent power production into dispatchable (firm) energy.

6.2. The development of those efficient DHC systems relies on a new balance between cooperation and competition within open, evolutive systems

6.2.1. DHC grid models have changed quite radically

a) Some of the existing grids were developed in an altogether different energy context

The large district heating grids that were successfully developed in the 1970's and 1980's, like Brescia in its early phases, or other dense, existing urban areas, **relied, first and foremost, on centralized, fossil fuel based energy supply, economies of scale and urban density**. They were implemented in a global context where competition was not organized in European countries in the energy sector, especially at consumer level, and where end users were a lot more passive as regards their supply options than they are today.

Cost-efficient heat supply could be developed on a large scale in connection with city planning. At later stages, the good knowledge of energy needs and profiles, and the centralisation of supply, did facilitate the fuel switch to renewable sources, like in Copenhagen or Stockholm. And other benefits could also emerge from those "traditional" patterns: as an example, district heating and new tramway lines have sometimes been developing jointly within city centres recovery plans: new tram lines reduced car footprint and air pollution, and enabled cities to get rid of "urban highways", which fostered new constructions and allowed densification to occur in those areas. In turn, this evolution could benefit to district heating and pave the way to new, cheap and price-stable energy supply.

But **altogether, the systems bore a certain degree of rigidity, little transparency, and left little space to consumer choice**. To an certain extent, the model which prevailed in former communist countries before 1989, where district heating was extensively developed, as a component of a centralized, uniform city planning, based on relatively cheap and widely accessible fossil fuel based energy, can be regarded as an extreme form of this traditional model.

b) **New DHC systems follow different goals and development paths, and rely on partly different economics**.

A close connection to urban planning remains, as shown in the analysis of key factors of success and their replicability. But in a very different fashion.

As evidenced by such case studies as Copenhagen or Stockholm for large cities, or Hafencity, Saclay or Barcelona for new areas, new DHC grids have been planned and implemented as a mean of meeting simultaneously two sets of targets, while keeping the required level of price competition:

- **making the best of a very broad spectrum of local energy resources**, not all of which were thoroughly identified before a DHC grid project provided an incentive to search, evaluate and use them, and developing new supply schemes, in line with **carbon reduction targets**;

- providing cities new areas with a **flexible, collective infrastructure, the implementation of which can be linked to the actual city development**, at a flexible pace, and in a way that provides ground for constant technical evolutions of the grid.

6.2.2 A new balance between cooperation and competition, within open, evolutive architectures

As a consequence of this evolution, DHC grids have become a lot more open to competition, but also, more broadly, to stakeholder's participation, and cooperation. Examples of efficient incentives to this openness are being observed throughout various regulatory patterns.

We believe this to be an important element of understanding for European policy makers and regulators: **those new systems do not develop only on traditional public procurement competition patterns, but on a more elaborate balance between competition and cooperation.**

a) Competition as such should play a part at four stages in the development, construction and operation of efficient DHC systems.

- Upstream, when planning options and energy supply architectures are benchmarked against one another: this critical phase has sometimes been reduced to local lobbying between various energy providers or grid operators, lacking a long-term integrated approach. It is of significant importance, especially in new urban areas, that **cities follow transparent procedures, and clarify the principles along which they make their energy planning decisions**, before they make some of the fundamental choices that will, potentially, lead to develop or extend a DHC grid, which is strategic choice bearing long-term consequences.

- For the construction, financing and operation of the grids, classical PPP - concession or management contracts- or EPC tenders, or other public procurement patterns can play their normal role. Due to the difficulty to transport heat on large distances, DHC grids do have some characteristics of natural local monopolies, though to a lesser extent than water and wastewater grids. **Competition for the market is therefore due to keep a central place in their organization**. In countries where the market is centrally regulated, this upstream competition focuses on overall supply scenarios and system design comparison before public choices are made at various crucial stages of the system development. Some cities, like Barcelona, have integrated innovative requirements in their DH tenders to develop a locally regulated market and increase the climate awareness of their citizens, highlighting the role of DHC consumers in the city's energy transition.

- The contractual / organisational patterns also have to **secure that scope and incentives for ongoing supply optimization are in place**, and that new sources of energy are integrated into the system pattern as they are developed: the case studies provide numerous examples of how this can be achieved, in Stockholm, Copenhagen or Hafencity for example.

- Finally, although some modern grids rely on mandatory connection rules in given areas, in order to secure the coverage of important investment costs, and allow non-recourse debt project financing, **an opt-out possibility for potential users who propose more competitive, autonomous solutions has to be designed, and usually are**, even in demand sensitive new projects like Saclay or Hafencity. Yet the competitiveness comparison here has to encompass both full costs and environmental efficiency, in order not to undermine the main purpose of DHC grids they compete with.

b) Yet cooperation is equally important to optimize those systems, and maximize their community benefits and collective value for money.

Studied cases evidence an extensive range of points of cooperation, all of which substantially contribute to the efficiency of those DHC grids.

- **Cooperation between DHC project managers and urban planners** is crucial to the relevance of the supply scheme and economic robustness of any DHC project, as almost every case study illustrates.

- **Cooperation with real estate developers and building owners** is equally important in order to coordinate the connection to the grid, secure the grid's demand and fine tune, step by step, demand forecasts which shape DHC grids as they build up. The reliability of those forecasts enables DHC developers to save investment costs and improve affordability of the future service and to strike the right balance between financial viability (especially in new grids) and security of delivery. It can also be important in order to best adapt DHC grids to the specific needs in some buildings or industries (or vice versa) and, if relevant for the overall efficiency system, combine DHC supply with individual supply systems, as the Saclay example illustrates.

- **Cooperation with potential surplus heat/cold providers** should be actively sought, as they very seldom take the initiative of it, not being aware of possibilities that can be developed with neighbouring DHC grids; in active areas such as ports, new opportunities can emerge from various suppliers such as LNG terminals, as seen in Barcelona. Such cooperation should also be pursued and specifically supported, as the huge community benefits of surplus heat supply can be hampered by conflicts of interest as the Hafencity example shows.

- **Cooperation with other DHC operators,** to share best practices and optimise the overall competitiveness of DHC in specific areas, e.g. through grid interconnections and joint dispatch procedures.

- **Cooperation with end users and consumer associations** on prices can also be fully integrated in price setting procedures, like it is the case in Stockholm for example: DHC grids having some local monopoly components, local or national regulation can be usefully fed and supported by this constant dialogue, which provides irreplaceable insights on affordability and local consumer perceptions. Moreover, an enhanced cooperation with consumers often leads to higher quality services, adapted to their users' needs.

- Interesting forms of cooperation can be sought on the investment financing side through various forms of **local, community based ownership and participation, for example through cooperative structures**, which developed in Scandinavia more than they did in Germany for example, where they remained in the field of classical decentralized renewable production; this citizenship involvement also helps building up systems which are better endorsed and understood by end users, which secures their long term sustainability.

- Last but not least, **cooperation with entities managing other energy services will become increasingly important**, especially in countries like France where the national electricity and gas distribution grid managers are completely separate from DHC operators, most of which, public or private, are controlled by municipalities or their associations: materialising the scope for smart multi-energy grids, for which affordable solutions, primarily relying on CHP, heat pumps and thermal storage, already exist, as examples from Denmark or Sweden evidence, will highly depend on a cooperation which, in some countries, is still at a very early stage.

6.3 Potential implications on some policy guidelines

As most of the decision making power for developing DHC grids lies at municipality level, which can be developed through PPPs but also in-house by those public local bodies, EU energy policies and procurement rules obviously can’t shape the DHC markets as directly as they have done for gas and electricity supply.

But several policies can support and orient the development of cost efficient, environmentally friendly DHC systems. And it is of utmost importance, given their role as potential backbones to efficient local systems, that they are fully integrated in Europe’s energy markets design and strategies. Without being exhaustive on those matters, which exceed the scope of the current report, we would like to emphasize a few important points.

a) Supporting the in-depth design and comparison of optimal new local systems

Due to the close link that exists between developing efficient DHC systems and broader local energy planning, programmes and initiatives supporting in-depth, upstream, pre-optimisation work on the best energy solutions are helpful. Cases like Saclay and Gram evidence the relevance and value of this pre-conception and modelling work which addresses, beyond DHC design as such, other important issues like demand forecast in new areas, optimisation possibilities through the combination of various energies within a local grid system, or comparison and potential combination with standalone, autonomous solutions at building level. Integrating this comprehensive energy planning in urban planning activities is therefore strongly recommended.

The holistic assessment of the merits of various options, and the evolutive nature of DHC grids, which constantly build up by addressing new needs and tapping new energy supply resources, make it difficult to design a one-size-fits all evaluation methodology: municipalities or other authorities in charge of organising those services have to prioritize their criteria. But it is of great importance that those criteria are defined and disclosed, in order to allow for a fair and open comparison of various systemic solutions.

More broadly, the various means by which National and European policies and institutions, including the long-term financing provided by the EIB and guarantee schemes such as the one provided by the EFSI, can support and finance efficient local energy systems and infrastructures, based on a combined assessment of needs and resources, also provide indirect support to DHC grids, which often emerges as the relevant off-taker of newly tapped local energy resources, and integrates them into a balanced, real-life response to energy needs.

b) Revisiting regulatory patterns

The fact that DHC grids are usually under the control of local authorities, that their supply schemes and key features can strongly differ from one place to another, and that they are usually not fully unbundled, does not provide ground to impose a classical centralised regulation, based on comparative competition and on the reference to a typical "efficiently managed" DHC operator, as the one which is applied to electricity and gas distribution grids.

Nevertheless, cases reviewed in Denmark and Estonia evidence the possibility of a centralised regulation, and the "soft" regulation in Sweden shows that there is ground for improving the remote steering of DHC operators performance by providing benchmarks and comparisons from national regulatory authorities, and contractual patterns and guidelines. This can be combined with stronger customer involvement at the local level. That would favour a better comparison of in-house, cooperative and market based (PPP) schemes, for managing and developing those grids. And support a faster spread of innovation, especially non-technical innovation, which has been evidenced as a key factor of success in most reviewed cases.

It has to be recognised though that, even in countries where regulation of DHC grids is entirely left to local authorities, non-governmental structures and associations, such as Amorce in France, or national DH associations, do provide both DHC operators and their controlling authorities with benchmarks and best practice material.

c) Better supporting cogeneration and trigeneration

On the supply side, it has been strongly emphasised throughout this report that cogeneration and trigeneration plants, of various sizes, often appear as the cornerstone and the first brick of smart local systems including DHC grids, especially when they combine industrial and household customer bases. The fact that, in an adverse market context, due to the combination of cheap coal and insufficient carbon prices, many of the gas-fuelled cogenerations which had been built in Member States in the mid 2000's have been decommissioned a few years later, is a non-sense, and a large scale waste of opportunity and resources for European countries. In our view, market design and corresponding support schemes should better value the positive systemic externalities of production sources that enable systems to better perform, and provide technical flexibility and/or price stability on the mid-long term.

The issue is not that simple, because private financers, as regards both equity and debt financing, spontaneously favour projects which combine feed-in tariffs for electricity, and take-or-pay or other forms of guaranteed offtake for heat. But the systemic benefits of cogenerations and trigenerations -beyond their intrinsic energy efficiency and rather good carbon record, depending on their fuels- rely, to a large extent, on their business model: it has to provide incentives for a flexible, market reactive production of electricity, heat and cooling. This flexibility has to be oriented by market prices in order to balance local systems: a combination of feed-in-tariffs and take-or-pay contracts do not provide the incentives for that.

Though support to cogenerations and trigenerations should, in our view, be stronger and better established on the mid-long run, further thoughts should be given to the right way to **focus this support on those who provide more systemic benefits**, by making efficient energy coupling actually possible. This support could, on the one hand, be built-in the **capacity market design**, which should specifically target cogenerations and trigenerations, which provide broader systemic benefits than classical plants. It should also select the most effective CHP and trigeneration plants, as it is already generally required by EU institutions such as the EIB to provide their funding.

Efficient policies and schemes existing in some countries with a high CHP market share, like Denmark, could be looked at and replicated as relevant across the EU. As explained in Copenhagen’s case study, since the 1970's there is a maximal use of CHP in Danish cities, and these plants were installed at optimal locations to facilitate their connection to DH systems.

d) Putting a greater focus on DHC grids in the overall smart grid and innovation programmes

Last but not least, research on smart grids systems must focus on **multi-energy systems**, and should integrate a stronger DHC component. The first demonstrators were mostly electricity focused, and lacked multi-energy dimensions. Those goals are better integrated in some of the new programmes, and this focus should be maintained.

New European research programmes will also have to be up-scaled in order to enable public authorities to use system operation feedback as an input to new system architecture, and save investments in production capacity and grid reinforcement due to an enhanced management of local energy systems enabling peak shaving. They could also integrate a broader variety of energy uses such as electric mobility into the scope of their experiment.

ANNEX 1 Preliminary questionnaire sent to DHC networks

Stage1 : Case study selection

DHC NETWORK NAME :	Network NAME
Contact:	Contact NAME

	QUESTIONS		ANSWERS (in English)
General information	**Year of Commercial Operation**		
	Location		
	Type of network (choose one)	District Heating	
		District Cooling	
		Both	
	Dominant customer structure (choose one)	Industrial	
		Service	
		Residential	
		Balanced mix	
	Energy sources	Biomass, CHP, waste heat/cold, etc. (inlude %)	
	Network access (choose one)	Single-buyer model	
		Third party access (regulated or negotiated)	
Network characteristics	**Type of DHC network** (choose one)	Old network recently upgraded	
		Relatively new network in an existing urban area	
		Relatively new network in a new urban area	
	Size	Energy production (GWh/y)	
		Nr of dwelling equivalents supplied	
		Size of network (total lenght of trench in km)	
	DHC market	Local market share (%) among total heating or cooling needs	
		Market share trend: growing, stable or decreasing?	
	Business model	Governance model (In-house, PPP,...)	
		Average price of DHC (EUR/MWh)	
	Environmental aspects	CO_2 emissions ($kgCO_2$/MWh heat, cold supplied)	
		Renewable and surplus heat/cold fraction (%)	
	Innovative features		

Data availability	Please **confirm the disponibility of your organisation to participate** in the JRC study on district heating and cooling markets in the EU. In case your DHC network was selected by the JRC, a case study would be developed based on your experience to identify the key success factors. A preliminary questionnaire is available on the worksheet **"Stage 2"**.
	Y/N

ANNEX 2 Evaluation grid and case studies selection

tilia

JRC Study on district heating and cooling systems in the EU
European Commission DG JRC - Institute for Energy and Transport - NL-Petten

Performance indicators	Range of values	Weighting	Benchmark*	XXX** (DE)	Hafencity (DE)	XXX** (FR)	Saclay (FR)	Ecoenergies Barcelona (ES)	XXX** (ES)	Brescia (IT)	XXX** (SE)	Copenhagen (DK)	Gram (DK)	Stockholm (SE)	Tartu (EST)	XXX** (SVK)
				Western Europe				Southern Europe			Northern Europe				Central and Eastern Europe	
1. Well -functioning business model	Y/N		-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Economically viable	Y/N		-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Allows the expansion of the district heating and cooling network	Y/N		-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Price competitiveness	[0,100]	15%		60	60	60	20	100	100	80	60	60	60	80	80	60
Average price of heat (EUR/MWh)	[1,5]		quantitative (1)	3	3	3	1	5	5	4	3	3	3	4	4	3
3. Innovation	[0,100]	15%		60	80	53	80	67	67	60	87	100	100	87	47	53
Policy design/legal framework	[1,5]		qualitative	3	4	3	4	3	3	3	4	5	5	4	2	3
Technology	[1,5]		qualitative	3	4	3	5	4	4	3	5	5	5	5	3	3
Environment & Social	[1,5]		qualitative	3	4	2	3	3	3	3	4	5	5	4	2	2
4. Growing market	[0,100]	10%		80	60	100	60	100	100	60	40	100	100	60	100	60
Growing market share for DHC	[1,5]		qualitative	4	3	5	3	5	5	3	2	5	5	3	5	3
5. Competitive market	[0,100]	10%		33	67	100	67	67	67	100	67	67	67	67	67	67
Competition for the market (DHC management)	Y/N		-	N	Y	Y	Y	Y	Y	Y	N	N	N	N	Y	Y
Competition exists in practice between different heat producer companies	Y/N		-	N	N	Y	N	N	N	Y	Y	Y	Y	Y	N	N
Regulation allows new heat producers to join the network	Y/N		-	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6. Environmental performance	[0,100]	20%		50	90	70	80	90	30	60	100	100	90	100	70	20
CO_2 emissions ($kgCO_2$/MWh heat, cold supplied)	[1,5]		quantitative (2)	3	4	3	4	4	2	3	5	5	5	5	3	1
Renewable and surplus heat fraction (%)	[1,5]		quantitative (3)	2	5	4	4	5	1	3	5	5	4	5	4	1
7. Replicability	[0,100]	20%		100	92	100	80	88	72	100	100	84	76	88	96	92
Type of network (i.e. H/HC; size; urban framework)	[1,5]		qualitative	5	5	5	3	4	3	5	5	5	3	5	5	5
Policy design/legal framework	[1,5]		qualitative	5	5	5	5	5	3	5	5	4	4	4	4	4
Business model	[1,5]		qualitative	5	4	5	5	5	3	5	5	4	4	4	5	4
Technology	[1,5]		qualitative	5	5	5	3	4	5	5	5	5	4	5	5	5
Complexity	[1,5]		qualitative (4)	5	4	5	4	4	4	5	5	3	4	4	5	5
8. Willingness to cooperate / reactivity	[0,100]	10%		100	90	100	100	80	70	90	100	100	100	100	100	50
TOTAL SCORE	[0,100]	100%		69	79	81	70	85	69	78	83	87	84	85	79	57
Ranking	-	-	-	11	7	6	10	2	12	9	5	1	4	2	8	13
Proposed case studies					5		8	3		7		1	4	2	6	

* Note 1	Qualitative assessment using a 5-level Likert scale, where 5 indicates the best performance
** Note 2	Not selected DHC systems anonymised

Best performing (8 cases)
Complementary group (agreed with JRC)

(1) 1: >110; 2 (90,110]; 3 (80,90]; 4 (60, 80]; 5: <=60
(2) 1: >250; 2 (200, 250]; 3(150,200]; 4 [70,150]; 5: <70 kg/MWh
(3) 1 [0,10]; 2 (10,30]; 3 (30, 50]; 4 (50, 80); 5 [80, 100]
(4) low score indicates high complexity

Complementarity check

COMPLEMENTARITY CHECK		Notes
1. Geographical coverage: The south, central and northern EU should be covered in at least one case study each;	ok	
2. Type of network: different types of energy supplied (i.e. heating or heating and cooling), different scales and urban frameworks;	ok	**District Heating:** Brescia, Hafencity, Gram; **District Heating and Cooling:** Barcelona, Copenhagen, Saclay, Stockholm, Tartu **Small**: Barcelona, Gram, Hafencity, Saclay ; **Medium**: Brescia, Tartu; **Large:** Copenhagen, Stockholm **Old network renovated**: Copenhagen, Gram, Stockholm, Tartu; **New network in existing urban area**: Barcelona, Brescia**,** Copenhagen ; **New network in new area**: Barcelona, Copenhagen, Hafencity, Saclay
3. Regulatory framework: More than half of the case studies should concern a heat market that uses unregulated heat prices and at least one case study should treat a heat market with regulated prices;	ok	**Unregulated**: Barcelona (local regulation), Stockholm, Brescia, Hafencity, Saclay; **Regulated** (at national level): Copenhagen, Gram, Tartu
4. Access model: Different models for competitive district heating systems should be covered, e.g. single-buyer model or network access model;	ok	
5. Balanced coverage of the main **customer structures** (residential, service, and industry);	ok	
6. Diverse sources of heat/cold supply: e.g. co-generation, waste heat/cold from industry, renewable energy (e.g. geothermal, solar, biomass), heat pumps, thermal storage, etc.	ok	CHP (biogas, biomass and fossil), electric boiler, geothermal, heat pumps, thermal storage, solar, waste incineration, surplus heat/cold, fossil fuels

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